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INTER-AMERICAN TROPICAL TUNA COMMISSION

COMISION INTERAMERICANA DEL ATUN TROPICAL

Special Report 11

PROCEEDINGS OF THE INTERNATIONAL WORKSHOP ON THE ECOLOGY AND FISHERIES FOR TUNAS ASSOCIATED WITH FLOATING OBJECTS

February 11-13, 1992

Compiled by

Michael D. Scott, William H. Bayliff, Cleridy E. Lennert-Cody, and Kurt M. Schaefer

La Jolla, California
1999

The Inter-American Tropical Tuna Commission operates under the authority and direction of a convention originally entered into by Costa Rica and the United States. The convention, which came into force in 1950, is open to adherence by other governments whose nationals fish for tropical tunas in the eastern Pacific Ocean. Under this provision Panama adhered in 1953, Ecuador in 1961, Mexico in 1964, Canada in 1968, Japan in 1970, France and Nicaragua in 1973, Vanuatu in 1990, Venezuela in 1991, and El Salvador in 1997. Canada withdrew from the Commission in 1984.

The IATTC's responsibilities are met with two programs, the Tuna-Billfish Program and the Tuna-Dolphin Program. The principal responsibilities of the Tuna-Billfish Program are (1) to study the biology of the tunas and related species of the eastern Pacific Ocean to estimate the effects that fishing and natural factors have on their abundance and (2) to recommend appropriate conservation measures so that the stocks of fish can be maintained at levels which will afford maximum sustainable catches. The principal responsibilities of the Tuna-Dolphin Program are (1) to monitor the abundance of dolphins and their mortality incidental to fishing through the collection of data aboard tuna purse seiners fishing in the eastern Pacific Ocean, (2) to analyze these data and make appropriate recommendations for the conservation of dolphins, (3) to study the causes of mortality of dolphins during fishing operations and encourage fishermen to adopt the techniques of fishing which minimize these mortalities, and (4) to study the effects of different modes of fishing on the various fish and other animals of the pelagic ecosystem.

The Commissioners serving at the time of publication are:

La Comisión Interamericana del Atún Tropical funciona bajo la autoridad y dirección de un convenio establecido originalmente por Costa Rica y los Estados Unidos. El convenio, vigente desde 1950, está abierto a la afiliación de otros gobiernos cuyos ciudadanos pescan atunes en el Océano Pacífico oriental. Bajo esta estipulación, Panamá se afilió en 1953, Ecuador en 1961, México en 1964, Canadá en 1968, Japón en 1970, Francia y Nicaragua en 1973, Vanuatu en 1990, Venezuela en 1991 y El Salvador en 1997. Canadá se retiró de la Comisión en 1984.

La CIAT cumple sus obligaciones mediante dos programas, el Programa Atún-Picudo y el Programa Atún-Delfín. Las responsabilidades principales del primero son (1) estudiar la biología de los atunes y especies afines en el Océano Pacífico oriental para estimar las consecuencias de la pesca y los factores naturales sobre su abundancia y (2) recomendar las medidas de conservación apropiadas para que los stocks de peces puedan mantenerse a niveles que permitan capturas máximas sostenibles. Las responsabilidades principales del segundo son (1) controlar la abundancia de los delfines y su mortalidad incidental a la pesca, mediante la toma de datos a bordo de embarcaciones atuneras de cerco que pescan en el Océano Pacífico oriental, (2) analizar esos datos y hacer recomendaciones adecuadas para la conservación de los delfines, (3) estudiar las causas de la mortalidad de delfines durante las faenas de pesca e instar a los pescadores a adoptar aquellas técnicas de pesca que minimicen esa mortalidad, y (4) estudiar los efectos de los distintos modos de pesca sobre las poblaciones de peces y otros animales del ecosistema pelágico.

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PREFACE

It has long been known that tunas frequently associate with floating objects, such as trees washed out to sea during periods of heavy rainfall, and fishermen have taken advantage of this behavior to facilitate the capture of fish. In some coastal areas, such as the Philippines, artisanal fishermen construct anchored fish-aggregating devices (FADs) to attract fish. More recently, large numbers of free-floating FADs have been constructed for deployment by large purse seiners on the high seas. The FADs often can be interrogated by the seiner and located at great distances using radio telemetry and/or GPS (Global Positioning System) technologies. In some cases a fleet of fishing vessels has a tender vessel which deploys and maintains the FADs, and notifies the fishing vessels when fish are seen around them.

Unfortunately, floating objects tend to attract smaller tunas, and also other species of animals. With a few exceptions, *e.g.* sea turtles and sharks and rays, most of these quickly die when they are caught. Some of the tunas which are caught are so small that they are unmarketable, so they are discarded at sea. Even those which are marketable may bring prices that are less than those of medium and large tunas. Bigeye tuna were infrequently caught by surface-fishing vessels until man-made FADs came into use. Bigeye are the principal target of the longline fishery, and the prices paid for longline-caught bigeye are many times those of surface-caught bigeye. Accordingly, longline fishermen are concerned that the use of FADs will decrease their catches of bigeye. Some of the other species, *e.g.* mahi-mahi, wahoo, rainbow runners, sharks, and billfishes, which cannot be sold at the facilities where purse-seine caught tunas are normally unloaded, are important constituents of the catches of artisanal and recreational fisheries. Also, some of the other species, *e.g.* sea turtles, are endangered or threatened. Because of these problems, legal restrictions have been put on the use of FADs and/or making sets on fish associated with floating objects in the Atlantic and Pacific Oceans.

This workshop was convened by the Inter-American Tropical Tuna Commission and sponsored by Bumble Bee Seafoods, Inc., for the purpose of bringing together scientists and fishermen who have studied the association of tunas with floating objects. Special efforts were made to get participants from all the areas in which tunas associated with floating objects are the targets of fisheries. Thus the "regional review papers" include contributions for the eastern Atlantic, the southern Caribbean Sea, the Indian Ocean, and the eastern and western Pacific Oceans. Many of these reviews and other contributed papers are published in this proceedings volume. Other papers discussed in the workshop were published elsewhere; these papers are cited in the list of background documents in the Report of the Workshop.

The participants were asked to address the following basic questions:

- What makes a "good" floating object? What attracts tunas to flotsam and under what circumstances?
- What is the role of floating objects in tuna ecology?
- What is the role of floating objects as community aggregators? Are they aggregators for nomadic ecosystems?

- What are the similarities and differences among the tuna-floating object associations in the different oceans?
- What is the role of floating objects (especially natural ones) in the overall pelagic ecosystem? What are the dynamics of floating objects?

The participants also discussed questions about the following topics:

Schooling behavior

- Why do tunas associate with floating objects? What research is needed to develop attractors for large yellowfin tuna?
- Is there fidelity to single objects?
- What makes an object attractive?
- Are all floating objects, including living ones, equivalent?
- Why are tunas attracted to floating objects?
- Do floating objects affect the survival, recruitment, movements, or migrations of tunas?

Logs and circulation

- What are the major sources of floating objects?
- Are there seasonal or long-term trends in their production? What are the processes that affect their production?
- Are they meaningful from the ecosystem point of view (cycles)?
- What is their fate in the ocean? Are there areas of accumulation?
- How long do they stay afloat? Are they associated with rich water masses?

Log communities

- Are there communities associated with the objects that are different from the unassociated pelagic community?
- What is the role of the objects for the different species associated with them?
- Are all the objects equivalent from the point of view of their associated community?
- Are the species assemblages associated with logs similar in different oceans?
- Is there a succession while drifting offshore?
- Are the objects aggregators for nomadic ecosystems?

All of the contributions for these proceedings were reviewed by a committee consisting of Michael D. Scott (chairman), William H. Bayliff, Cleridy E. Lennert-Cody, and Kurt M. Schaefer, all of the Inter-American Tropical Tuna Commission. The contributions were not peer-reviewed in the traditional sense, however, because there was no requirement that the authors and reviewers be in agreement on their content.

The committee would like to note the passing of two of the contributors to the Workshop. Kevin Bailey, who co-authored the review of the western Pacific fishery, was tragically taken from us several weeks after the Workshop. Kevin was a young scientist of great commitment and passion. He had keen insights into the biology and ecology of tropical tunas from long periods spent at sea on research and commercial fishing vessels. At the South Pacific Commission, he made a major contribution to the successful implementation of the SPC's 1989-1992 Regional Tuna Tagging Project. That this project is widely recognized as one of the best tuna tagging projects ever undertaken is testimony to Kevin's skill and determination. A promising career, and life, sadly cut short.

Ken Norris, a professor and naturalist at the University of California at Santa Cruz, had a long and exceptional career most known for his pioneering studies of cetaceans, his influence in crafting the U.S. Marine Mammal Protection Act, and his study of the dolphins associated with tuna in the eastern Pacific Ocean. His insight and broad field experience sparked discussions on the schooling of tunas and their attraction to floating objects. He was well-known for his design of research vessels combining marginal seaworthiness and maximal discomfort for viewing the underwater lives of dolphins. He proposed the deployment of a large raft-like FAD-and-manned-research platform (dubbed the "Ken Tiki" by other participants) for studying the behavior and movements of tuna around floating objects. The scientific community will miss both of these talented biologists as friends and colleagues.

REPORT OF THE WORKSHOP ON THE ECOLOGY AND FISHERIES FOR TUNAS ASSOCIATED WITH FLOATING OBJECTS

Michael D. Scott

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Regional Fisheries

The tuna fisheries for tuna associated with floating objects (referred to as logs in this report) were reviewed by Martín Hall (eastern Pacific), Erwan Josse (central Pacific), Ziro Suzuki and John Hampton (western Pacific), Alain Fonteneau (eastern Atlantic), Daniel Gaertner (western Atlantic-Caribbean), and Jean-P. Hallier (Indian Ocean).

In the eastern Pacific, the unique feature is the significant association between dolphins and tuna. With respect to the log-associated fishery, there is evidence that the association of the tunas with floating objects is mainly a nocturnal one. It also seems that foraging occurs mostly during the daylight period. The length distribution of the yellowfin caught shows large differences between the different set types. Smaller fish are caught in logs and in free-swimming schools. Larger fish are caught in association with dolphins and the largest fish, on average, are caught by the longline fishery. An analysis of the floating objects indicate that most are wooden objects (mainly trees), although the type of tree had little influence in the catch obtained. A number of hypotheses were presented to explain some of the features of the fishery in the eastern Pacific.

In the central Pacific, fishing on anchored fish aggregating devices (FADs) is an important component of the fishery. Fishing activities take place during daytime, and involve mostly deep-water fish. Differences in average size of fish caught in different set types were also noted; fish caught on FADs are larger than fish caught on logs. The largest-size fish are caught in free-swimming schools. Species composition is also related to the type of fishery; the deep-water fishery catches are composed mainly of yellowfin tuna while the surface fishery is based on skipjack.

In the western Pacific, the fishery has shown an expansion in recent years with the addition of a Taiwanese and a Korean fleet. The predominant way of fishing is based on free-swimming schools, while FADs make up to 6 percent of total catches of purse seiners. There is virtually no fishing in association with dolphins, but there are sets on tuna associated with both live and dead whales. Differences in catch composition and size of the fish caught can be noticed between set types. Free-swimming schools and schools associated with whales are likely to be pure schools, while schools caught on FADs and logs are more frequently mixed schools. Sizes of yellowfin tend to be greater in free-swimming schools than in log-associated schools. The frequency of the different set types changes with time of the day; log-fishing occurs mostly at dusk and dawn, and school-fishing occurs throughout the day. Whale-associated fishing peaks early in the morning and then continues at a constant level throughout the day. An analysis of the density of floating objects suggests a seasonality in the abundance of objects with the greatest densities taking place in the third and fourth quarters. Influence of the climate in the abundance of floating objects is suggested by the fact that in 1987, a year with a moderate El Niño, there was a decrease in the number of log-associated sets and in the density of logs.

In the eastern Atlantic, log-fishing has become important in recent years, mainly after the expansion of the fishery to the area south of the equator and the introduction of artificial logs. Natural logs originating in the Zaire River tend to be retained in the Gulf of Guinea, where the fishing peaks during the third and fourth quarters, indicating a correspondence between the fishing and rainy seasons. Logs that are not retained move west until they reach the area of influence of the Amazon river. Catches on floating objects are greater than on free-swimming schools, with a higher proportion of successful sets. The length distribution of the yellowfin shows mixed sizes of fish in logs with fewer yellowfin of larger sizes. In general, fish caught on FADs are larger in size. There is a small proportion of fish associated with whales and apparently little association with dolphins (logbook data indicates < 1% of sets).

In the western Atlantic-Caribbean region, a large proportion of sets involve tuna associated with whale sharks. This category is the secondmost- frequent set type after free-swimming schools, followed by whale-associated fishing and log-fishing. There is a seasonality in the frequency of whale sharks sets. Length distribution of the fish is stable throughout the year for both yellowfin and skipjack, and there are no appreciable differences in the size distribution between different set types. The catch-per-set is largest in sets associated with logs.

In the Indian Ocean, where there was also an increase in the catches in recent years, the predominant mode of fishing is on free-swimming schools. A significant proportion of the sets are made on logs and, since 1991, there has been an increase in the usage of FADs. In contrast with what was reported for other oceans, catch per set is similar between sets on logs and on free- swimming schools, but the proportion of successful sets is greater on logs. There is a clear seasonal pattern in the fishery that peaks in the inter- monsoon periods. There is a large peak in September-October, followed by a smaller peak in March. As in other oceans, log sets are more frequent at dawn while school sets occur throughout the day. Species composition in the catches differs between the set types with skipjack being dominant in log sets, and yellowfin more frequent in free-swimming schools. Large differences are evident in the length distribution of yellowfin; fish of large and intermediate sizes are fewer in log sets. Catches of fish associated with seamounts seem to be different from other modes of fishing.

In general, logfishing occurs in productive waters that are adjacent to areas with productive tropical forests and abundant rainfall. The most successful logfishing season is also correlated with the rainy season. Many aspects of the association of tuna and logs are broadly similar across all oceans. In the eastern Pacific, however, yellowfin tuna often associate with dolphins, an association that is apparently not common in other oceans.

One common observation is that the behavior of tuna associated with fixed FADs differs than those associated with drifting logs. In most fisheries, it has been observed that the association with logs is nocturnal, with the tuna rising in the water column in the pre-dawn hours. A diurnal association, however, was reported from French Polynesia, where large yellowfin are found in association with FADs anchored in deep water. It was generally reported that larger logs produce larger tuna catches.

During the general discussions, the following questions were posed for future study:

1) What is the residency time of tuna associated with logs or dolphins?

2) Why do the tuna associated with FADS behave differently from those associated with logs?

3) Is food limiting for yellowfin tuna and is this reflected in the cost- benefit ratio for swimming with dolphins?

4) Why do anchored FADs produce catches that are productive at some times, and then are unproductive for long periods of time?

By comparing the tuna associations among the different oceans, we could further our understanding of the association with the following approaches:

5) Develop a standardized form to collect data on floating objects, the species associated and the environmental characteristics at the time of the set. A form currently used by the IATTC could be adapted to other fisheries. It is very important that objects without tuna associated are also included in the samples for some analyses.

6) Develop a shorter version of this form for cooperating fishermen (J. Pereira offered to prepare this).

7) Compare the communities and oceanographic conditions of the different oceans in more detail in order to explain why the tuna-dolphin association is prevalent in the eastern Pacific and not in other oceans.

8) The differences between areas in the proportions of different types of objects should be studied. A good example is the extremely high frequency of sets on whale sharks in the Caribbean-Western Atlantic area that is not found in the other areas studied. These differences may simply reflect regional differences in the relative abundances of different types of objects, or differences in oceanographic or ecological characteristics.

Log Communities

Pelagic communities and associations were discussed by Nikolai Parin and Pablo Arenas (log-associated fauna), David Au (seabirds and tunas), and Lisa Ballance (seabirds and sea turtles). Primary production in the eastern tropical Pacific Ocean was discussed by Paul Fiedler. The trophic linkage between tuna and other log-associated fauna was thought to be weak; it was not thought likely that enough prey are associated with logs for tuna to maintain themselves. The association of tuna with logs is not thought to be permanent, and fishermen believe that the environment is more influential in determining the size of the tuna catch on a log than the log itself. One study suggested was to compare the fauna associated with logs, FADs, and seamounts (Arenas).

The question whether the fauna associated with logs represent biological communities or facultative aggregations was discussed during presentations by John Hunter and Ken Norris. It was suggested that this question may not be important for designing a FAD. If, however, fauna associated with logs do reflect community structure, then we can examine how a collection of species "colonize" a log and fit into different niches over time. The ease of assembly and disassembly is interesting because it could reflect the coevolution of species. It was suggested that the prey species within these communities do not avoid predators, but that predator and prey are coadapted to keep each other in sight and to maintain appropriate inter-specific distances.

Several studies were suggested to explore the structure of log communities:

1) Using a floating observation vessel (the Ken Tiki) to study the inter- and intra-specific relationships of log-associated fauna and the behavior of tuna around the log (Norris). As a separate or integrated project, the tuna could be sonic-tracked to determine its spatial relationship and residency with the log.

2) Setting on logs at different times of the day will help clarify the diel variations of their associated species. Following individual logs with hydroacoustic systems will help establish the patterns of arrival and departure.

3) Examine existing data on the weights and lengths of tuna caught on logs to estimate body condition.

4) Conduct experimental fishing to make repeated sets on the same log to examine the turnover rates of species and size classes. Spatially stratified samples should be obtained (vertical and horizontal strata) around individual objects to establish the patterns of distribution in depth and radiating away from the objects. This would require a fine-mesh net to catch the smaller fish associated with the log.

5) Use hydroacoustic and ROV observations to study log communities (could also be incorporated with 1).

6) Seed the far-offshore areas of the eastern Pacific with drifting FADs to determine whether large yellowfin will associated with them.

7) Experiment with FAD design to determine whether different shapes and lower depths will attract large yellowfin (currently being done). In particular, it is necessary to understand which senses are involved in the detection of the floating objects by the tunas (visual, olfactory, auditory). Chemical attractants, lights, bubbles, and sound-producing devices should be tested.

8) Attach cameras to drifting satellite-monitored buoys to record the "colonization" of the buoy by fish species.

9) Using many of the above techniques, study the relationship between bigeye tuna and logs.

Sources of Logs

The movement of logs to the sea was discussed by James Sedell (North Pacific forests), Ariel Lugo (tropical forests), Samuel Snedaker (mangroves), John Walsh and Jeff Richey (organic carbon transport), Ruth Turner (fate of wood at sea), and Churchill Grimes (larval tuna and river plumes). It was noted that the amount of logs transported to the ocean by a particular river will not be proportional to the size of the river. Rivers that traverse extensive uplands will likely carry few logs. Also, few tropical trees would float for a extended period of time due to their chemical composition. Therefore, it seems likely that large logs would mostly originate from forests at lower altitudes. These logs would be carried to the sea by mountain rivers, with large flows and running through steep slopes. It was estimated that 0.05% of fallen tropical rain forest trees are exported to the ocean. About half of the floating objects reported at sea were human-caused.

Seasonal trends were considered common in the production of logs, with the peak usually related to the occurrence of the rainy season. Areas of log- fishing are also areas where hurricanes are frequent (Lugo). In the western Pacific, the seasonal pattern is less obvious, although this might be related to differences in the timing of the rainy season. It is unlikely that the production of man-made logs will exhibit any seasonal pattern.

It was questioned whether the tuna-log association could be an evolutionary adaptation if one assumes that floating objects have become plentiful only recently due to man's activities (*e.g.*, deforestation and dumping of debris into the oceans). It was noted, however, that natural logs were plentiful prior to logging activities in the Pacific, and that, in the long term, there seems to have been a decline in the production of logs. Progressive and continued deforestation might be the principal cause, but also the increase in water control and the building of dams might have reduced the transport of logs to the sea. It was not possible to ascertain how logging contributes to the production of logs. Some common practices, like leaving the slash resulting from the logging operation, might actually increase the production of logs in the short term. It was noted that catastrophic events, like severe storms or prolonged droughts, would likely create pulses in the production of logs that would be useful to trace the dispersion of the logs.

The contribution of logs to the oceanic productivity does not seem important in comparison with the amount of dissolved organic carbon transported by the rivers. On a smaller scale, the contribution might be more significant. It is possible that logs contribute to the development of detrital communities. The existence of retention areas might increase the concentration of logs. For example, sunken logs tend to gather in trenches in the deep-sea where they might serve as the basis for benthic communities.

The group recognized that identifying the sources of natural logs would be an important research project that could be easily carried out. The following methods were suggested:

1) Count how many logs leave a river mouth in a given time period. This would give an estimate of the recruitment of logs to the ocean, but it also would be necessary to know what proportion actually makes it offshore.

2) Assessments of the numbers, types, and characteristics of natural logs entering the ocean from a given river would give some ideas on the relative abundances of logs in different seasons and years.

3) Start a collection of samples of wood from natural floating objects. This will help establish the source of the objects, the types of trees that last longer, and their drift patterns. Institutions specializing in forestry in the different regions should be approached to help in the identification of the wood. A small wedge of wood is sufficient for the identification.

4) Start a collection of samples of wood-boring organisms to help answer questions in 3 above. Portions of wood-borer-bearing wood can be preserved by freezing and be sent to Dr. Ruth Turner.

5) The study of the hydrology of the major river systems of an area could provide better understanding of fishing patterns.

6) The study of river-ocean interfaces is of critical importance to understand the productive cycles in the coastal zone and their effect on the tuna populations. It is necessary to promote studies like the ones being performed in the Amazon basin.

Circulation Patterns

The effect of surface currents on the drift patterns of logs was discussed by Laurence Sombardier (satellite tracking of drifting buoys), Alejandro Parés-Sierra, Marco García, and Jean-Paul Rebert (computer simulation of drift patterns). Models of log circulation should include a balance between the influence of the wind stress and the influence of the currents, but it is not clear how logs actually behave with respect these two components. Do logs actually track the water mass in which they originate? In general, it is not possible to say that logs would be indicators of areas of rich primary productivity. Productive areas for tunas, however, would be areas with larger prey that should be downstream of areas of primary production. Convergence zones, which are not thought to be areas of primary productivity, would likely concentrate logs and tuna prey. It was noted that many major fishing areas are areas of current interfaces (convergence and divergence zones). Therefore, it would be interesting to study these areas in more detail, something that is possible with the current remote-sensing technology. The following studies were also discussed:

1) Tagging floating objects with visual markers or with satellite tags to understand their drift patterns, their "recruitment," and their "mortality."

2) Studies based on satellite-monitored buoys and computer models will allow us to observe drift patterns. Of special interest is the influence of the wind on non-submerged portions of the objects. Another study could determine the changes in drift patterns caused by El Niño.

3) Attachment of archival tags equipped with release mechanisms to logs, allowing the recovery of the tag and the recording of the location and time of the sinking of the log.

4) Drifting buoys that have lost their drogues may behave like logs and examination of existing data on the satellite-monitored movements of these buoys would be useful. A further experiment would be to release a log and a drifter at the same time and track them together.

5) Analyze existing data, or start collecting the information when not available, to obtain estimates of density of logs.

6) The fate of wood in the marine environment is little known. If some of the retention systems described concentrate and retain wood in the oceans, it is possible that wood may accumulate in some bottom areas.

7) Studies on the time elapsed for different types of wood to become waterlogged and sink will help us to understand the observed spatial distributions.

Schooling Behavior and Food Habits

Various aspects of schooling, feeding, and movements of tunas were discussed by John Hunter, Ken Norris, Kim Holland, Noel Barut, Martín Hall, Michael Scott, Julia Parrish, Robert Olson, and Troy Buckley. John Hunter proposed a systematic approach for designing FADs that will attract large yellowfin. Such a design should incorporate only a few treatments (because of the great variability in catches), a study of the psychophysics of vision, utilization of engineering and seamanship skills in FAD design, and cost effectiveness. Some consideration should also be given to improved longline design. For designing a FAD, a knowledge of the "how" of schooling may be more important than the "why" of schooling.

Tracking experiments suggest that schooling may not be the dominant mode for yellowfin around Hawaii. Kim Holland reported that they do not appear to school at night or while travelling. Tuna associate more tightly with the anchored FAD during the day, and then disperse within a 5-mile radius of the FAD at night. Capt. John Freitas reported that acoustic observations of yellowfin and skipjack tunas indicate that they begin to disperse at dusk and reform their schools in the pre-dawn hours.

The following studies of schooling in tunas were suggested:

1) Tracking studies similar to the ones conducted in Hawaii could give information in other oceans about daily variations in school size.

2) The question of whether these schools are aggregations vs. congregations could be determined from the distribution of size frequencies: aggregations would have a platykurtotic distribution, congregations would have leptokurtotic distributions.

Many of the questions emphasized the importance of knowing the feeding habits of the tuna in detail. The following food habit studies were suggested:

1) Comparison of the food habits of tunas caught in log, school, and dolphin sets.

2) Comparison of the food habits of all the log-associated fauna should be studied to examine the trophic structure.

3) Comparison of the food habits of tuna caught in different oceans. In particular, the eastern Atlantic should be compared with the eastern Pacific to determine whether this may explain the difference in the prevalence of the tuna-dolphin association.

4) Determination of feeding times will be important in interpreting why tuna associate with dolphins, logs, and FADs.

SUMMARY OF TUNA ASSOCIATIONS IN DIFFERENT FISHERIES

After the reviews of the different fisheries on floating objects in the oceans of the world, some similarities and some differences became apparent. An examination of the documents presented and of the presentations made suggests the following conclusions.

Log-fishing Areas

Areas of intensive fishing for tunas associated with logs occur:

- In areas where the Inter-Tropical Convergence Zone intersects the coastline.
- Offshore of areas of abundant coastal vegetation that provide the basic natural floating objects (forests, jungles, mangrove swamps).
- In areas with well-defined rainy season and high water surplus.
- Near the mouths of major river systems, or in areas with numerous rivers. Most logs entering the ocean originate in the coastal plains or are transported by mountain rivers running through steep slopes.
- Often near areas where seasonal hurricanes and intense storms can cause large numbers of trees to fall.

Tuna Behavior and Log Communities

Tunas generally aggregate under floating objects during the night, and they leave the log in the early morning.

Tunas display different behavior when associated with anchored objects than they do when associated with drifting objects.

Skipjack, yellowfin, bigeye, black skipjack, and Auxis are the main tuna species associated with floating objects.

The "communities" or aggregations associated with floating objects are similar in all oceans: the more common components include dorado, several tunas (yellowfin, bigeye, skipjack, black skipjack and bullets), several sharks (e.g. silky, and blacktip sharks), triggerfish, marlins, sea turtles, and seabirds (e.g., frigate birds and boobies).

The biomass of prey species encountered under logs seems to be insufficient to sustain the biomass of tuna and other predators associated with logs.

Associated epifauna attached to logs are generally barnacles (acorn and gooseneck barnacles). Logs entering the ocean do not appear to play a major role in the transfer of carbon and other elements between the continent and the ocean.

Factors Related to Tuna Catch

Sets on floating objects are successful more than 90% of the time; sets on free-swimming schools are successful only 50%-70% of the time.

Tunas caught under floating objects usually comprise the smallest sizes taken in purse seines.

Most of the characteristics of floating objects (shape, size, color, materials, *etc.*) were not significant in the statistical tests performed for the ETP data. However, this could be the result of small sample sizes.

The most significant factors in determining whether a floating object has tunas and the level of the catch were the location (area and distance to the coast), the season, and the time of the day.

The environmental variables studied were not significant.

Of the log characteristics, only the percent of the object submerged was significant in several cases. The objects made of discarded fishing gear appear to be more attractive for skipjack than the other types.

Fish-Aggregating Devices (FADs)

Emphasis should be placed on the selection of areas and seasons for deployment of FADs rather than on the design of the objects.

In the eastern Pacific, the area south of 8°S and east of 90°W shows the most promise for attracting large yellowfin tuna.

The objects should be designed to have a considerable proportion submerged.

Discarded fishing gear could be added as an attractant. One possible reason for the attraction of the discarded gear is that it has retained the smell of the fish caught in the webbing. Chemical attractants in other forms should be explored.

AGENDA OF THE WORKSHOP ON THE ECOLOGY AND FISHERIES FOR TUNAS ASSOCIATED WITH FLOATING OBJECTS

TUESDAY, FEBRUARY 11, 1992

0830 Opening: James Joseph
Announcements

Regional Fisheries on Floating Objects

Facilitator: James Joseph

Martin Hall	0900-0930	Introduction
Martin Hall	0930-1000	Eastern Pacific
E. Josse	1000-1030	Central Pacific
	1030-1100	Coffee break
John Hampton	1100-1130	Western Pacific
Ziro Suzuki	1130-1200	Western Pacific
	1200-1330	Lunch Break
Alain Fonteneau	1330-1400	Eastern Atlantic
Daniel Gaertner	1400-1430	Western Atlantic/Caribbean
Jean-Pierre Hallier	1430-1500	Indian
	1500-1530	Discussion
	1530-1600	Coffee break

Log Communities

Facilitator: David Au

Nikolai Parin	1600-1630	The pelagic communities associated with floating objects
David Au	1630-1700	Tuna avifauna and tuna other species associations
Pablo Arenas	1700-1730	The association of epipelagic fauna with floating objects in the eastern Pacific
Lisa Ballance	1730-1800	Associations between seabirds and a special type of floating object, the sea turtle

Primary Production

Paul Fiedler	1800-1830	Biological productivity in the eastern tropical Pacific.
	1830-1900	Discussion

WEDNESDAY FEBRUARY 12, 1992

Sources and Fate of Logs, Continent-Ocean Interactions

Facilitator: Martin Hall

Ariel Lugo	0800-0830	Litter production and coarse woody debris turnover in tropical forests
James Sedell	0830-0900	Sources of natural floating objects
Samuel Snedaker	0900-0930	Mangroves and coastal vegetation dynamics
John Walsh	0930-1000	Use of dissolved organic carbon as a satellite-sensed tracer of river plumes
Jeffrey Richey	1000-1030	Organic matter sources and riverine transport to the tropical oceans
	1030-1100	Coffee break
Ruth Turner	1100-1130	Fate of wood at sea
Churchill Grimes	1130-1200	Tropical river plumes and the ecology of scombrid larvae
	1200-1300	Lunch break

Circulation of logs

Facilitator: Jean-Paul Rebert

Laurence Sombardier	1300-1330	Surface circulation patterns in the log fishing areas as inferred from drifting buoys
Alejandro Parés-Sierra	1330-1400	A simulation approach to study the drift of floating objects
Marco García	1400-1430	Drift simulation results: eastern Pacific
Jean-Paul Rebert	1430-1500	Recent developments in tropical Atlantic French oceanography in relation to floating objects
	1500-1530	Discussion
	1530-1600	Coffee break

Schooling and other fish behavior

Facilitator: Bob Francis

John Hunter	1600-1630	Fisheries on floating objects and schooling behavior
Kenneth Norris	1630-1700	Sensory Integrated System (SIS) of schools
Kim Holland	1700-1730	Fish behavior and floating objects: radiotracking experiments
Noel Barut	1730-1800	Ecology and behavior of tunas around payaos.

THURSDAY FEBRUARY 13, 1992

Schooling and other fish behavior

Facilitator: John Hunter

Martin Hall	0800-0830	Behavior inferred from repeated sets on the same object
Michael Scott	0830-0900	Diel changes in group size: tunas and dolphins
Julia Parrish	0900-0930	Schooling behavior and floating objects: congregation or aggregation?
Robert Olson	0930-1000	Food and feeding behavior of fish associated with aggregation devices and floating objects
	1000-1030	Discussion
	1030-1100	Coffee break
	1100-1200	Working group discussions
	1200-1330	Lunch
	1330-1500	Plenary discussions
	1500-1530	Summing up
	1530-1600	Coffee break
	1600-1700	Summing up (continued)
	1700-1830	Brainstorming session on yellowfin migrations

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BACKGROUND DOCUMENTS FOR THE WORKSHOP ON THE ECOLOGY AND FISHERIES FOR TUNAS ASSOCIATED WITH FLOATING OBJECTS

-A- M. Hall, P. Arenas, and F. Miller
The Association of Tunas with Floating Objects and Dolphins in the Eastern Pacific Ocean. I - ENVIRONMENT AND FISHING AREAS.

-B- M. Hall, C. Lennert, and P. Arenas
The Association of Tunas with Floating objects and Dolphins in the Eastern Pacific Ocean. II - THE PURSE-SEINE FISHERY IN THE EASTERN PACIFIC OCEAN.

-C- M. Hall, M. García, C. Lennert, and P. Arenas
The Association of Tunas with Floating Objects and Dolphins in the Eastern Pacific Ocean. III - CHARACTERISTICS OF FLOATING OBJECTS AND THEIR ATTRACTIVENESS FOR TUNAS.

-D- M. Hall, and M. García
The Association of Tunas with Floating Objects and Dolphins in the Eastern Pacific Ocean. IV - STUDY OF REPEATED SETS ON THE SAME OBJECT.

-E- M. Hall, M. García, A. Parés-Sierra, and P. Arenas
The Association of Tunas with Floating Objects and Dolphins in the Eastern Pacific Ocean. V - SIMULATED TRAJECTORIES OF FLOATING OBJECTS ENTERING THE EASTERN PACIFIC OCEAN.

-F- P. Arenas, M. Hall, and M. García
The Association of Tunas with Floating Objects and Dolphins in the Eastern Pacific Ocean. VI - ASSOCIATION OF FAUNA WITH FLOATING OBJECTS IN THE EPO.

-G- M. Hall
The Association of Tunas with Floating Objects and Dolphins in the Eastern Pacific Ocean. VII - SOME HYPOTHESES ON THE MECHANISMS GOVERNING THE ASSOCIATION OF TUNAS WITH FLOATING OBJECTS AND DOLPHINS.

-H- M. Hall. and C. Lennert
The Association of Tunas with Floating Objects and Dolphins in the Eastern Pacific Ocean. VIII - A PROPOSED MIGRATORY CIRCUIT FOR YELLOWFIN TUNA IN THE EPO.

-I- LOG COMMUNITIES

-J- Gaertner, D. and M. Medina-Gaertner.
AN OVERVIEW OF THE RELATIONSHIP BETWEEN TUNAS AND FLOATING OBJECTS IN THE SOUTH OF CARIBBEAN SEA.

-K- Josse. E.
DIFFERENT WAYS OF EXPLOITING TUNA ASSOCIATED WITH FISH AGGREGATING DEVICES ANCHORED IN FRENCH POLYNESIA.

-L- Au, D.W., R.L. Pitman, and L.T. Ballance.
TUNA AVIFAUNA AND TUNA OTHER-SPECIES ASSOCIATIONS.

-M- Barut, N.C.
THE PAYAOS FISHERIES IN THE PHILIPPINES AND SOME OBSERVATION ON THE BEHAVIOR OF TUNAS AROUND PAYAOS.

-N- Caddy, J.F. and J. Majkowski.
TUNAS AND TREES: A REFLECTION ON THE LONG-TERM PERSPECTIVES FOR TUNA FISHING AROUND FLOATING OBJECTS. Published as: Tunas and trees: A reflection on a long-term perspective for tuna fishing around floating logs. 1996. Fisheries Research 25: 369-376.

-O- Hallier, J.P. and J.I. Parajua.
FISHING FOR TUNAS ON THE SAME FLOATING OBJECT.

-P- Hallier, J.P. and J.I. Parajua.
REVIEW OF TUNA FISHERIES ON FLOATING OBJECTS IN THE INDIAN OCEAN.

-Q- Hallier, J.P. and J.I. Parajua.
TROPICAL TUNA AT SEA: WHAT ARE THEY ASSOCIATED WITH?

-R- Parajua. J.I. and J.P. Hallier.
WESTERN INDIAN OCEAN PURSE SEINE FISHERY ON YELLOWFIN TUNA. ITS SPECIFICATIONS REGARDING LOG AND FREE SWIMMING SCHOOL CATCHES.

-S- Ariz X., A.Delgado, A. Fonteneau, F.Gonzales Costas, and P. Pallares.
LOGS AND TUNAS IN THE EASTERN TROPICAL ATLANTIC. A REVIEW OF PRESENT KNOWLEDGES AND UNCERTAINTIES.

-T- Lugo, A.E. and S.C. Snedaker.
THE ECOLOGY OF MANGROVES. Published in 1974 in the Annual Review of Ecology and Systematics 5: 39-64.

-U- Suzuki, Z.
GENERAL DESCRIPTION ON TUNA BIOLOGY RELATED TO FISHING ACTIVITIES ON FLOATING OBJECTS BY JAPANESE PURSE SEINE BOATS IN THE WESTERN AND CENTRAL PACIFIC.

-V- Hampton, J. and K. Bailey.
FISHING FOR TUNAS ASSOCIATED WITH FLOATING OBJECTS: REVIEW OF THE WESTERN PACIFIC FISHERY. Published in Tuna and Billfish Assessment Technical Programme (now the Oceanic Fisheries Programme) Technical Report No. 31, Secretariat of the Pacific Community.

-W- Hiratuka. K.
A NOTE ON AN ATTEMPT TO MAKE FREE SWIMMING TUNA SCHOOLS ASSOCIATE WITH STREAMER TOWED BY SPEED BOATS IN THE TROPICAL WESTERN AND CENTRAL PACIFIC.

-X- Parin. N.V. and B.I. Fedoryako.
PELAGIC FISH COMMUNITIES AROUND FLOATING OBJECTS IN THE OPEN OCEAN.

-Y- REGIONAL MANGROVE AREAS

-Z- Leontiev, S.V.
CHARACTERISTICS OF FORMATION AND BEHAVIOR OF ASSOCIATED AGGREGATIONS OF TUNAS IN THE WESTERN INDIAN OCEAN.

-ZZ- Buckley, T.W. and B.S. Miller.
FEEDING HABITS OF YELLOWFIN TUNA ASSOCIATED WITH FISH AGGREGATION DEVICES IN AMERICAN SAMOA. Published in 1994 in the Bulletin of Marine Science 55(2/3): 445-459.

LOGS AND TUNAS IN THE EASTERN TROPICAL ATLANTIC: A REVIEW OF PRESENT KNOWLEDGE AND UNCERTAINTIES

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ABSTRACT

The goal of this study is to review the tuna fisheries associated with floating logs in the eastern tropical Atlantic. In the Atlantic, the log fishery contributes a relatively minor proportion of the purse-seine catches (approximately 15% during the period 1988-1990). The dominant species in log sets is skipjack (76% for the same period), followed by yellowfin (17%) and bigeye (7%). Skipjack taken with logs have a weight distribution identical to those in free schools (average weight 1988-1990 = 2.2 kg). Yellowfin and bigeye associated with logs show a majority of small fishes (less than 5 kg) in numbers, but also a significant proportion of large individuals (average weight of 5.3 kg for yellowfin and 4.5 kg for bigeye). The fishing seasons and locations on logs are geographically restricted and stable from year to year during the period under study.

As in other oceans, the catch per set under logs is on the average greater than on free school (34 t versus 19 t), and the rate of unsuccessful sets is low compared to free-swimming schools (6% versus 28%). Many logs in the Atlantic seem to be from natural origin and are drifting in the surface currents of the area. The exact origin of the logs is still questionable, especially the proportion from the Amazon and from African rivers (especially Zaire), both located at similar distances from the fishing zone. The accumulation of logs in the north equatorial convergence zone has been noticed and contribute to important tuna catches. Since the end of 1990, artificial logs have been deployed in large numbers in the offshore area by purse seiners, and have enabled catches of skipjack and larger yellowfin in new fishing zones. Yield per recruit analysis has been conducted and concludes that a further development of the artificial log fishery should increase the yield per recruit of the total fishery, the potential benefit being mainly for skipjack. Research recommendations are developed in order to improve knowledge about tuna and log dynamics, and also to estimate the tuna abundance in a purse-seine fishery developing a log fishing strategy.

INTRODUCTION

The fishing method of catching tunas under floating objects is quite old in the eastern Atlantic; it probably has taken place since the early years of the purse-seine fishery during the early sixties. However, sets on floating logs were seldom noted in most of the logbooks, and this information was not recorded on a routine basis in the computerized logbook file until 1988. For the previous years, only incidental data has been previously collected and analyzed on some French, Ivorian and Senegalese purse seiners unloading in Abidjan. As this method of fishing is now being developed with the use of artificial logs in conjunction with more fishing on natural logs, it is of prime importance to describe and analyze in detail this log fishery. A primary goal of this paper is to provide estimates of the log-associated catches by species, and of the sizes of tunas taken. The time/area distributions of the fishery will also be studied, as well as the average sizes of sets and success rates in log sets. The comparison between artificial and natural log dynamics is also of major importance. Another important topic is to compare the yield per recruit for the free-school and log-associated fisheries (as those two types of fisheries are often catching different sizes of tunas). These analyses will be conducted for the three major species taken by the log fishery: yellowfin, skipjack and bigeye. The final goals of these analyses will be to assess the potential benefits and dangers in developing log-associated fisheries and to make research recommendations to understand better the tuna-log relationship and the potential impact of this association in the rational exploitation and management of the tropical tunas.

THE PHYSICAL ENVIRONMENT

Ocean and Surface Currents

This description was based on the text by Y. Gouriou. (in A. Fonteneau and J. Marcille, 1988) with more consideration of currents and oceanography of the western Atlantic.

The wind is the major driving force in the circulation of the surface of the ocean. Friction produced by the wind pulls a rather thick layer of the ocean's surface; thus, in each hemisphere, there is an anticyclonic circulation which is associated with the anticyclones of the Azores and of St. Helena. The asymmetry of the geographical position in relation to the equator is also reflected in the circulation of the ocean surface. The area studied is subject to the influence of the circulation in the southern hemisphere. Figure 1 shows the system of surface currents of the intertropical Atlantic Ocean.

The following are found in the northern hemisphere:

- The Canary Current, which occurs along the coasts of Morocco and Mauritania, leaving the African coast around 20°N and moving towards the southwest.

- On the equatorial side of the North Atlantic Drift, the North Equatorial Current (NEC), which is a prolongation of the Canary Current, flows towards the west. It has a southern component which flows towards the east and a northern component which flows towards the west. Its average speed surpasses 10 cm/s and is weaker along the eastern border than along the western side. This current presents small seasonal variations and becomes weaker to the east between the months of June and September.

- Between 4°N and 8°N, the North Equatorial Countercurrent (NECC) moves towards the east. It stays to the east of 20°W and continues in the Gulf of Guinea as the Guinea Current (GC). It has large seasonal variations. Beginning in May-June, the NECC shifts northwest, reaching its maximum width around the month of September, when it occupies the entire basin to the east of 5°W, between 4° and 10°N. Its speed is around 40 cm/s. From November to January, the NECC gradually disappears to the west and in March it can be found only to the east of 20°W.

- The continuation of the NECC, or the Guinea Current (GC), borders the African coast to the bottom of the. Bight of Biafra. It becomes more intense to the east of Cape Palmas, reaching speeds around 30 cm/s. Between 4°E and 8°W two maximum speeds are observed, one in July-August (60 cm/s) and another in February (40 cm/s). The presence of this current causes the accumulation of water in the back of the Bight of Biafra, which flows along the northern branch of the South Equatorial Current

The following are found in the southern hemisphere, bordering the South Atlantic Drift:

- The Benguela Current, which occurs along the coast of Namibia, flowing towards the north. It turns towards the west at the level of Cape Frio (17°S).

- In the equatorial side of the South Atlantic Drift, the South Equatorial Current (SEC), which moves towards the west, is much more developed than the NEC, as it reaches 3°N. In the central Atlantic, the equatorial current divides into two branches, around 2°N and 4°S. moving towards the west. The average speed of both branches is around 35 cm/s.

Off South America, the southern branch of the SEC separates into two: the Brazil Current (15 cm/s) moving towards the south, and the North Brazil Current (NBC) moving towards the north (60 cm/s). The northern branch of the SEC meets with the latter at approximately 4°N and 50°W. The northern branch of the SEC shows an annual. cycle marked by maximum speeds in June and December (Figure 2). The southern branch shows weaker monthly fluctuations, dominated by an annual period. From September to February, the two branches have the same speed; from June to August, the northern branch is faster, although from March to May the reverse occurs.

To the west of the basin (35° to 45°W) this two-branch structure of the SEC is only observed from August to November. To the east of the basin (10° to 20°W) the northern branch reaches its maximum speed (66 cm/s) in June, at around 2°N. The minimum speeds are observed in October and February. The southern branch reaches a maximum speed of 50 cm/s from May to July at around 4°S. During some months, from December to February, the northern and southern branches join, forming a single current. The relative minimum speed of the southeast equatorial current is the result of the equatorial upwelling which slows the current near 1°S.

The oceanographic buoys put at sea by oceanographers can provide direct evidence of those surface currents and of the drift of floating logs in the fishing area. Some results obtained from drifting buoys are of special interest for the tuna-log problem, for instance:

1) The seasonality of the NECC is well shown by Figure 3 taken from Richardson and Reyerd in 1987.

2) The change from a westward drift of oceanographic buoys south of the equator, to an eastward drift of logs in the Amazon area north of the Equator, is well shown by Figure 4.

3) Floating objects located south of the Equator east of Greenwich may show an upward circular movement, being trapped in the Bay of Biafra, instead of being carried westward by the SEC, as shown by Figure 5.

RIVERS AND FORESTS

Rivers

Figure 6 shows the major rivers that flow into the intertropical Atlantic Ocean.

East Atlantic

The annual average contribution of the western African rivers (from the Senegal River to the Zaire River) to the Atlantic Ocean is $2{,}660*10^9$ cubic: meters per year. The Zaire River is the largest and contributes 50% of the total volume. In the last few years, several large anomalies can be noted, for instance one in 1962 with an excess of 23% and another in 1983 with a deficit of 34% (Mahe, G. and Olivry J.C. 1991). Examination of the regional variations shows that the drought of the last 20 years is much less severe in equatorial Africa than in the tropical areas. Data on rainfall indicates that when a spectacular drought was observed in the Sahelian areas during recent years, only moderate or no decreases in rainfall were observed in the Equatorial areas. As for the seasonality of the African rivers, it should be noted that from November to June, the Zaire River contributes more than 50% of the total contribution and the contributions of water from the rest of the African rivers together are greater only in the period from August to September (Figure 7).

West Atlantic

The Amazon is the largest river in the world in terms of water flow, with around $5{,}521*10^9$ cubic meters/year (Dessier A. 1990), approximately five times more than the Zaire River (which is the second largest river). Its relative contributions are stable throughout the year, with a minimum between October and December and a maximum in the month of June. The Orinoco River, which flows to the north of the Amazon River, is third in water flow, contributing $1{,}131*10^9$ cubic meters/year.

Forests

The forests which cover these river basins have thick and dense vegetation, characteristic of large equatorial jungles. Outside the equatorial area, the river basins have abundant vegetation, composed of grasses, bushes and trees. Figure 8 shows the different types of vegetation which cover the basins of the main rivers flowing into the intertropical Atlantic Ocean. It can be assumed that the area of dense equatorial forest can be a major source of natural floating logs.

THE LOG FISHERY IN THE EASTERN TROPICAL ATLANTIC

Fishery Data Available

All logbook information and samples collected from purse seiners of all countries at the two major landing ports in Abidjan and Dakar during the period 1988 to 1991 were available for the present study. However, logs were noted only in the French and Spanish logbooks. Consequently, only Spanish and French logbooks and samples were used in the present analysis. French and Spanish purse seiners contribute an average of 87% of the purse seiner catches. In the logbooks, each individual set was usually identified and was coded in the computer file. When a floating object, porpoise or whale was noted in the logbooks, they were also recorded (only since 1988). Artificial and natural logs are often distinguished in the logbooks; however there is probably some misreporting of this parameter, and some artificial logs are probably reported and coded erroneously as "natural logs." This potential problem should be kept in mind in the interpretation of the data since the end of 1990.

The null sets are also reported in the logbooks, but probably with some unknown rate of underestimating. This underestimation may also exist for all types of associations, but to an unknown degree.

The species composition given in the logbook was corrected on a routine basis (since 1980) using data from an *ad hoc* sampling plan established to estimate simultaneously the sizes and species taken (see Cayre 1984). The goal of this *ad hoc* sampling scheme was to estimate the real proportion of each species in the catches; this method was developed when it was shown by scientists that the small bigeye were often underestimated in the logbooks (*e.g.*, Fonteneau 1975) and that most small tunas caught were called. "skipjack" when this species was dominant. The effects of those corrections are quite significant; on the average, the corrections increase the proportion of yellowfin and bigeye. Those two species amount respectively to 11.1% and 2.1% in the logbook catches associated with logs, and amount to 7% and 17% after species composition corrections. During the same correction, skipjack is decreased from 80% to 76% of the total catches.

The numbers of fishes sampled in this program is quite important, and an average 95,000 tunas were measured yearly from French and Spanish landings by purse seiners between 1988 and 1990 (among them 13,500 tunas were measured yearly from log-associated schools).

The size composition of the catches are estimated using a standard ICCAT procedure. Each multi-species sample is first weighted to the original sampled strata (usually the sampled well or the sampled set when identified). Then the total of all weighted samples taken in all 5°-month strata are extrapolated to the corresponding catches of each fleet. When a catch is not sampled at the 5°-month level (this occurs for less than 10% of the catches), a strata substitution is done with adjacent strata.

Description of the Fishing Operation With Floating Objects

In the intertropical Atlantic Ocean, there are no appreciable differences in the fishing operations of purse seiners catching tuna schools associated with floating objects (natural or artificial) and those catching free schools or associated with whale sharks, whales, etc.

Once the object is located, either by sighting or by bird radar (in the frequent case where birds are found near the object), the boat goes toward the object, proceeding to evaluate the characteristics of the school (size and species), by sight as well as by sonar. Some skippers prefer not to approach the object with the boat, and they launch a small boat with a spotter to approach the object and evaluate the possible catch.

If it is decided that a set should be made, the boat is moved a certain distance from the object which will be in the center of the circumference of the area that will be surrounded by the net. From that moment, the traditional fishing operation is effected; the auxiliary skiff is lowered, which carries the end of the net; the boat begins to circle. Once finished, the purse line begins to be drawn and then the net, until the catch can be scooped. Before recovering the gear, the object is tied to the side an auxiliary launch and very carefully pulled out of the circle.

Depending on the results obtained in the fishing operation, the captain of the tuna boat will take one of the following decisions:

a) Abandon the object and continue searching for new schools;
b) Place a streamer or a radio beacon on the object, with the idea of returning to it at some other time, and continue searching; or
c) Remain next to the floating object so that it cannot be used by other vessels, proceeding to take tunas associated whenever it is felt that it is opportune, generally every day at dawn.

Sometimes, if the object is found near the continental plateau and the currents cause it to move towards the plateau, a long cable is placed from the boat to the object and another to a auxiliary launch or skiff which proceeds to function as a towboat for the tunaboat (which stops its motors) and consequently for the object, counteracting the effect of the current and preventing it from reaching the continental plateau, thus avoiding possible damage to the net (the nets used by Spanish purse seiners in the Atlantic Ocean reach a depth of 200 m).

There are other variations; sometimes the tuna boat itself acts as an involuntary object when it remains adrift at night. At times, auxiliary skiffs anchored in certain areas have acted as fixed objects, and in the beginning of the fishery, some companies operated with the help of "maciceros" (boats from which bait was thrown) causing the tunas to remain in one area.

From the end of 1990, and especially in 1991, tuna fishing associated with artificial floating objects has become more common. The artificial objects that are used are square, with approximately 1.5-m-long sides, and 30 cm high. They are made of thick bamboo poles about 20 cm in diameter, covered with a black net cloth on the upper side. A buoy is added to these objects that has a radio beacon.

These radio beacons can emit signals continuously or can be "sleepers," that is, a radio signal from the tuna boat causes them to begin transmission. Each boat uses different and secret frequencies for its radio signals. Beside the rafts that the boats leaving the port of Abidjan carry, there are at least three auxiliary boats that construct the rafts at seas. These boats also make continuous trips to monitor the beacons constructed by them or those set by tuna boats from their company, alerting the purse seiner by radio if there are tunas associated with the object. The purse seiners, beside their traditional operation, use the night-time to move from one object to another, so that with this type of fishing the efficiency of the purse seiners is increased by an amount that has not been quantified.

The “seeding” areas of the objects up to now have been between 4°N and 5°S latitude, usually at 5°W longitude (Abidjan longitude). Fishing with these objects began when reaching about 10°W and 20°W (after some weeks or months of drifting) and a latitude similar to the “seeding."

More recently, during the end of 1991 and beginning of 1992, new experimental types of artificial logs were being tested by the auxiliary boats and the Spanish purse seiners. Those new fish aggregating devices (or FADs) are similar to the ones previously described, but with at least two additions:

- Addition of dead small tunas in the net hung under the FAD.
- Addition of battery-powered flashing lights (red and green) hung under the FAD.

The effects of those changes on the tuna aggregation are still unknown but need to be followed and estimated.

Catch Trends: History of the Fishery

At the beginning of the 1950's, first handline boats and later baitboats began to operate, basically in the area, of Dakar (Senegal). These were French and Spanish boats that seasonally fished during the winter, alternating with fishing in other areas. The catch rates obtained in this period were excellent, which caused these fisheries to develop rapidly during the 1960's and 1970's, incorporating other fleets. The main species caught were yellowfin and skipjack. More recently, since the early seventies, an important baitboat fleet targeting mainly skipjack was developed in Tema. This fleet is still very active and is presently developing its fishing activities on artificial logs (Kwei, pers. com.). Unfortunately, due to the lack of published or available information on this baitboat activity, the present review will not cover this interesting topic.

The longliners appeared in the area in the mid-1950's and have remained since the early seventies at a moderate level of activity targeting mainly bigeye tuna during recent years. As far as we know, the longline fishery is not using logs in its fishing activities.

In 1964, the first small purse seiners appeared in the area, which were French and Spanish. The most striking characteristic of. the development of this fleet is the marked increase in the size of the boats and gears used, as well as the continuous technological innovations, which caused a continual increase in fishing effort exerted by this fleet which, in just a few years, became the highest in terms of catches.

The purse seiners exploited the coastal area up to 1974 and, beginning in 1975, increased their area of operation towards the offshore areas. The main target species for the purse seiners has always been yellowfin, although the catches of skipjack have been high in some years, especially for the Spanish fleet. Following these two species, but at quite low levels, is bigeye.

In 1984 there was a sharp decline in purse-seine effort, due to the fact that almost the entire French, Ivorian and Senegalese (or FIS) fleet and a large part of the Spanish fleet left the fishery and moved to the Indian Ocean. This departure was caused by low catch rates of yellowfin in 1983 and 1984.

The fishing on logs by purse seiners has probably taken place since the beginning of the purse-seine fishery in the early sixties. However as this mode of fishing was rather incidental and poorly reported in the logbooks, the first estimate of this type: of fishing has been conducted only since 1976 in Abidjan on the French, Senegalese and Ivorian fleet by Stretta (and reported by Cayre *et al.* 1988). In this study, an average 20 percent of the total catch has been recorded in Abidjan as being associated with natural floating logs. The monthly catches recorded with logs are given in Figure 9, with a comparison of the corresponding total landings. The average quarterly fishing zones on logs during this period are given in Figure 10.

A more-detailed overview of the present log fisheries will be given below, for which detailed information has been collected on various purse-seine fleets during 1988-1991.

In summary, recent total catches taken on natural floating logs and the total catches by purse seiners are given in Table 3. This table shows that approximately 17% of their total catch is taken on natural floating logs. The major percentage is taken on bigeye (26%) and the major catches in weight are taken on skipjack (average 23 000 tons, 13% of the total purse-seine catches).

Species Composition of the Log-Associated Schools (1988-1991)

The period between 1988 and 1991 is studied based on the French and Spanish logbooks available (80% of the total purse seine catches). The species composition was obtained from the multi-specific sampling scheme conducted throughout this period. in Abidjan and Dakar. The multi-species sampling scheme used is following the guidelines given by Cayre (1984) or Bard and Vendeville (1986). For the first three years (1988-1990), the species composition was obtained. from catches associated with natural objects, while that for 1991 was obtained from catches with both natural and artificial objects, as this was the first year the fleets deployed FADs on a massive scale. For 1991, the corresponding percentage of small tunas was also taken into account.

The floating "objects" correspond to the major category of floating devices associated with tunas and. used by fishermen; they contribute an average 17% of the catches during the period 1988-1990. Other floating objects such as whale sharks, and live and dead whales, contribute an average of 8.6%. Porpoise are very seldom recorded in the logbooks as being associated with tuna schools, less than 0.2% of the catches. This percentage may be biased downwards, but in the eastern Atlantic, none of the purse seiners are equipped for fishing on porpoises and this type of association and catch probably are rare.

In general, the species composition of tunas associated with floating logs is quite stable from year to year and. from area to area (Figure 13). Skipjack is always the dominant species with an average 76% of the catches, followed by yellowfin (17%). Bigeye tuna is the third most commonly landed species with an average 7% of the catches (Figure 12). Those figures do not include several other species which are associated with the tunas in most of the log schools. Those species are usually discarded at sea or sold at the local market, but are not recorded in the statistics. The data from observers demonstrate qualitatively the diversity of species caught under logs.

Sizes of Tunas Taken Under Logs

The sizes of tunas associated with natural objects were studied. The sizes of the major species, skipjack, are similar in free schools and in log-associated schools (Figure 17). This also applies somewhat to bigeye tuna, but with a lower proportion of large fishes in the log-associated catches (Figure 17). The yellowfin taken are predominantly small individuals less than 70 cm. However, a significant proportion of the yellowfin caught under logs are large individuals, and as a result approximately half of the yellowfin catch in weight is comprised of large fishes (Figure 18).

The sizes of three species sampled from sets on natural and artificial objects were compared during 1991. The size range associated with both types of objects are very similar for skipjack and for bigeye. However, yellowfin taken during 1991 under artificial logs have a greater average size and weight of large individuals larger than 120 cm or 30 kg (Figure 25). This can possibly be explained by the operational areas of artificial logs which are more offshore than the traditional "log area" (see Figures 14 and 16).

A more-detailed analysis of the size structure and variability of the yellowfin caught under logs is necessary. The average weight calculated for yellowfin for all purse-seine fisheries (free school or logs) does not correspond in fact to any significant group of fishes, but is only, because of the predominantly bimodal distribution of sizes caught, an average size between a group of small fishes (1 to 5 kg) and a group of large fishes (more than 30 kg). Figures 19 to 22 show the complexity and the variability of the sizes taken (showing individually all the significant yellowfin samples with more than 25 fishes measured). Those raw samples (unweighted) show well that a wide variety of yellowfin sizes are taken under logs.

Each year, the two following types can be observed:

- Samples of pure schools very small (<2 kg) or small (<5 kg) yellowfin. These categories account for approximately half or less of the samples.
- Samples with a mixture of large and small yellowfin, commonly in the range of 1.5 to 60 kg with variable proportions of small and large individuals.

It can be noticed that the sizes taken under artificial logs during 1991 (Figure 22) are similar, the major proportion of large yellowfin (Figure 25) being the result of a higher proportion of large fishes in the mixed-size samples.

Seasonality and Fishing Areas on Natural and Artificial Logs

Natural logs

Figure 15 depicts the tuna catches associated. with natural objects by quarter, from 1988 to 1990. The strong and stable seasonality observed year after year should be noted.

At the beginning of the year, fishing activities take place near the equator (5°N-5°S) and between 5°E and 20°W longitudes, that is, in a very wide area. In the second quarter, a bipolarization begins to occur in the fishing areas, which continues and is even more marked in the third quarter. One of these two areas is located in the back of the Gulf of Guinea (5°N-5°S and 9°E-1°W) and the other is off Senegal-Guinea (10°N-15°N and 15°W-20°W). Finally, the fourth quarter is when the highest catches are made in very restricted areas (Equator-5°N and 10°W-15°W).

Artificial logs

Figure 16 gives the catches of tunas made in 1991 on natural and artificial objects between 5°S and 5°N (by 1/10 of latitude degrees). Tuna catches on artificial objects occur to the north and to the south of the equator, while those made near natural objects are predominantly observed to the north of the equator, and almost never occur to the south.

A major factor in the artificial log fishery is that the fishing zone for skipjack is extended to the offshore area south of the Equator and west of 10°W, in a fishing zone where this species was previously unavailable to any fishery. Consequently, the new artificial log fishery now exploits a new geographical. fraction of the stock which was "cryptic" until 1990.

Data on the seasonality of fishing activities associated with artificial floating objects are available only for 1991 (since this activity began in 1991) and only for the Spanish fleet (Table 8). The analysis of these data indicate that the highest proportion of catches are obtained in the fourth quarter of the year (43%). In the first and second quarter, 23% and 26% of the annual catches, respectively. are made, and the lowest catches (8%) are made in the third quarter.

Catch Per Set and Null Sets on Log Schools *Vs.* Free-swimming Schools

The number of sets, average catch per set and number, and percentage of null sets were calculated for FIS and Spanish fleets together, for 1988 to 1990. The 1991 data correspond exclusively to the Spanish fleet and should be considered as partial. The sets were separated into three groups: natural objects, artificial objects (1991) and other associations, and free schools. The catch data are for the three main species: yellowfin, skipjack and bigeye. The results are presented in the Table 6.

Several facts must be pointed out:

a) The percentage of null sets (6%) is low when fishing on floating objects (either natural or artificial), compared to fishing on free-swimming schools (about 27%).

b) The yield per set is considerably higher when fishing on floating objects (41 t) than when fishing on free schools (19 t). This is due to a higher relative frequency of large or very large sets (Table 7): 64% of the sets on logs yielded greater than 50 t *vs*. 4.5% in free-swimming school sets.

c) There is a continual increase in the average catch per set during the period 1988 to 1991 in schools associated with floating objects, as well as those on free schools (Table 6). The possible reasons, for this increase are not yet known.

d) A provisional estimate indicates that almost half of the Spanish catches in 1991 were taken near floating logs (53,000 MT of 109,000 MT), which explains the high proportion of skipjack in the total catches.

e) It appears that the average catch per set on logs is higher than on free schools, but it is obvious from observer data and logical that various logs which are associated with a too-small biomass of tunas are not "sampled" by the purse seiners. Consequently this average catch per set on logs overestimates the average tuna biomass associated with logs.

Review of Observer Data

The International Yellowfin Year Program (IYYP) was carried out by ICCAT in the intertropical Atlantic Ocean during 1986 and 1987. During this program, only 6 cruises were monitored by scientific observers. The sampling coverage (in the different time/area strata) was low, thus the data presented should basically be considered descriptive, but they deserve some attention because of their good quality.

The percentage of schools detected in association with floating objects was around 16%, compared to 84% that included free schools. The sets made with floating objects were 17% of the total sets (17.6% in the International Skipjack Year Program or ISYP) and the percentage of null sets on floating objects was around 5.6% (4.7% in the ISYP) (Table 4).

The small tunas (frigate tuna *Auxis* spp., and Atlantic black skipjack *Euthynnus alliteratus*) show high catches when caught with floating objects (30.8% in weight of the total catch in this type of association) and very low in other associations (only 5.2%).

Several other genera of fishes (*Coryphaena* spp., barracuda, *Balistes*, etc.) were also recorded by observers in most of the sets. Those fishes are usually dumped at sea or sold at the local market.

Annex 1 presents the dates, location, hour, brief description of the objects, with comments upon the species caught. Most of the observations have been done in areas which are not typical of the log fishing activities. However, several observations are probably of general interest, especially those concerning the specific diversity of the log-schools.

LOG FISHING AND ESTIMATION OF TUNA ABUNDANCE

In the eastern Atlantic, log fishing has been treated in the past by scientists as a rather negligible event, and all the catch per unit of effort (CPUE) have been calculated in tons of tunas taken by searching time. It is clear, at least as a concept, that the catch per searching time cannot provide a good measure of abundance in a log-school fishery. In such a fishery, the purse seiner locates a log-school and then the boat will have different opportunities: among them, the boat can stay with the log (without searching) for several days to fish on it once a day; in many cases, the purse seiner may also receive assistance from a specialized boat which follows the logs, estimates the biomass of tunas by echo sounder and calls the purse seiner by radio to catch the school. In none of these two cases can the searching time be used as effort, nor can the CPUE be used as a measure of abundance. Consequently the recent change in fishing pattern and the development of log fishing introduces a critical potential bias in the present estimation of abundance.

The catch per set under logs, however, can potentially be used as a measure of local abundance of the resource. This hypothesis is, at least for skipjack and juvenile yellowfin and bigeye, that:

"There is some proportionality between the density of the local biomass available in an area and the biomass of tunas concentrated in the tuna schools under each log."

This concept is quite simple and strong, but is unfortunately hampered by various factors such as:

- **Nature of the log:** The attractiveness of each type of log may be variable.

- **Area:** The attractiveness of each type of log may be different depending on the local conditions: abundance of food, transparency of waters, currents, etc. The potential effect of surface currents seems to be of special importance considering the more successful fishing zones of artificial logs. This can simply be due to the geographical area "covered" by the log during its drifting.

- **Duration effect:** Concentration of tunas under a “virgin” log probably needs some days or weeks; it is consequently difficult, when few tunas are observed under a log, to know if this is due to a low local biomass or due to a short duration at sea (a “fresh log” and an “old log” recently fished by a purse seiner may have identical low biomasses). This duration effect has two potential components: the first one linked with the object's past “life,” the second one with the fishery intensity and the density of logs in the area.

All those parameters could adequately be analyzed using a generalized linear model (GLM) if the detailed corresponding data were available.

This complex situation could be clarified, understood and possibly modeled, if detailed information were obtained on many individual logs. This detailed information may be difficult to obtain, however, and part of the future research conducted under the tuna/log program should concentrate on obtaining a better understanding of these dynamics. The results would also be of major interest in understanding the tuna and log association and the development of this type of fishery.

LOG FISHING AND EFFICIENT EXPLOITATION OF THE TUNA STOCKS

What Potential Catch Rates and Catches Can Be Predicted for Yellowfin, Skipjack, and Bigeye With a Further Development of a Log Fishery?

The potential. of natural logs in the Atlantic seems to be quite limited, primarily because of the relatively small numbers of natural logs. However, the efficiency of the artificial logs deployed recently by the purse seiners shows that an increased number of artificial logs can increase the log-associated catches of tunas, with a wider time and area coverage. This new situation raises new questions about the potential benefits and dangers for the stocks and fisheries of this new fishing technique. Some of those factors will be subsequently discussed.

Multi-gear and Multi-species Yield Per Recruit Analysis

A multi-gear yield per recruit (Y/R) analysis (using the Ricker 1958 model) has been conducted simultaneously upon the three major species exploited by the eastern Atlantic: fisheries: yellowfin, skipjack and bigeye.

This analysis assumes that the most recent estimates of fishing mortalities are the ones which are presently applied to each stock. The following estimates were selected :

- Yellowfin: IYYP results, period 1986-1988.

- Skipjack: ISYP results, period 1979-1981. No analyses have been conducted since that estimate, but as the total catches of skipjack during this period is very similar to the present one (95,000 t versus 107,000 t presently) and as the size taken are nearly identical, the fishing mortalities by age during this period may be very similar to the present ones.

- Bigeye: Pereira (1990), period 1987-1989.

The fishing mortalities on logs were calculated for the three species in proportion to the catches on logs (by age) *versus* the same result for the entire fishery. Those fishing mortalities (total and on logs) are shown in Figure 26. The Y/R calculated for each species and for the combined three species fishery are given in Figure 27.

The following comments can be made for each species

- Yellowfin: The log fishery can produce a very small theoretical increase of the total Y/R. For instance, multiplying the fishing mortality on logs by a factor of three (with a stable fishing mortality for the other fisheries), could theoretically increase the total Y/R by 1%. On the other hand, doubling the free-school fishery could increase the total Y/R by 12% if the present log fishery is stable at its 1988-1990 level, and by 14% if the log fishery was not exploited by any purse seiner. An opposite result was obtained for the eastern Pacific yellowfin by Punsly *et al.* 1994, because of the major differences in the age-specific fishing mortalities of the various types of schools taken in the eastern Pacific (associated with porpoise or with logs).

- Bigeye: This stock is assumed to be moderately or even lightly exploited (Pereira 1990). The purse-seine fishery catches only a small proportion of the total catch of this species (average purse-seine catch for 1988-1990 = 12%), the bulk of the catch being large fishes taken by longliners and artisanal fisheries. As a consequence of those two factors, the log fishery has a small positive impact on the Y/R of the total fishery. For instance, tripling the fishing mortality on logs (with a stable fishing mortality of the other fisheries), could theoretically increase the total Y/R by 2%. On the other hand, doubling the "non-log" fisheries could increase the total Y/R by 48% if the present log fishery remained stable at its 1988-90 level. However, if such an increased fishing mortality was exerted, the increase of the log fishery would not produce any change (positive or negative) in the total Y/R (when the other fisheries still could potentially increase their Y/R).

- Skipjack: This stock is assumed by the Standing Committee on Research and Statistics (SCRS) of the ICCAT to be moderately exploited. The purse-seine fishery catches a predominant proportion of the total catch of this species (average 1988-1990 = 58%), the other fraction being caught by baitboats. The log fishery is consequently estimated to have a significant positive impact on the Y/R of the total fishery. For instance, tripling the fishing mortality on logs (with a stable fishing mortality of the other fisheries), could theoretically increase the skipjack Y/R by 20%. On the other hand, any increase of the fishing mortalities by the other "non-log" fisheries could also produce an identical increase of the total Y/R if the present log fishery is stable. This is obviously due to the similar_sizes taken in the two modes of fishing.

Discussion

The Y/R analyses strongly rely on the level of exploitation estimated for each stock. This can be a serious limitation for all the present results. The quantities of bigeye and yellowfin taken under logs are moderate (skipjack is always the dominant species), however, and the average sizes taken are moderately small (a significant number of large yellowfin and bigeye are often taken). The sizes of skipjack taken on logs and other fisheries are identical and the Y/R are subsequently identical.

Consequently, the log fishery provides presently an efficient way to increase the Y/R of the total fisheries, the benefit for skipjack being greater than the possible minor changes expected for yellowfin or bigeye. This conclusion seems to be consistent and logical, under the present fishing patterns on the stocks, and because those stocks are still not intensively exploited (because of the reduced fishing efforts observed in the area since the departure in 1984 of many purse seiners to the Indian Ocean).

However, the further development of the log fishery should be biologically monitored carefully, because of the great numbers of small yellowfin and bigeye taken in association with skipjack. Also, it appears that the huge catches of small tunas taken under artificial logs may have a strong negative economic impact on the tuna market.

DISCUSSION ON LOG AND TUNA FISHERY PROSPECTS IN THE EASTERN ATLANTIC

Present Knowledge and Uncertainties

The present review of the tuna and log relationships in the eastern Atlantic provide some valuable information:

1) Floating logs originate either from rivers or are built and dumped at sea by the fishermen. Natural logs are primarily located in the outflow areas of rivers such as the Zaire and the Niger. However, a major area of log concentration and tuna fishing is located at 2°N and 15°W in a convergence area, but whether the origin of those logs is the African rivers or the Amazon is unknown. This problem should be clarified as soon as possible by adequate sampling of the floating logs. The use of artificial logs have been recently developed very actively by fishermen.

2) The sets under logs are interesting for the tuna fishermen because of the large sizes of those schools and because of the low rate of unsuccessful sets with this type of fishing. Consequently, the catch rates under logs can be very high.

3) The species composition under logs is quite stable, with most schools being multi-species schools comprised of skipjack, yellowfin, bigeye and other small tunas and in association with a small amount of other pelagic species such as *Coryphaena*, barracudas, *Balistes*, sharks, wahoo, *Seriola*, billfishes, *Elagatis*, etc.

4) The sizes of tunas taken under logs are also typical and stable from year to year, the fishes being predominantly of small sizes. However, large yellowfin and bigeye are often taken under logs.

5) Artificial logs deployed in convenient areas concentrate tunas with similar characteristics as natural logs: large schools that are easily caught, multi-species schools containing mainly small fishes and some large yellowfin and bigeye.

The major difference between natural and artificial logs is that the natural-log fishery is seasonal and restricted geographically, while artificial logs can be deployed efficiently over wider time and area strata. The potential times and areas for efficient artificial log fishing are still unknown, as only some successful fishing areas are known.

6) The ecological and ethological processes of the association of tunas with logs are still poorly understood. It appears that a floating object can be a reference point for the tunas in the uniform field of the ocean. However, it is not known from existing data what feeding mechanism can explain such high biomasses of tunas (commonly 100 tons), in such a small area where the available food can hardly be found. It seems unrealistic: to assume that those tunas can find under the log itself the huge biomass of food required. It is more probable that the tunas which spend the night under a log then travel during the day in the vicinity of the log in order to feed (this is suggested by the apparent lower biomasses of tunas found by fishermen under logs during the day). The ecological advantage for a tuna to be associated with a log is not clear. In the presence of fisheries, however, this association clearly has a negative effect on survival,

especially for skipjack and small yellowfin and bigeye, as it increases the fishing efficiency of the purse seiners on those three groups.

7) In terms of rational management of the tuna resources, log fishing (on natural or artificial logs) can be considered as a more-efficient way to catch tunas, particularly skipjack stocks that are not yet fully exploited, as is presently the case in the Atlantic. The log fishing increases the fraction of skipjack stock which can be fished and subsequently increases the equilibrium skipjack catches and catch rates. The artificial log fishery allows the catch of the offshore segment of the skipjack stock (west of Greenwich and south of the Equator) which was, until 1990, unavailable to any fishery.

The potential negative effects of the log fishery on the yellowfin and bigeye yield per recruit seem to be null or very minor under present conditions.

8) There is an unknown use, apparently increasing, of artificial logs by the Tema baitboat fleet. This new type of fishing operation should be described and analyzed quantitatively.

The important parameters influencing the association of tunas and logs in the Atlantic can usefully be compared with fishery and scientific: information available from other oceans. The various papers presented at the this meeting will offer a good opportunity to develop those comparisons.

Research Needed

As the aggregation of tunas under floating logs is a world-wide phenomenon, it is clearly useful to develop coordinated research plan on this topic at the worldwide level in the three oceans. Much research can probably be conducted in selected geographical areas, and their results extrapolated (with caution) to other geographical areas.

In the eastern Atlantic, some major research recommendations are listed:

- Study the geographical origin (West Africa or South America) of the floating logs accumulated seasonally (November to January) in the North Equatorial convergence (2°N-15°W) where log-associated catches are important.

- Review all oceanographic: knowledge about the drifting of floating objects in the intertropical area from existing data (merchant ship drift, oceanographic buoys, research cruises, and modeling).

- Conduct new experiments of oceanographic drifting buoys seeded in areas of special interest to the eastern tropical Atlantic: tuna fisheries. Study the aggregation dynamics of tunas under logs in order to be able to use a "catch per set" index as a measure of local abundance. This program should cover:

    - tagging of natural logs (even knowing that similar tagging of logs has been conducted in the eastern Pacific and western Indian Oceans with poor success) and exact identification of artificial ones.

- tagging of tunas with spaghetti and sonic tags in the area of logs to study their movements relative to the logs.

- collect more-detailed and exhaustive information in the logbooks for all log-associated catches.

- conduct at-sea experiments of artificial logs conducted by research boats (well-equipped with echosounder and oceanographic devices) in a log fishing area.

- conduct statistical analyses and modeling of the aggregation dynamics of tunas under logs.

- The auxiliary boats used by the Spanish fleet to follow the logs are equipped with echo sounders and experiment with new types of logs and would make good research platforms for observations on logs. Such a program should, be discussed by the IATTC working group and should further be conducted by the scientific observers from the Instituto Español de Oceanografia on board these boats.

- Study the stomach contents and feeding behavior of tunas taken under logs to understand how large biomasses of tunas can survive under the logs.

CONCLUSIONS

The present study was a first review of the tuna fisheries associated with floating logs in the eastern tropical Atlantic. This topic has received very little attention by scientists until now because of its relatively low quantitative importance (especially for the more-important species, yellowfin) likely due to the low numbers of natural logs. The recent development of the artificial log fishery allows a significant increase of the global fishing efficiency of purse seiners associated with a change in fishing patterns. The catch is predominantly on skipjack, but also on yellowfin and bigeye in larger size ranges. The yield per recruit calculation presently conducted combining skipjack, yellowfin and bigeye suggests that this new fishery increases the global Y/R of the fisheries, despite the significant numbers of small yellowfin and bigeye taken. Consequently, the provisional scientific advice would be that this development of the log fishery is positive and could be further developed under close scientific monitoring. This monitoring is necessary because the fishing pattern of the log fishery is quite different from the fishing pattern of the free-school fishery. The amount of bycatch dumped at sea may, for instance, pose various potential ecological problems. Among other problems, the association of tunas and logs is still poorly understood, and the development of the artificial and natural log fisheries present new problems for estimating stock abundances, since the concept that "*searching time = fishing effort*" may not be valid in a log fishery, especially when auxiliary boats are tending artificial logs and guiding the purse seiners towards the best school associated with a log, at a known position.

LITERATURE CITED

BARD (F.M), STRETTA (J.M.) and SLEPOUKHA (M.) 1985. Les épaves artificielles comme auxuxiliaires de la pêche thoniére en Océan Atlantique. Quel avenir? La pêche maritime n° 1291. pp. 655-659.

BARD (F.X) and VENDEVII.LE (P.) 1986. Note sur l'échantillonage plurispécifique des thons tropicaux au port d'Abidjan. Rec. Doc. Scient. ICCAT. Vol.25: pp37-45.

CAYRE (P.) 1984. Procédure suivie pour la révision de la composition spécifique des statistiques thoniéres FISM. Rec. Doc. Scient. ICCAT. Vol. 21(2): p 102-107.

CAYRE (P.), AMON KOTHIAS (J.B.), STRETTA (J.M.) and DIOUF (T.) 1988. Biologie: des thons. In Fonteneau (A.) and Marcille (J.) ed. Resources, pêche et biologie: des thonidés tropicaux de l'Atlantique est. FAO Doc. Tech. Pêches, (292): pp. 157-264.

DESSIER (A.) 1990. L'impact des effluents fluviatiles sur les écosystèmes marins. L'Amazone et l'Atlantique tropical Nord Ouest. Compilation bibliographique. Doc. interne ORSTOM Paris.

FONTENEAU (A.) 1975. Note sur le problème d'identification du patudo dans les statistiques de pêche. Rec. Doc. Scient. ICCAT, Vol. 5 (1): pp 168-171.

GOURIOU (Y.) 1988. Le milieu. dans l'Atlantique tropical est. In Fonteneau (A.) and Marcille (J.) ed. Resources, pêche et biologie: des thonidés tropicaux de l'Atlantique centre est. FAO Doc. Techn. Pêches (292): pp. 11-32..

MAHE (G.) and OLIVRY (J.C.) 1991. Changements climatiques et variations des écoulements, en Afrique occidentale et centrale, du mensuel à l'interannuel. Doc. soumis au congrès AISH "Hydrology for water of large river basins", Vienna, Austria, August 1991.

PEREIRA (J.) 1990. Etat du stock de patudo de l'Atlantique. Rec. Doc. Scient. ICCAT. Vol. 32(1): pp 83-110.

PITON (B.) and FUSSEY (F.X). 1982. Trajectories of two satellite tracked buoys in the Gulf of Guinea, July 78-July 79. Tropical Ocean Atmosphere Newsletter. March 1982.

PUNSLY (R.G.), TOMLINSON (R.K.) and MULLEN (A.). 1994. Potential tuna catches in the eastern Pacific Ocean from schools not associated with dolphins. Fish. Bull., Vol. 92 (1): pp 132-143.

RICHARDSON (P.L.) and PHILANDER (S.G.H.) 1987. The seasonal variations of surface currents in the Tropical Atlantic Ocean: A comparison of drift data with results from a general circulation model. Journal of geophysical research, Vol. 92, No. C1: pp715-724.

RICHARDSON (P.L.) and REVERDIN (G.) 1987. Seasonal cycle of velocity in the Atlantic north equatorial countercurrent as measured by surface drifters, current meters and ship drifts. Journal of Geophysical Research. Vol. 92. No. C4: pp. 3691-3708.

RICHARDSON (P.L) and WALSH (D.) 1986. Mapping climatological seasonal variations of surface currents in the tropical Atlantic using ship drifts. Journal of Geophysical Research, Vol. 91, No. C9: pp. 10537-10550.

RICKER (W.E.) 1958. Handbook of computations for biological statistics of fish populations. Bull. Fish. Res. Board Canada (119): 300 pp.

Table 1. Yearly total catches by gear for yellowfin and skipjack in the eastern Atlantic and bigeye in the entire Atlantic (LL = longline, BB = baitboat, PS = purse seiner).

	YELLOWFIN			SKIPJACK		BIGEYE		
YEAR	BB	LL	PS	BB	PS	BB	LL	PS
1950	1.2	--		0.7	--	0.8	--	--
1951	1.2	--	--	0.5	--	1.7	--	--
1952	2.6	--	--	1.8	--	2.0	--	--
1953	3.6	--	--	2.1	--	3.0	--	--
1954	3.4	--	--	2.1	--	2.9	--	--
1955	4.3	--	--	2.6	--	4.8	--	--
1956	5.7	--	--	2.7	--	2.8	--	--
1957	9.4	10.3	--	2.1	--	8.3	0.4	--
1958	10.3	14.0	--	1.9	--	3.8	0.4	--
1959	5.9	32.8	--	2.3	--	6.3	1.5	--
1960	11.3	40.6	--	0.5	--	6.1	3.0	--
1961	10.0	40.9	--	1.4	--	5.8	11.2	--
1962	10.8	17.4	--	5.2	--	7.1	15.9	--
1963	17.8	23.2	1.3	9.0	0.4	10.9	15.0	--
1964	21.1	18.9	7.2	5.5	0.9	5.6	17.7	--
1965	18.5	27.6	8.3	10.3	3.3	9.8	29.4	--
1966	15.1	12.5	15.7	10.5	6.1	5.2	19.7	--
1967	16.8	17.1	18.7	18.8	24.2	3.8	18.8	0.4
1969	15.9	20.4	44.2	10.3	14.3	9.7	23.1	3.0
1970	9.5	16.0	33.3	13.7	29.8	10.4	27.5	3.4
1971	10.6	14.7	32.2	20.2	48.8	11.8	39.1	4.0
1972	13.1	18.0	47.0	17.8	48.8	9.4	32.5	4.6
1973	14.7	20.4	44.5	19.9	49.8	13.6	38.0	4.9
1974	19.7	19.4	53.0	30.6	74.2	18.0	39.2	6.6
1975	8.7	15.4	83.0	13.1	35.4	14.5	40.9	5.2
1976	12.5	12.8	83.7	23.4	32.3	9.9	27.4	6.9
1977	10.7	15.7	88.4	31.1	55.9	12.8	29.2	11.5
1978	8.8	11.3	94.5	33.4	56.8	14.5	28.3	8.6
1979	13.7	6.8	89.9	38.6	35.6	9.5	27.2	7.9
1980	7.4	12.4	91.7	32.4	54.0	12.1	41.4	8.7
1981	9.6	7.9	111.8	31.8	64.5	9.6	41.5	15.3
1982	12.7	9.9	107.8	33.8	72.5	6.8	51.8	13.9
1983	10.8	6.1	101.6	30.9	63.6	9.9	33.3	15.2
1984	11.2	8.6	50.5	22.1	61.7	11.0	41.3	16.0
1985	13.2	7.5	87.3	21.8	47.7	17.7	48.5	8.0
1986	13.4	3.9	84.4	22.1	58.1	15.0	34.3	9.2
1987	13.7	4.7	86.0	27.0	50.6	12.3	28.7	7.1
1988	14.0	7.4	73.6	30.4	67.3	9.1	41.0	7.6
1989	11.4	6.4	101.2	28.0	47.4	12.4	49.6	6.3
1990	13.8	4.4	123.8	32.9	72.9	15.4	37.8	9.4

Table 2. Total catch of yellowfin, skipjack and bigeye by purse seiners in the eastern Atlantic and catch estimated as being taken associated with floating logs (this estimate is based upon French and Spanish logbooks).

	1988	1989	1990	AVERAGE
Total Purse-Seine Catches				
YFT	76,300	101,200	123,800	100,400
SKJ	67,300	47,400	72,900	62,600
BET	7,600	6,300	9,400	7,800
TOTAL	151,200	154,900	206,100	170,800
Total Catches on Floating Objects				
YFT	6,360	3,288	5,815	5,154
SKJ	23,835	17,127	27,590	22,851
BET	2,022	1,289	2,711	2,007
TOTAL	32,217	21,704	36,116	30,012

Table 3. Total catches by type of associations (in percentage) for the French and Spanish purse seiners given in the log books (1988 to 1990). ("All other associations" corresponds to fishing associated with whales, whale sharks, dead whales, porpoise, purse seiner itself, *etc.*)

	1988	1989	1990	Average
No association	71.5	78.2	73.5	74.4
Floating object	20.1	13.4	17.5	17.0
All other associations	8.4	8.4	9.0	8.6

Table 4. Catches classified by type of association observed on the Spanish purse seiners during the yellowfin year program. Catches are in metric tons.

	WITH OBJECT		WITHOUT OBJECT		TOTAL	
	No.	%	No.	%	No.	%
Detections	30	15.7	161	84.3	191	100
Sets	18	17.0	88	83.0	106	100
Successful Sets	17	94.4	46	52.3	63	
Null Sets	1	5.6	42	47.7	43	
Average catch per successful set			28.0		15.9	
Yellowfin catch	85.6	18.0	343.8	47.0		
Skipjack catch		232.9	48.9	348.6	47.7	
Bigeye catch	11.1	2.3	1.2	0.2		
Frigate tuna catch	24.9	5.2	36.2	4.9		
Atlantic black skipjack catch	121.7	25.6	1.6	0.2		
Total catch	476.2	39.34	731.4	60.6	1207.6	100

Table 5. Average catch per set of the French and Spanish purse seiners combined for the free-swimming schools and for the schools associated with floating objects.

	1988	1989	1990	1991
(a) Natural objects				
No. of successful sets	669	439	641	591
Catch per set (MT)	33	35	38	31
No. of null sets	36	34	43	52
Percent of total	5.1	7.2	6.3	8.1
Catch (MT)	22,086	15,404	24,041	18,421
(b) Free schools				
No. of successful sets	8,188	6,653	6,614	2,475
Catch per set (MT)	13	18	22	23
No. of null sets	3,319	2,355	2,627	874
Percent of total	28.8	26.1	28.4	26.1
Catch (MT)	105,917	119,092	44,497	56,419
(c) Artificial objects				
No. of successful sets				914
Catch per set (MT)				38
No. of null sets				46
Percent of total				4.8
Catch				34,677

Table 6. Percentage of the contribution in weight (in tons)of 6 size categories of sets, for the Spanish and French purse-seine fishery on log-associated schools and on free schools.

	1988		1989		1990	
	FREE	LOG	FREE	LOG	FREE	LOG
<5	1.8	0.8	1.1	0.6	0.8	0.5
5-9	7.6	2.9	5.1	2.5	3.9	1.9
10-24	26.3	12.3	19.5	11.4	17.5	12.4
25-49	29.1	21.7	25.1	20.6	27.4	21.4
50-100	20.4	27.8	26.7	34.0	28.7	27.9
>100	14.8	34.4	22.5	30.8	21.9	35.8

Table 7. Percentage of catch made near artificial objects for each of the species in the four quarters of 1991 and of the total catch (in metric tons).

	YFT	SKJ	BET	TOTAL
lst Qtr	17	24	13	23
2nd Qtr	19	26	30	26
3rd Qtr	9	8	11	8
4th Qtr	55	42	46	43
TOTAL	3,516.2	28,633.5	2,527.0	34,676.7

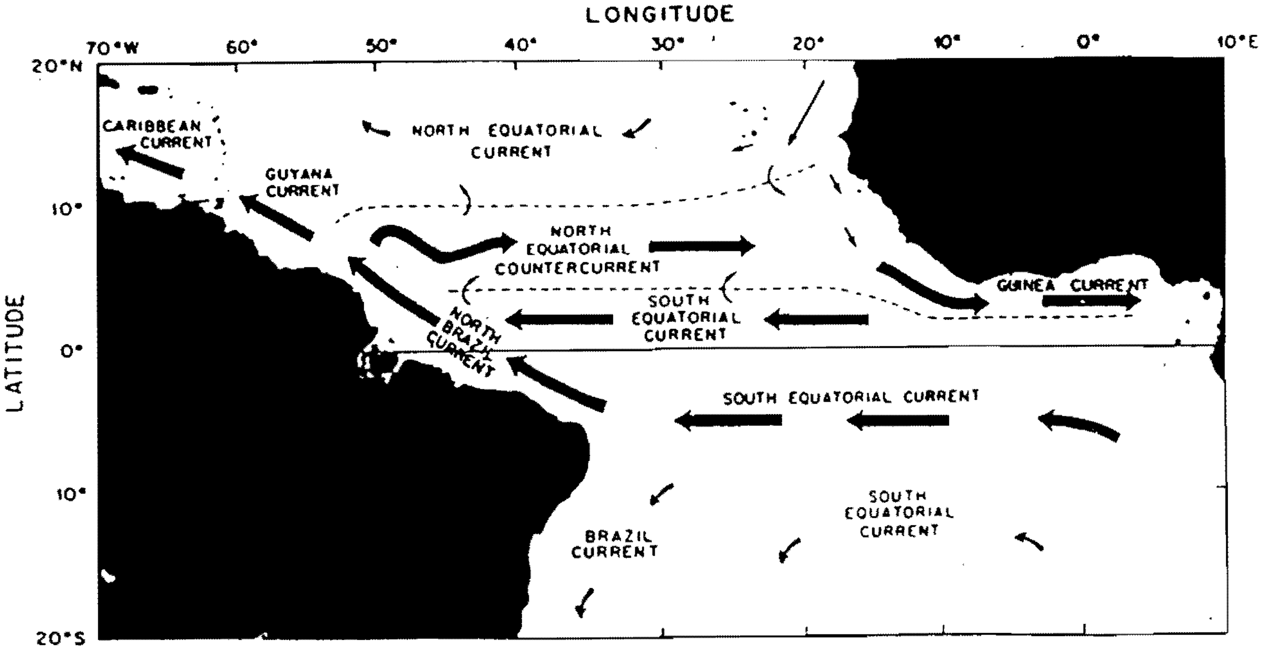


Figure 1.: Schematic map showing the major tropical currents in the tropical Atlantic Ocean (P.L. Richardson and D. Walsh, 1986, modified).

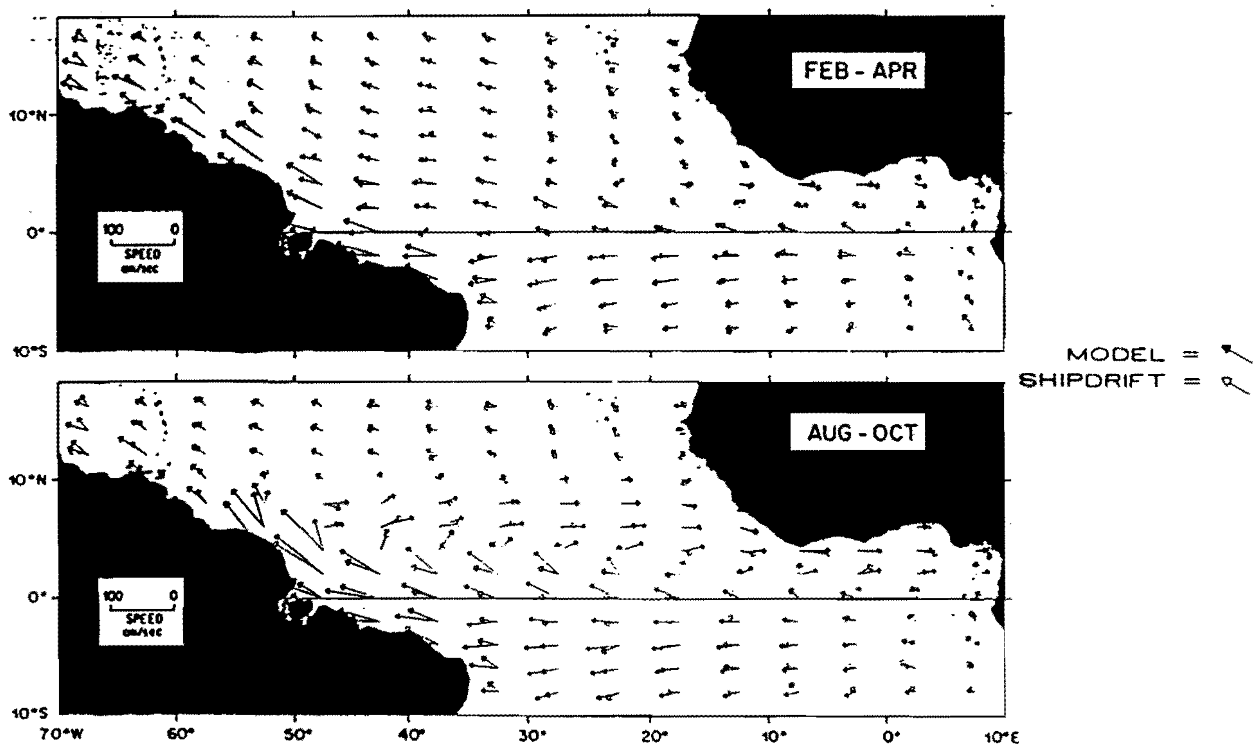


Figure 2.: Velocity vectors for February through April and August through October, calculated by grouping ship drift and model (upper layer) velocities into 2°x5° boxes. Speed is given by the length of each vector (from Richardson et Philander 1987).

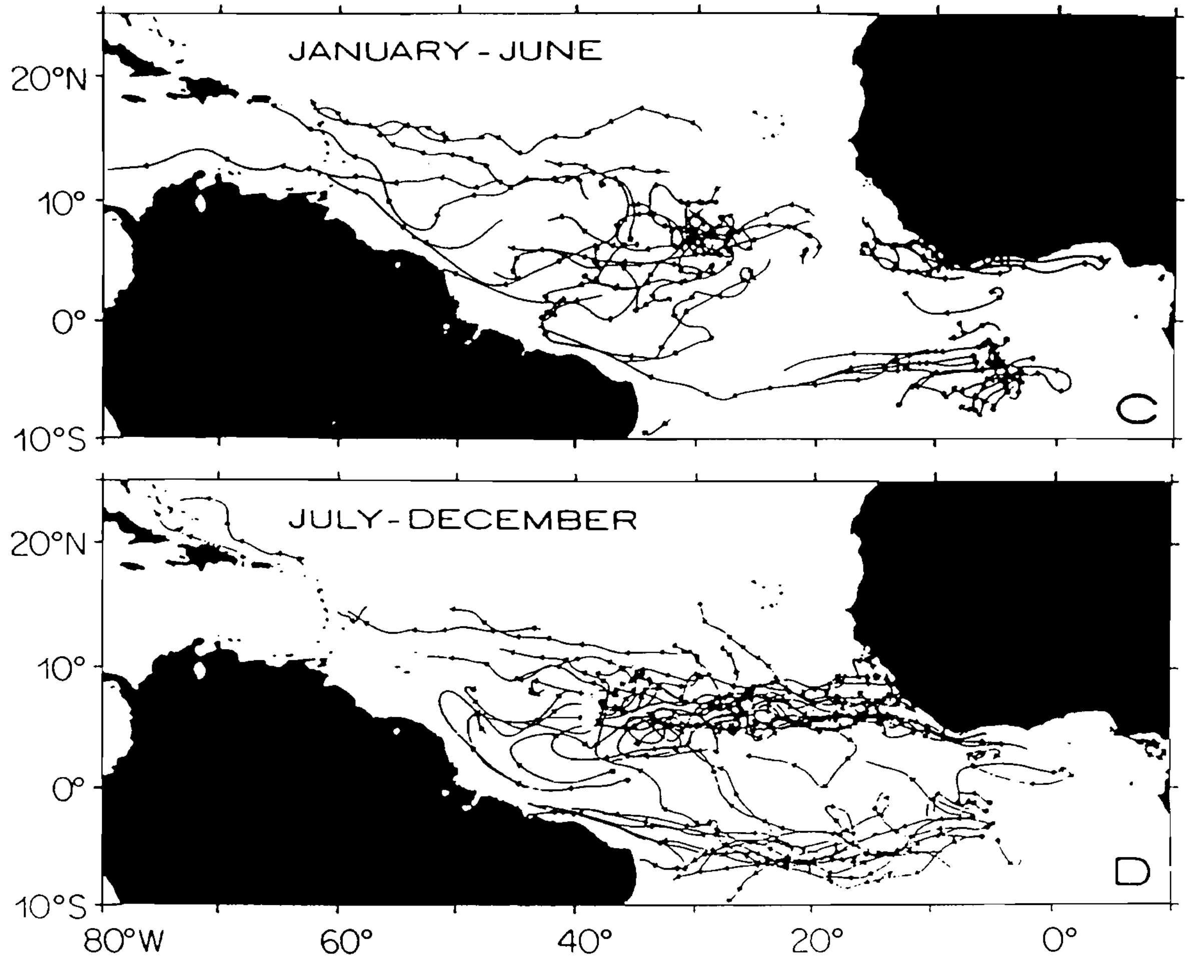


Figure 3.: Summary of drifting buoy trajectories. (a) Trajectories during spring (January through June) when the NECC disappears west of 20°W. Arrowheads are spaced at 10-day intervals. (b) Trajectories during fall (July through December) when the NECC flows eastward across the Atlantic into the Guinea Current (from Richardson and Reverdin 1987).

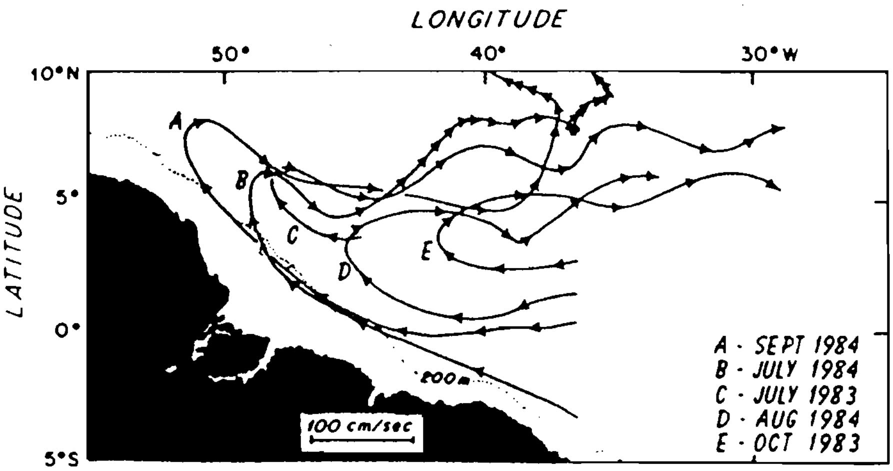


Figure 4.: Retroflection of the North Brazilian Current between 45° and 50°W as shown by the drifting of 5 Oceanographic buoys (from Richardson and Reverdin 1987.

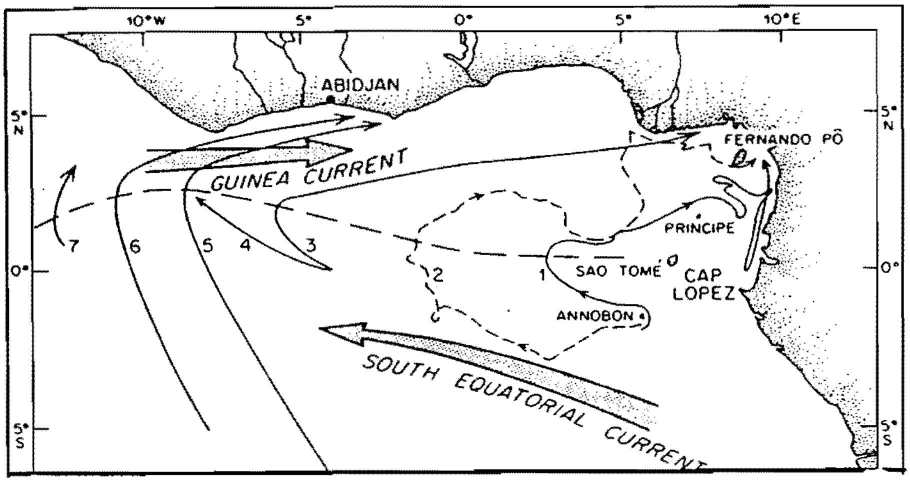


Figure 5.: Trajectories of floating objects in the Gulf of Guinea : (1) satellite-tracked buoy B10 from July 1978 February 1979 ; (2) satellite-tracked buoy B37 from January 1979 - July 1979 ; (3) a drifting acoustic release from July-September 1979 ; (4) a drifting surface buoy during July 1979 ; (5) and (6) presumed paths of plastic drift cards from January-April 1970 (Shannon et al. 1973 ; (7) drift of whale carcass followed by a seiner tuna boat during December 1978. The dashed line represents the convergence between the South Equatorial Current and the Guinea Current (from Piton B. and FUSSEY F.X. 1982).

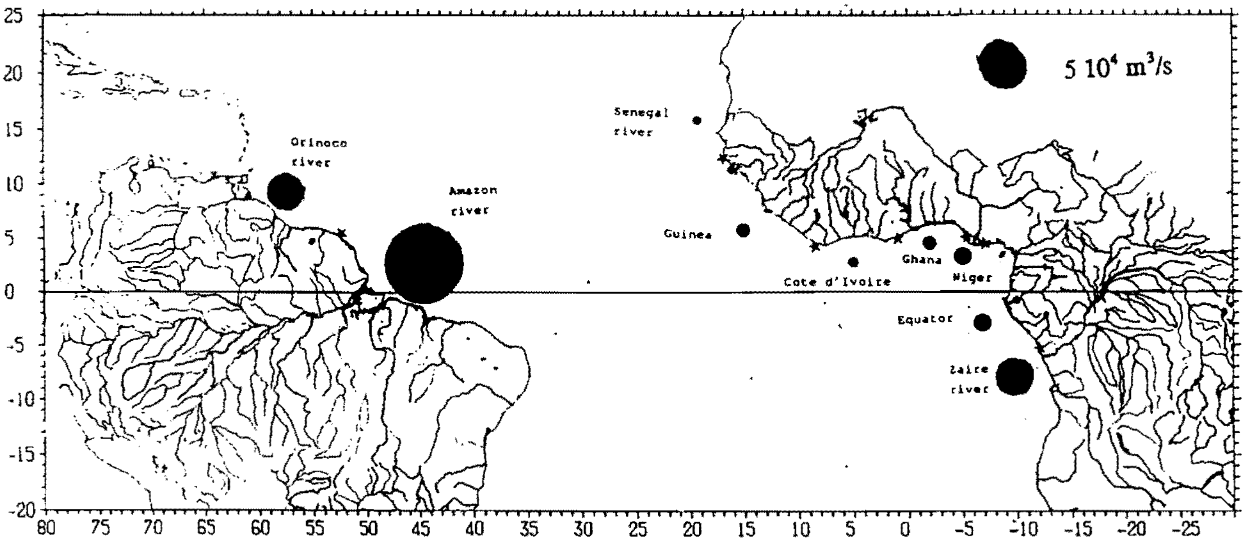


Figure 6: Major rivers and basins and their corresponding output flow of water to the Atlantic ocean in the area under study (The stars correspond to the limits between adjacent basins)

(The area of each circle are proportionnal to the average output flow of each basin).

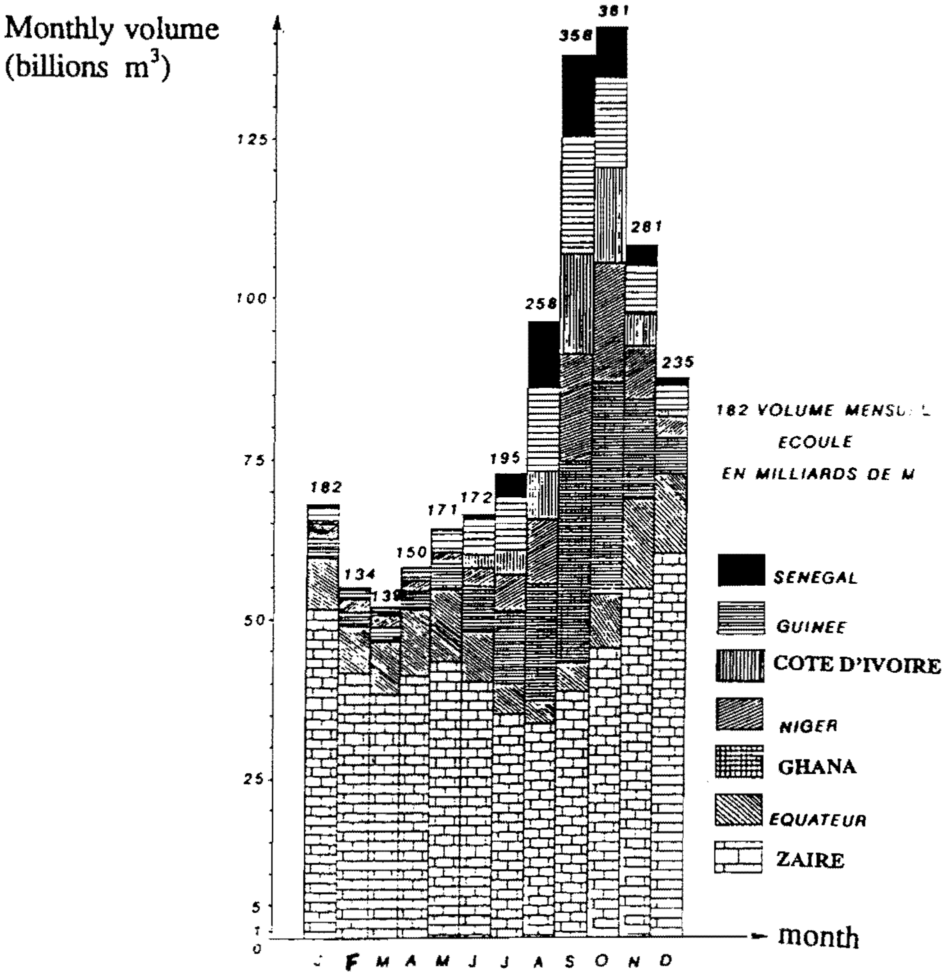


Figure 7: Seasonality of African river flows (from Mahe and Olivry 1991) *(The area of each geographical component of the figure are proportionnal to the monthly river flow each area.)*

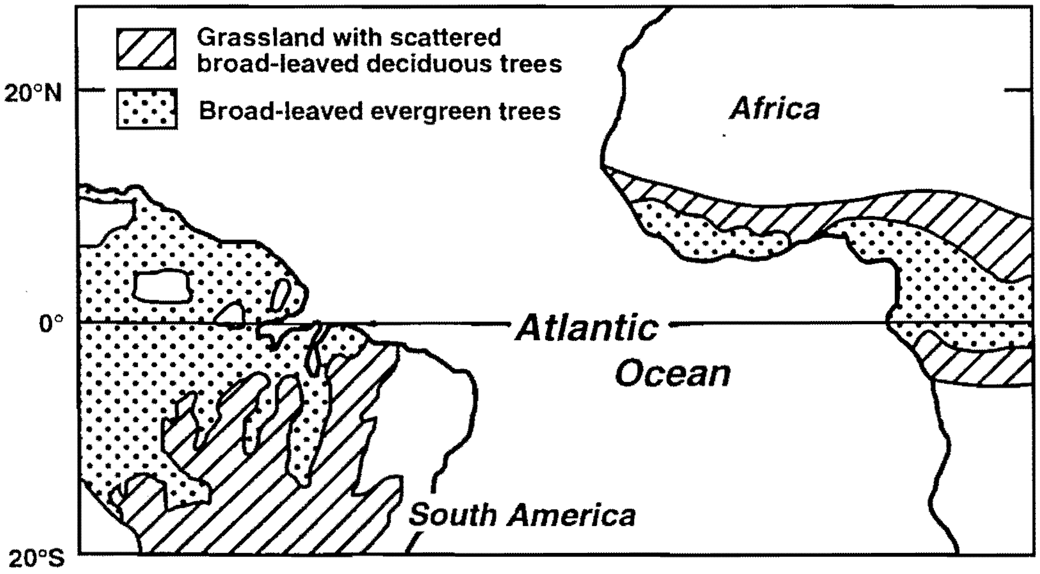


Figure 8: Areas of major forests in west Africa and south America.

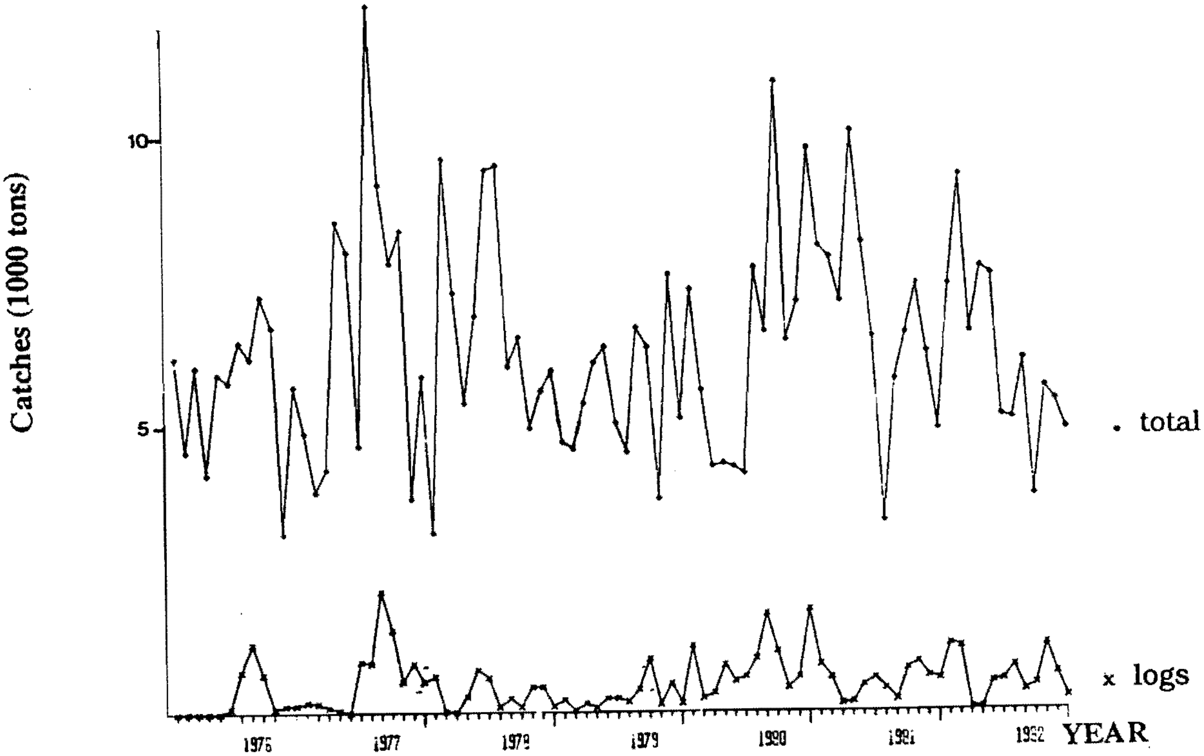


Figure 9: Monthly catches of tunas (yellowfin, skipjack and bigeye) taken by the French, Ivorian and Senegalese purse seine fishery and landing in Abidjan, (a) on floating logs and (b) total of the corresponding fishery, from 1976 till 1982.

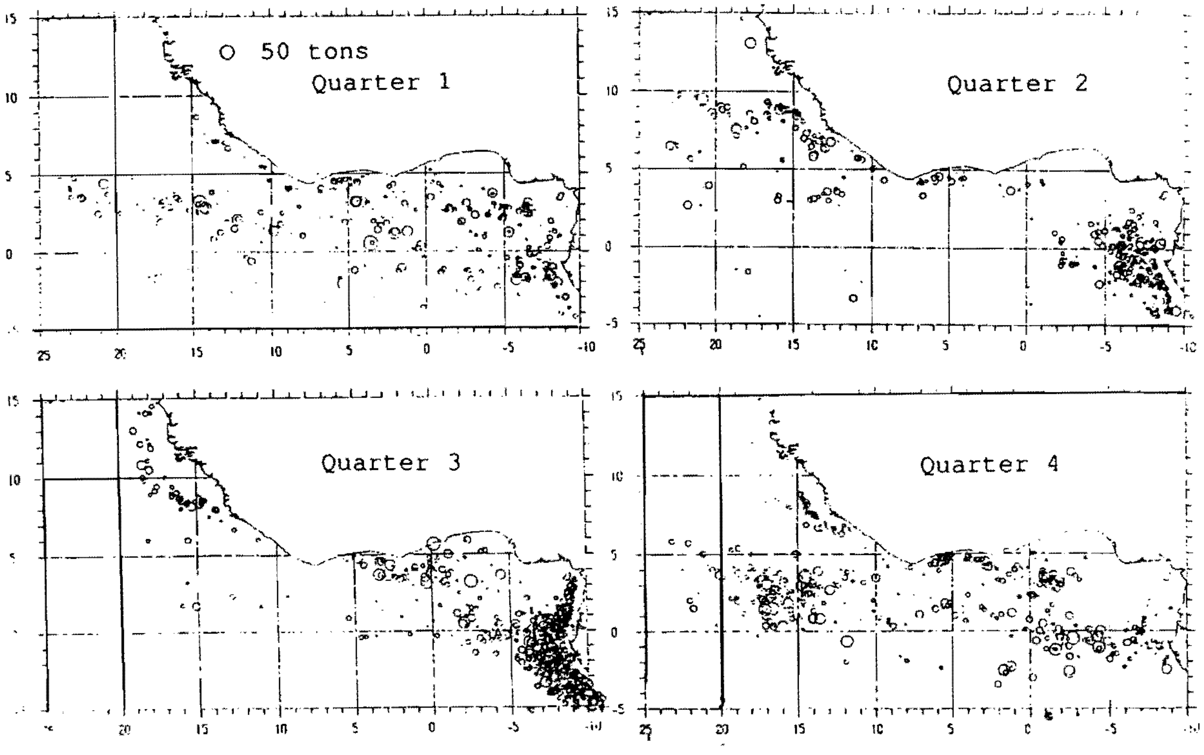


Figure 10: Average quarterly fishing maps on logs for the French, Ivorian and Senegalese purse seiners landing in Abidjan between 1977 and 1982.(1 circle= 1 set, area proportional to the catch).

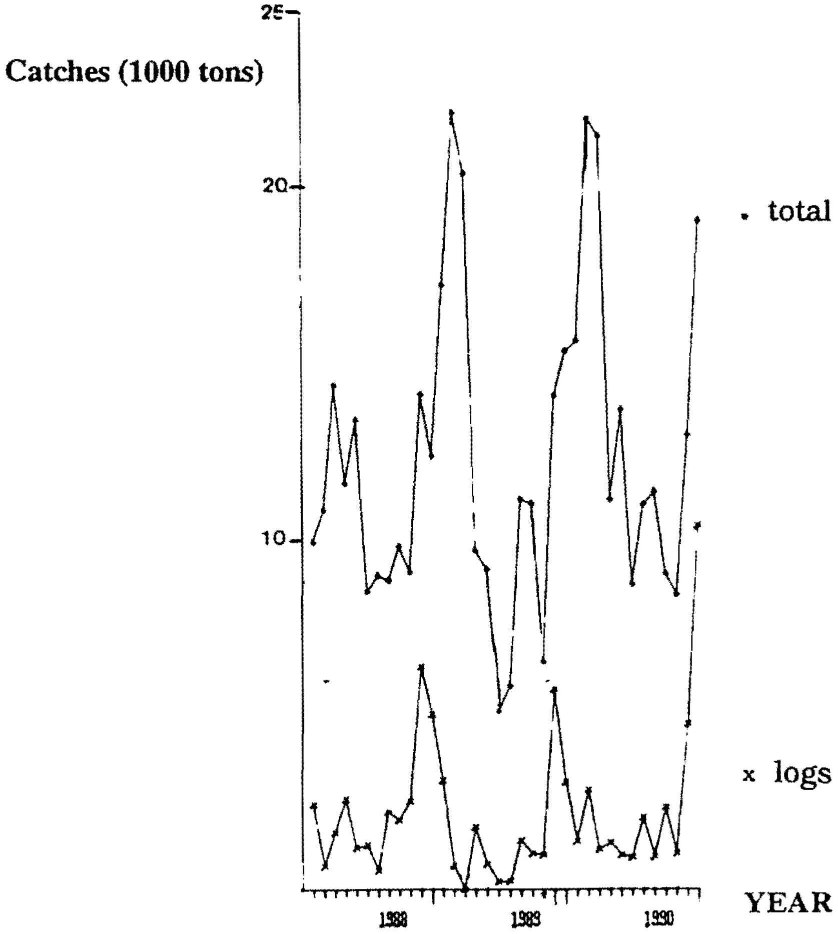


Figure 11. Monthly catches of tunas (yellowfin, skipjack and bigeye) taken by the French and Spanish purse seiners, (a) on floating logs and (b) total of the fishery, from 1988-1990.

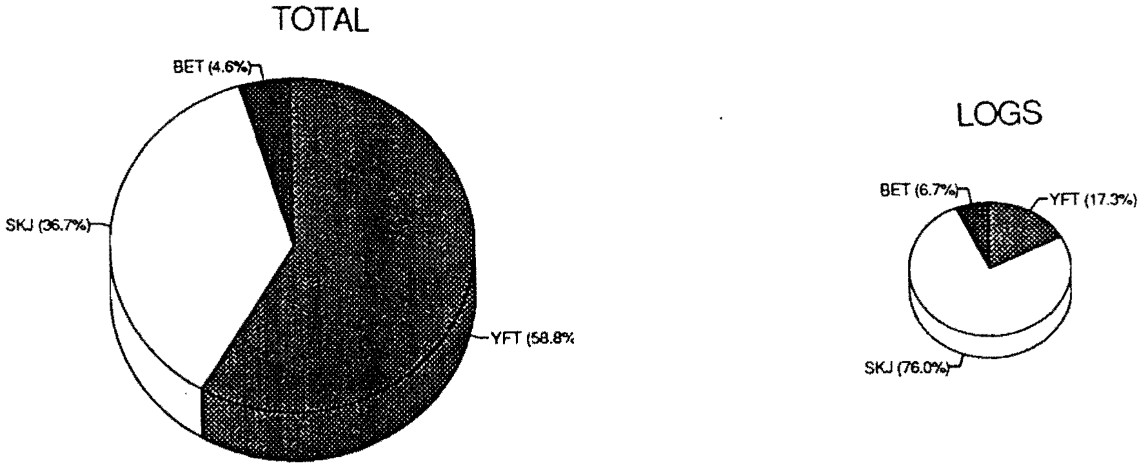


Figure 12. Species composition of the total catches and log-associated catches of French and Spanish purse seiners (average 1988-1990).

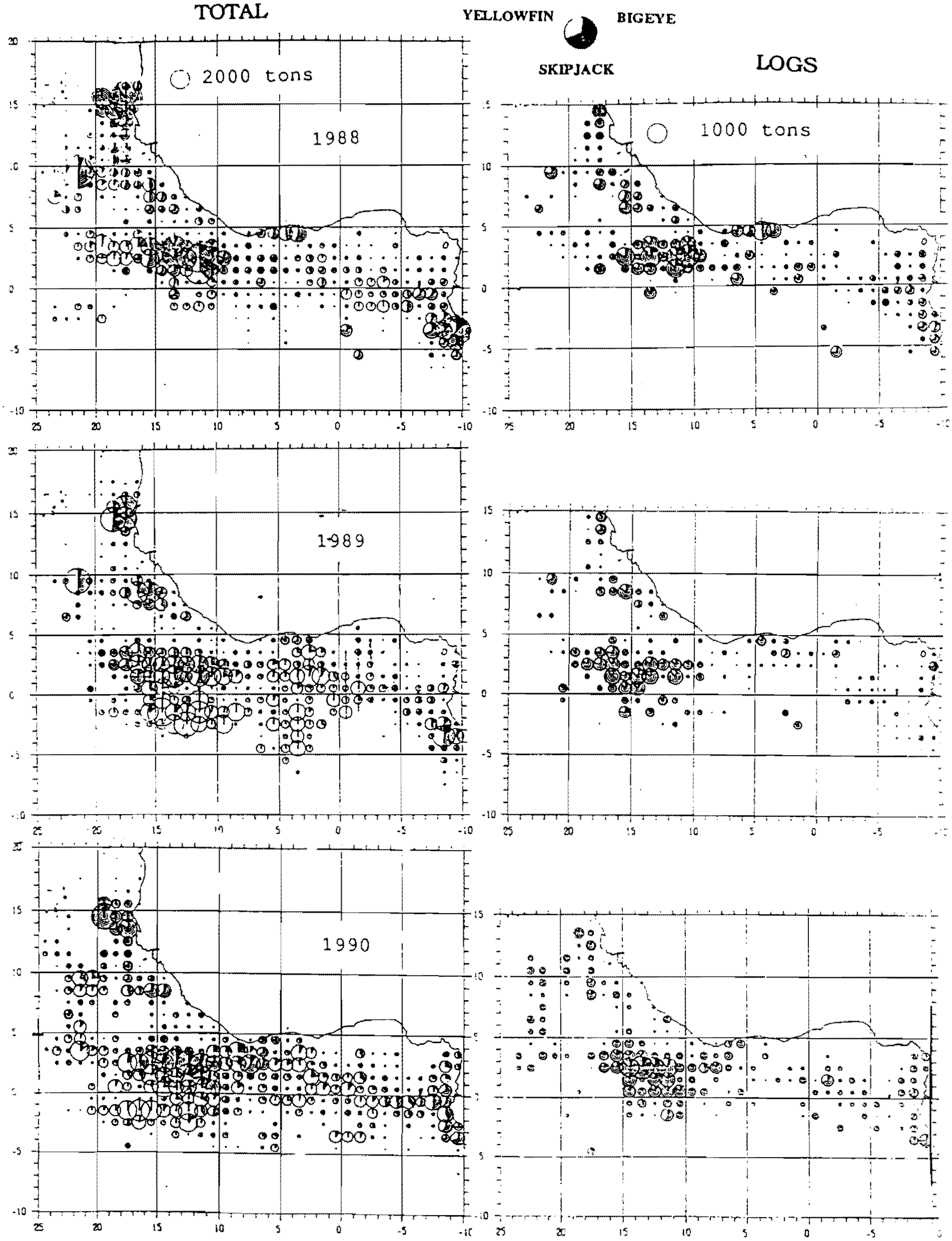


Figure 13. Yearly fishing maps for the three species (yellowfin, skipjack and bigeye), total (left) and on logs (right), for the French and Spanish purse seiners for the years 1988, 1989 and 1990 (area of each circle proportional to the total catch in the 1 degree square).

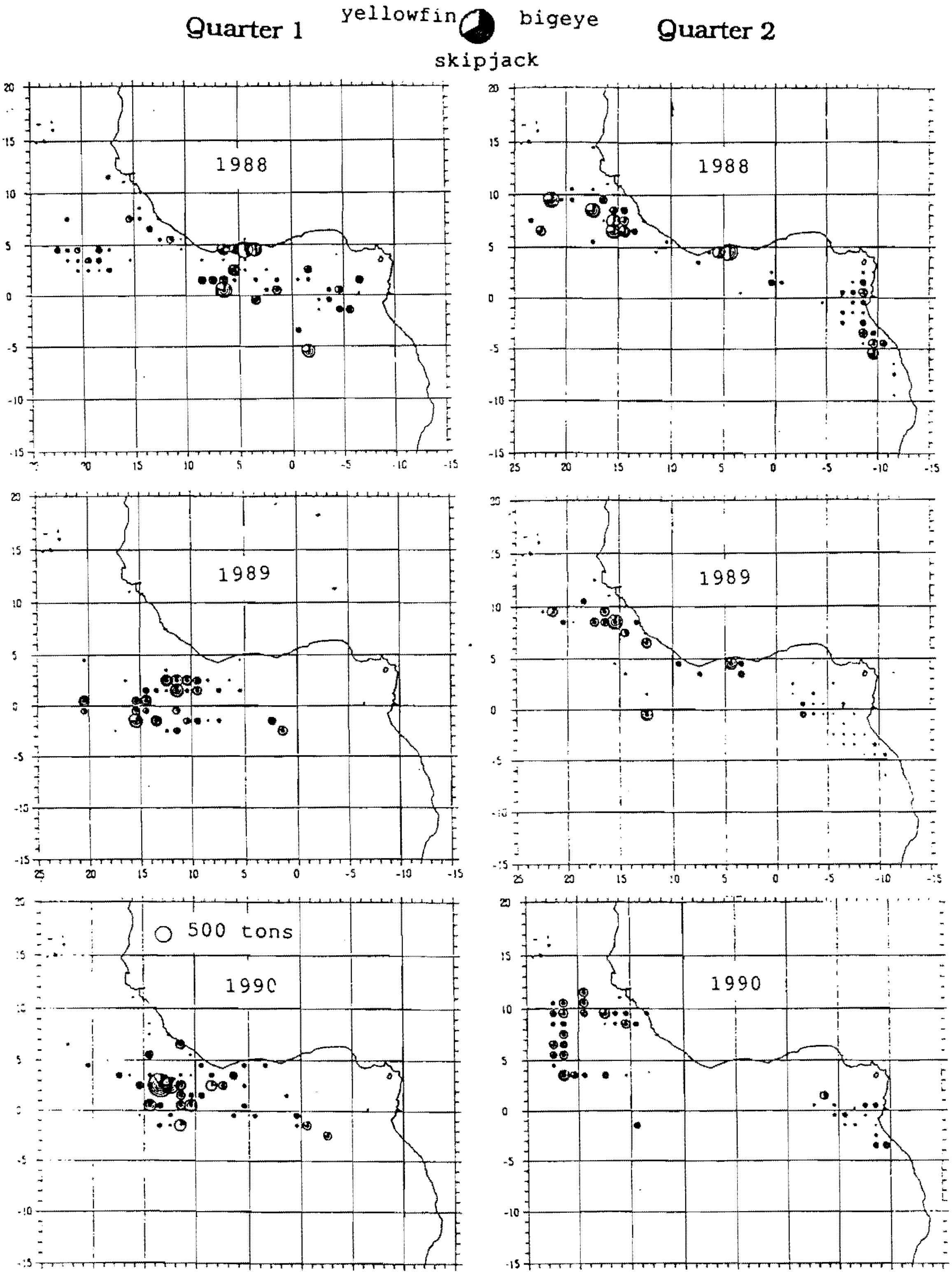


Figure 14. Quarterly fishing maps for the three species (yellowfin, skipjack and bigeye), on logs, for the French and Spanish purse seiners between 1988 and 1990 (Area of each circle proportional to the total catch in the 1 degree square).

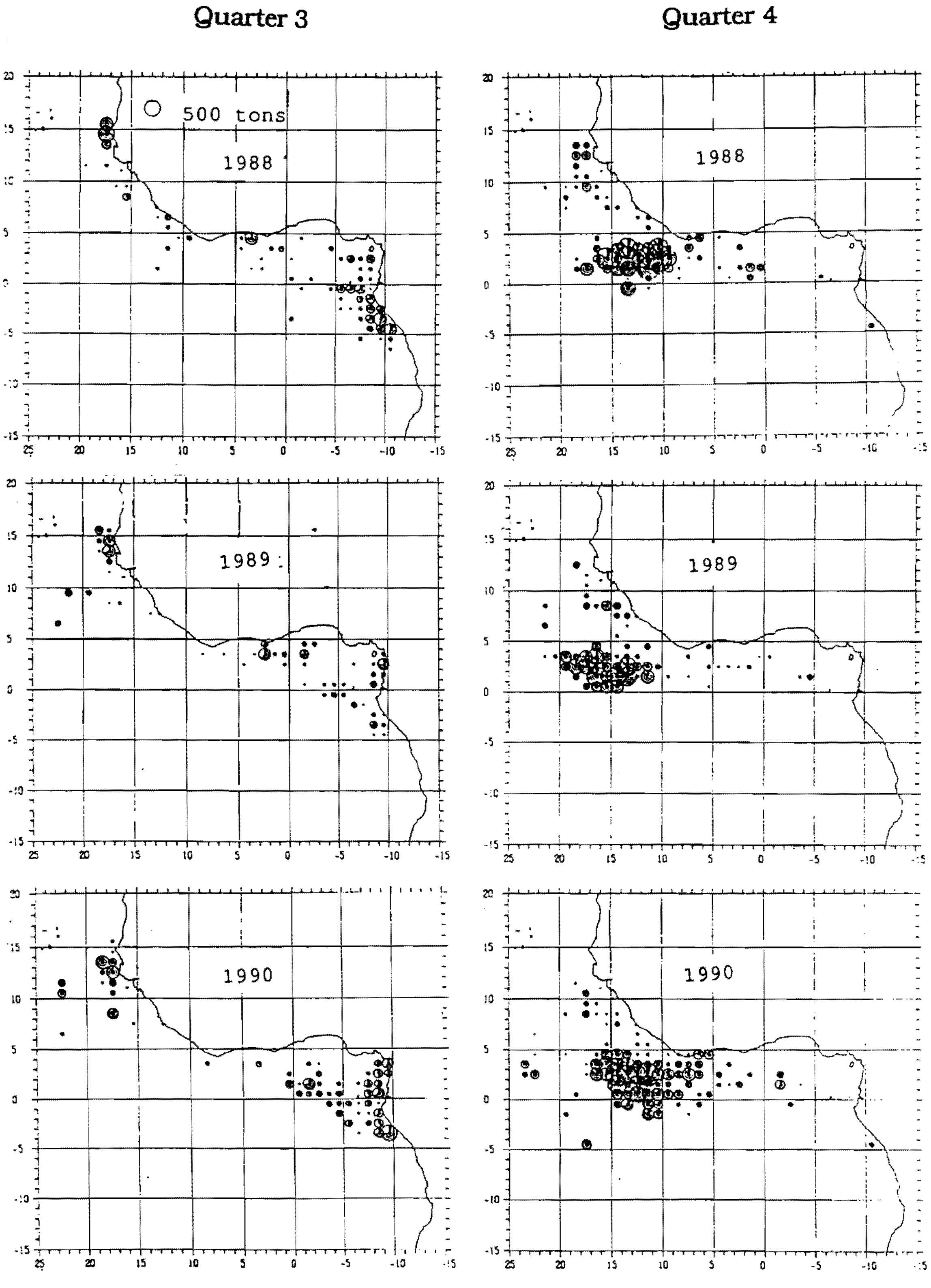


Figure 14 Continued.

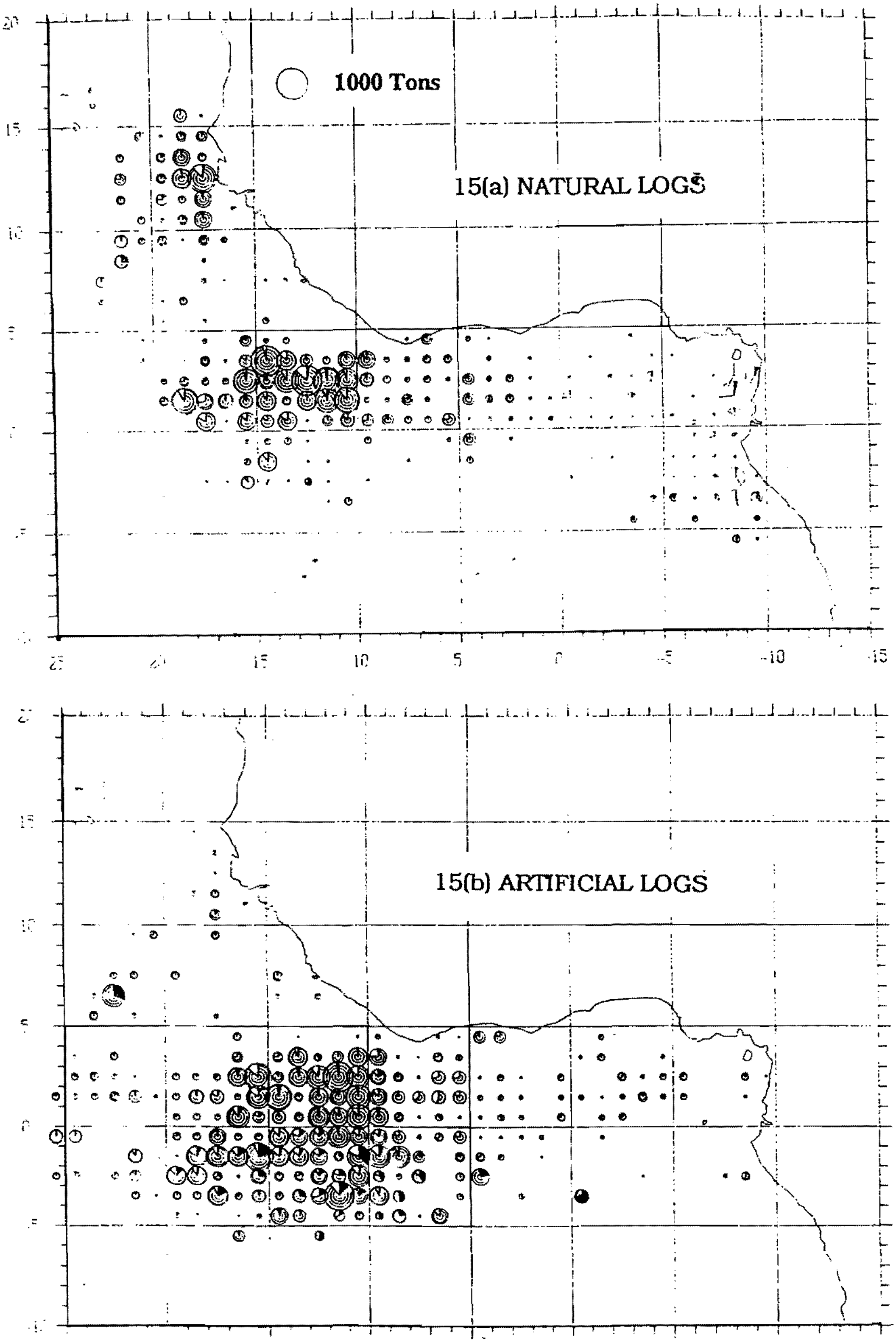


Figure 15. Catches of yellowfin, skipjack and bigeye during 1991 for Spanish, on natural logs (upper figure) and on artificial logs (lower figure) (The species composition of this figure is from log books without specific corrections).

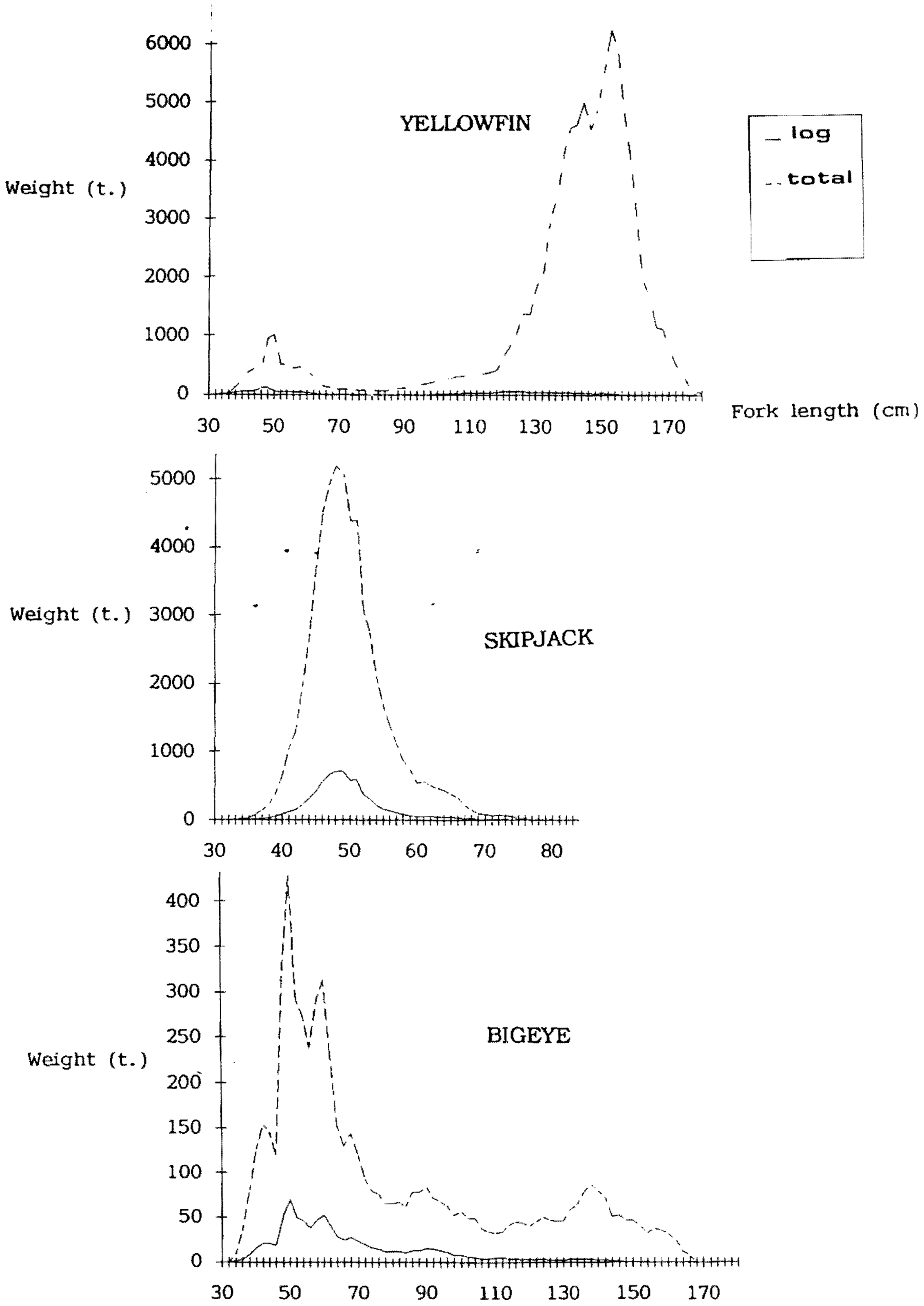


Figure 16. Weight of yellowfin, skipjack and bigeye taken (by 2 cm classes of fork length) by the French and Spanish purse seiners during the average period 1988-1990 under floating logs and by the whole fishery.

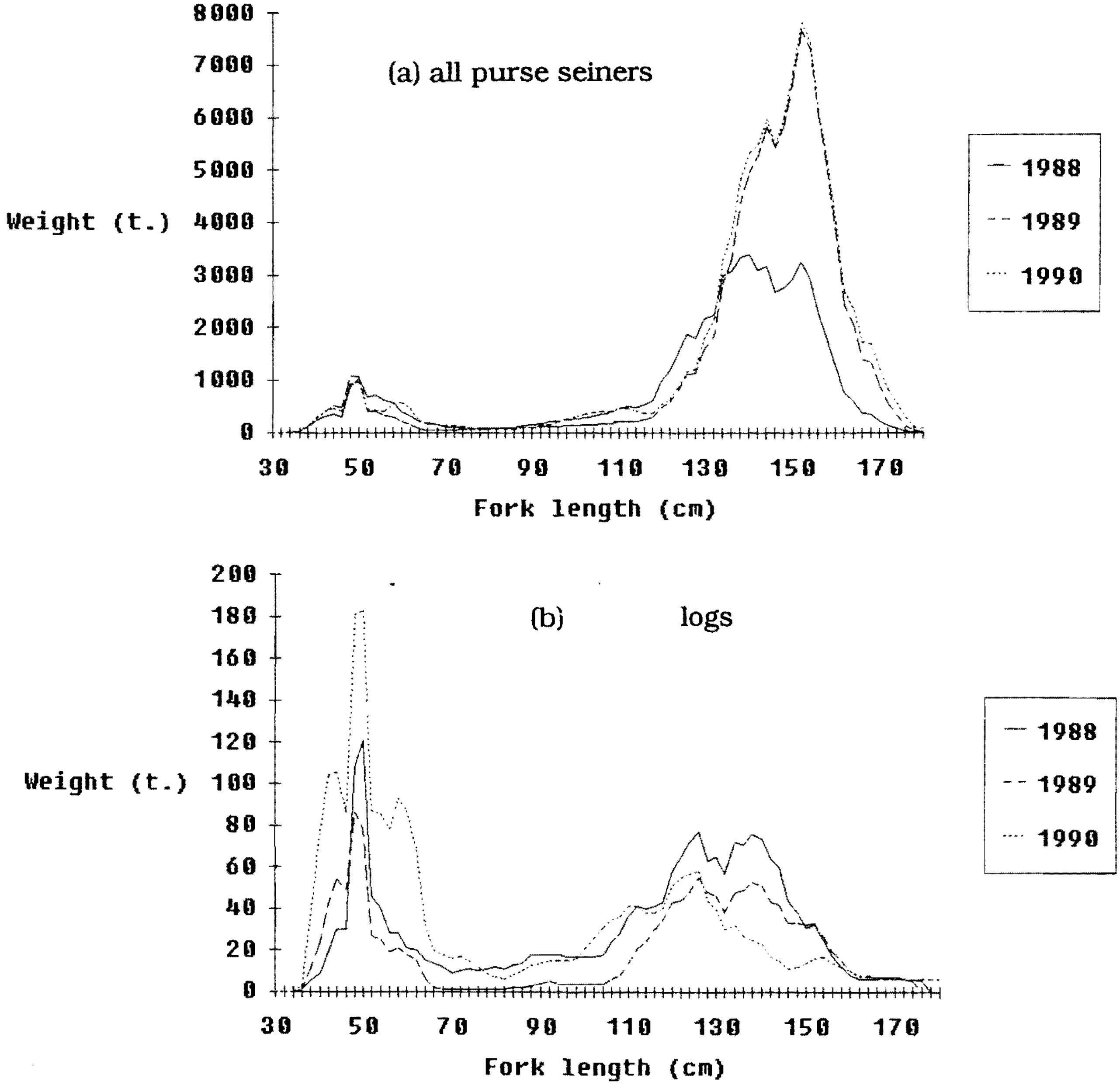


Figure 17. Weight of yellowfin (by 2 cm classes of fork length) taken by the French and Spanish purse seiners during 1988, 1989 and 1990, by the whole fishery 17 (a) under logs 17 (b).

Rank of sample with average increasing weight

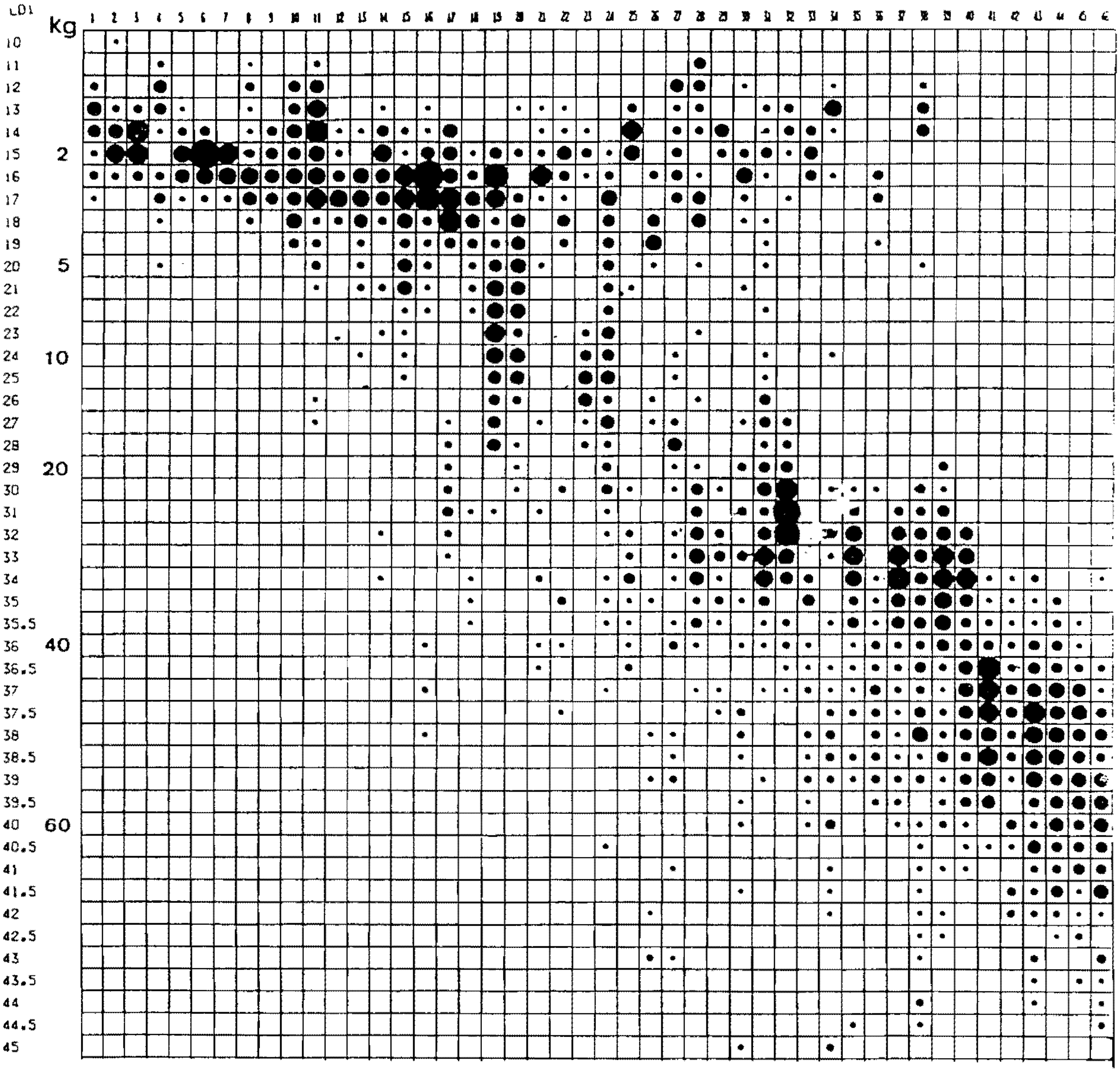
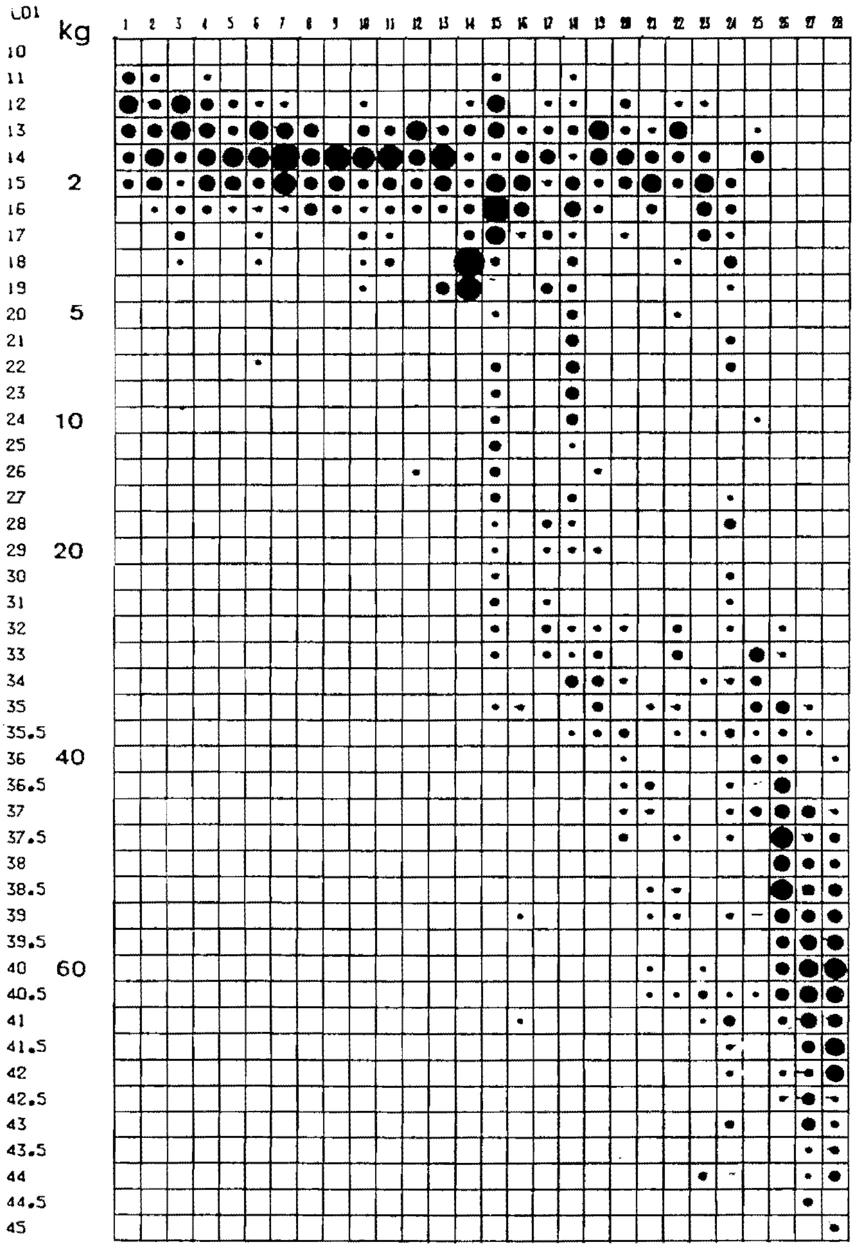


Figure 18. Diagrammatic representation of each of the 46 size samples for yellowfin taken with logs (with more than 25 fishes sampled) during 1988. Each circle has an area proportional to the number of fishes measured in each class of predorsal length.



Rank of the sample with average increasing weight

Figure 19. Same result as for figure 18 for the 28 samples measured in 1989.

Rank of the sample with average increasing weight

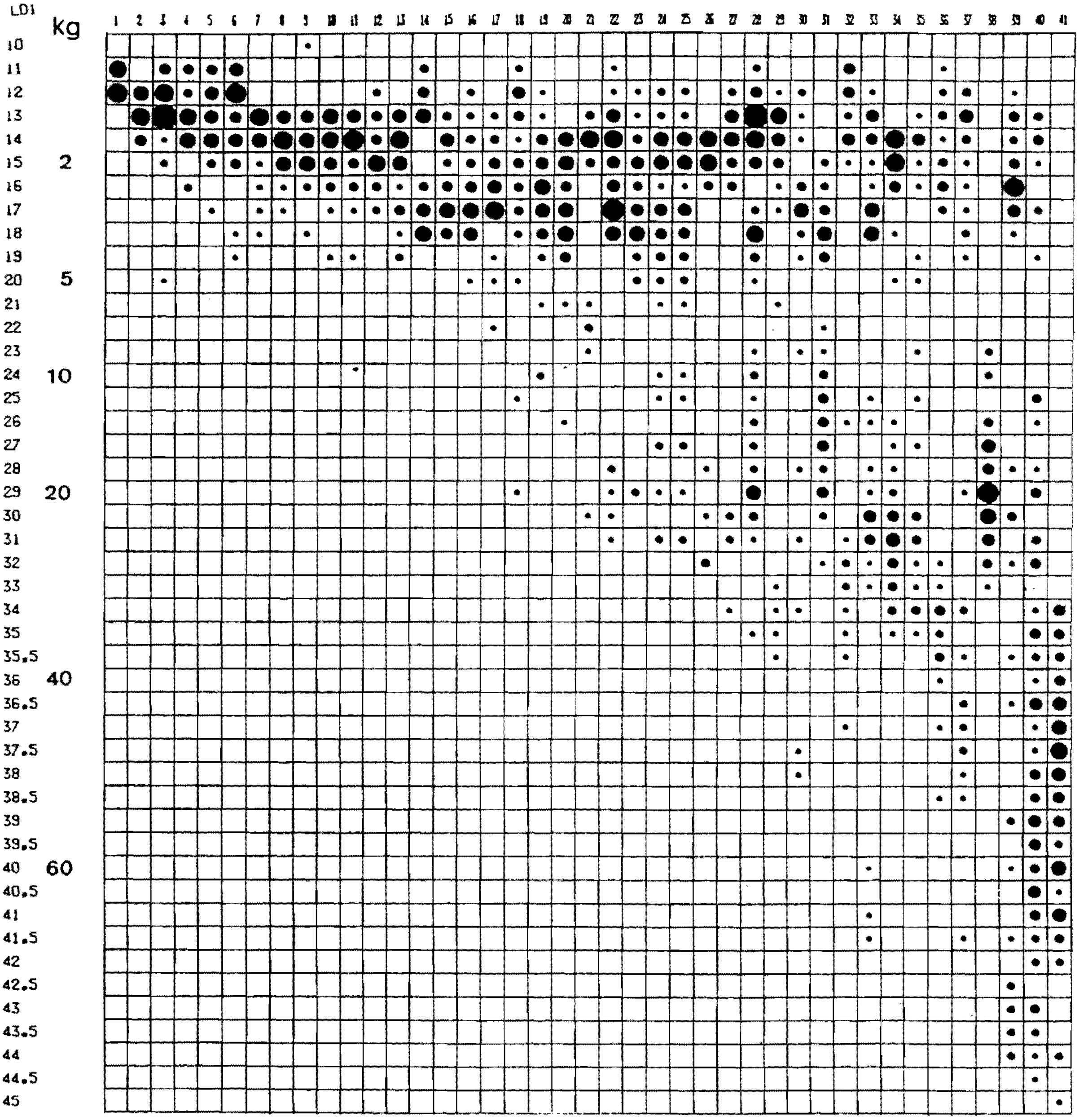


Figure 20. Same result as figure 18 for the 41 samples measured in 1990.

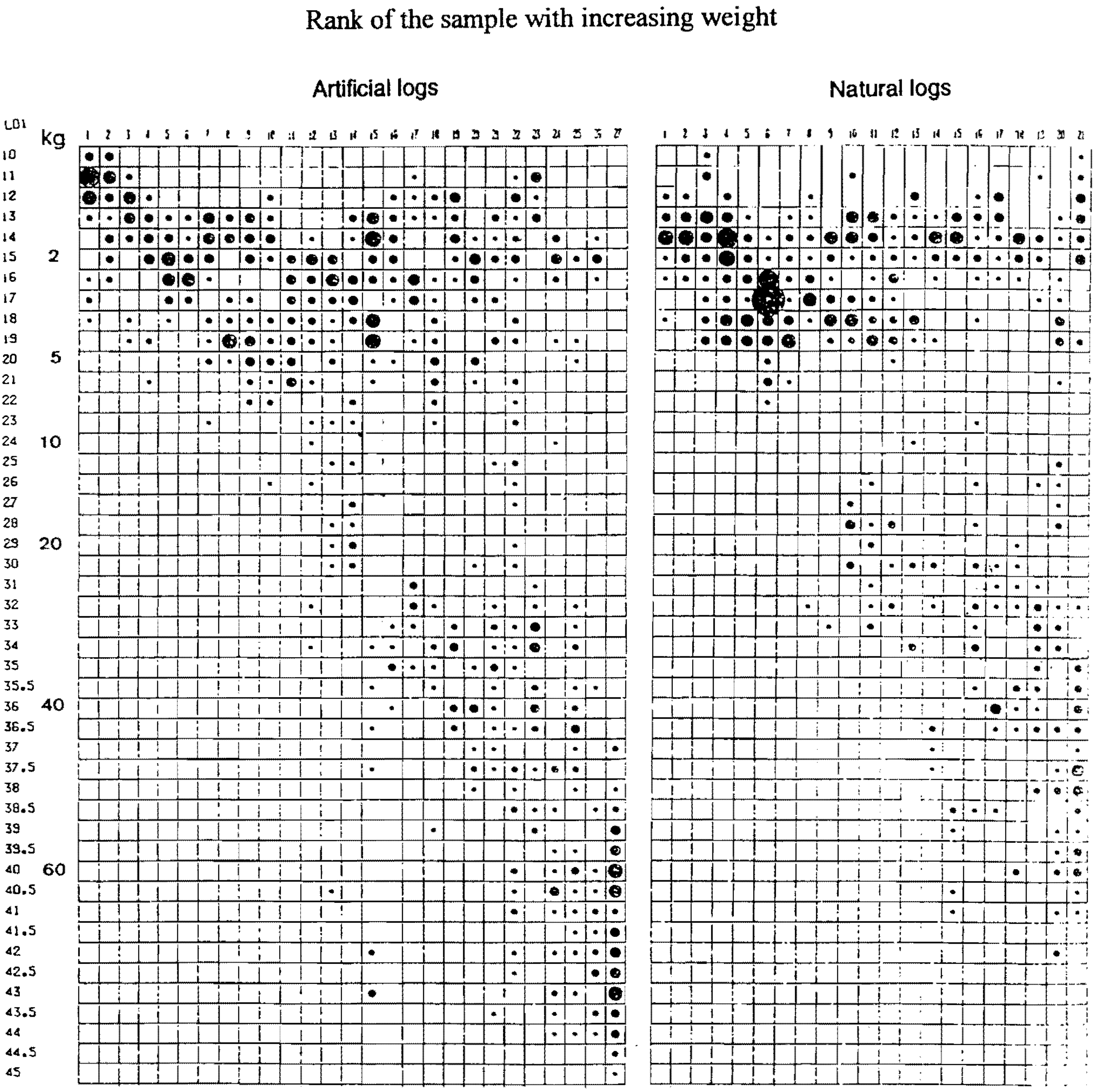


Figure 21. Same result as figure 18 for the 27 samples measured on yellowfin taken under artificial logs in 1991 (left) and for the 21 samples taken under natural logs (right).

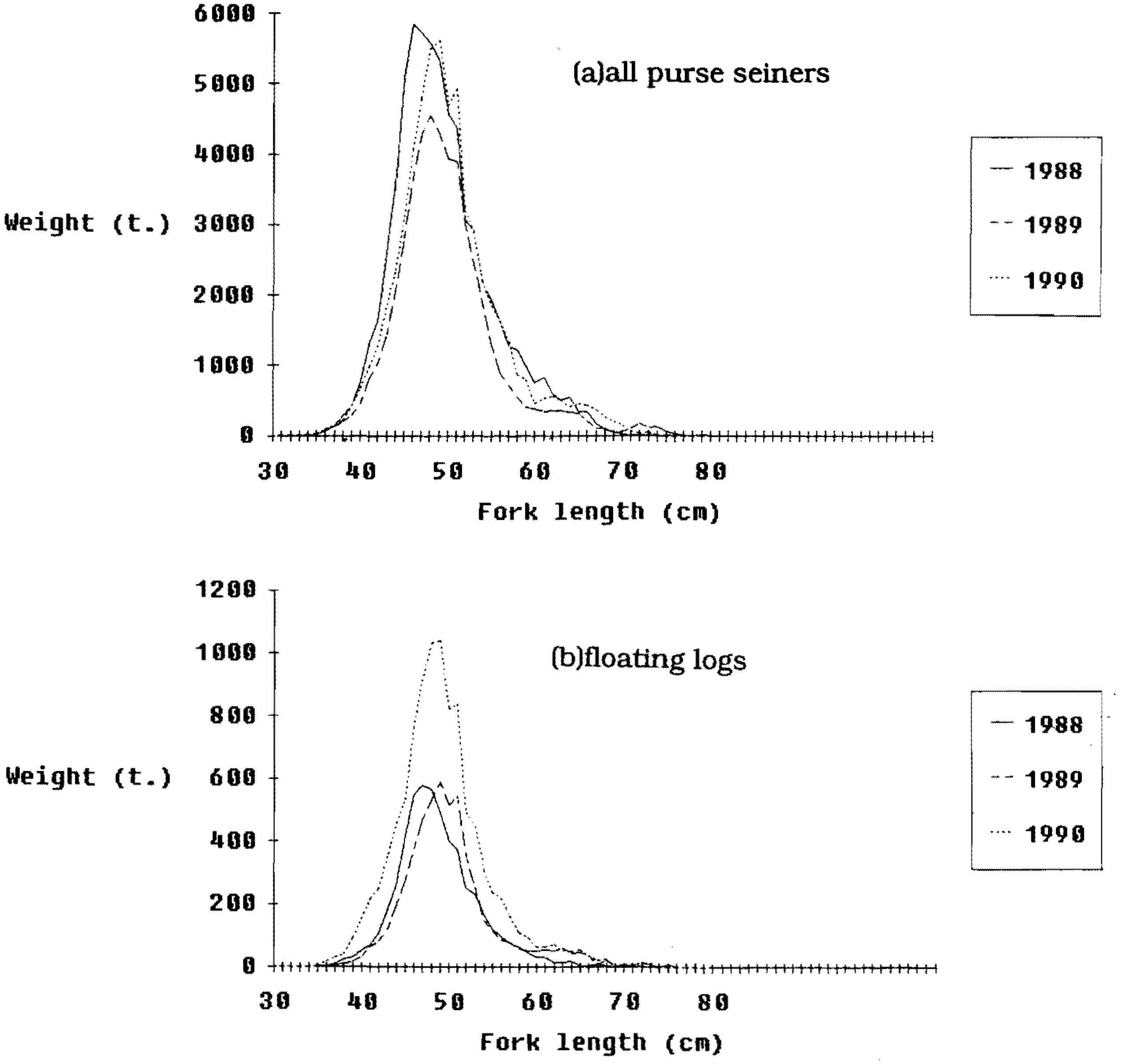


Figure 22. Weight of skipjack taken (by 2 cm classes of fork length) by the French and Spanish purse seiners during 1988, 1989 and 1990, by the whole fishery (a) and under logs (b).

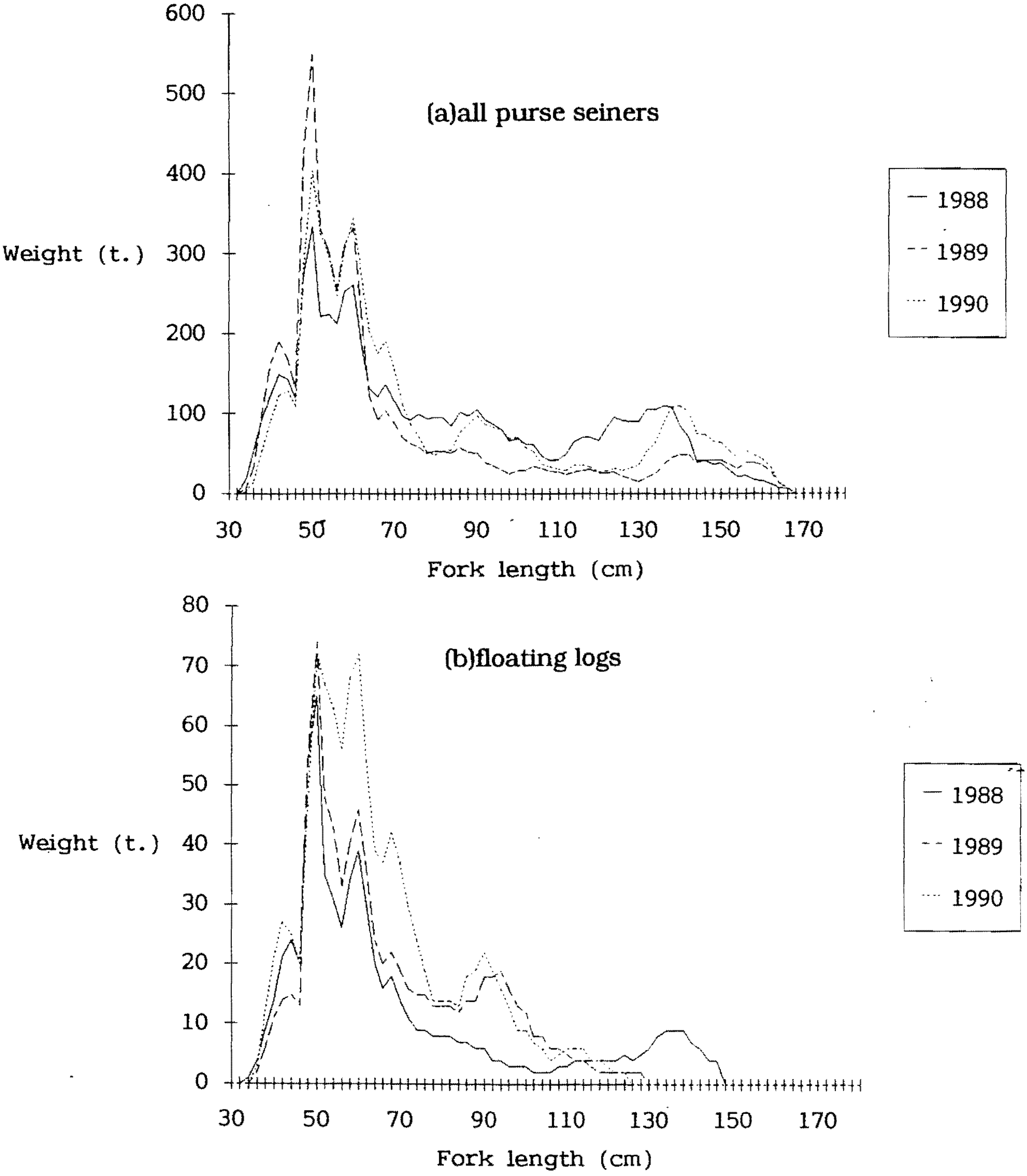


Figure 23. Weight of bigeye taken (by 2 cm classes of fork length) by the French and Spanish purse seiners during 1988, 1989 and 1990 , by the whole fishery (a) and under logs (b).

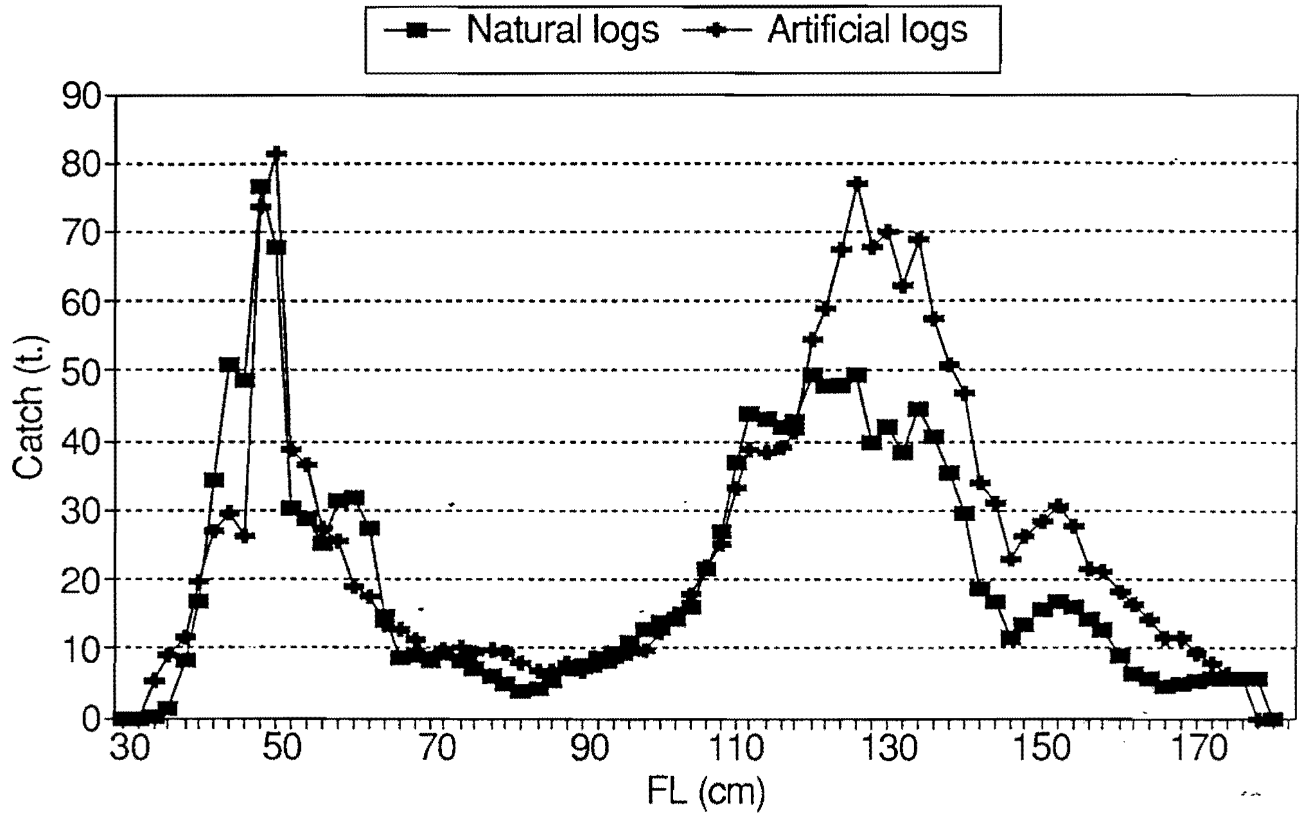
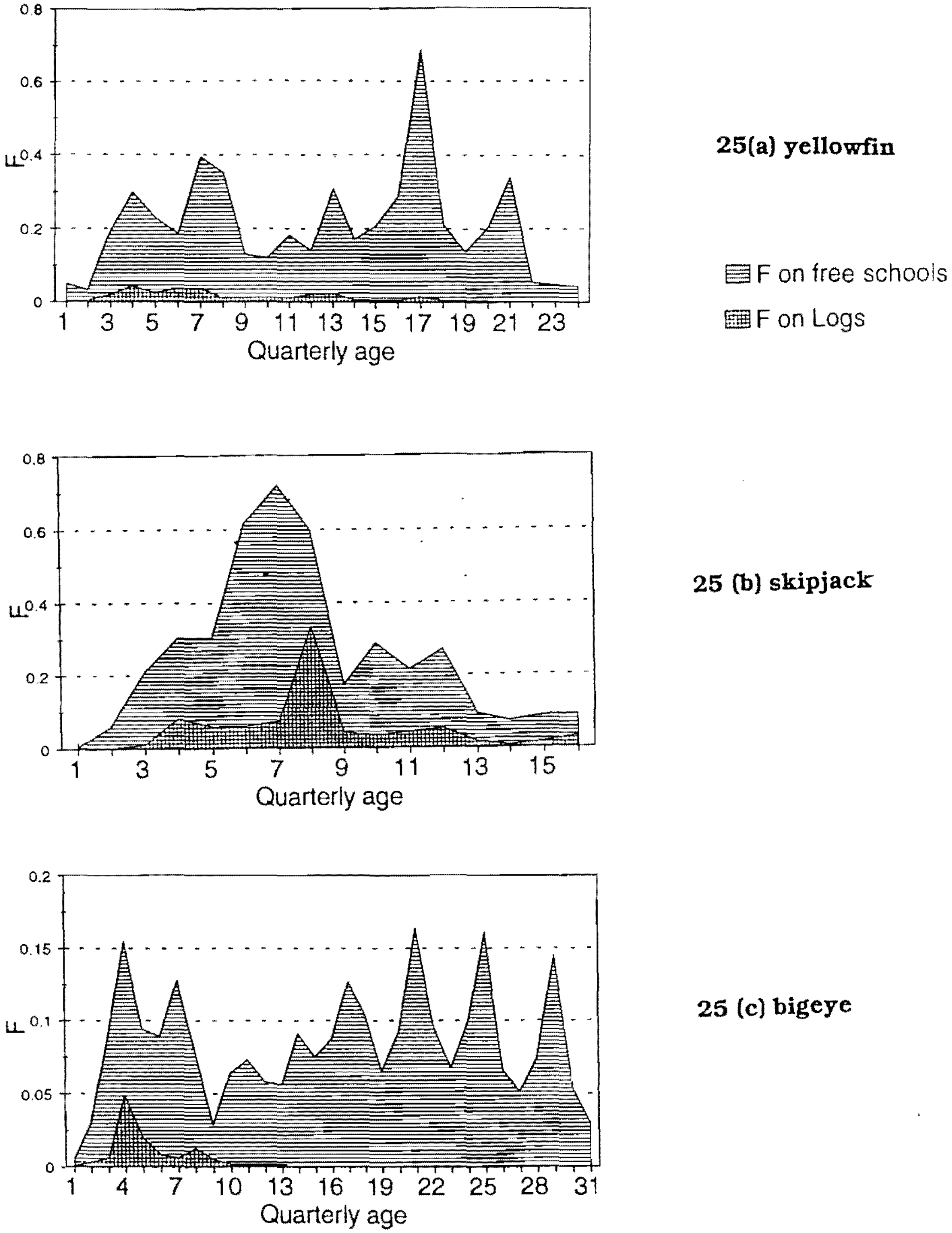


Figure 24. Weight of yellowfin taken under natural and artificial floating logs (by 2 cm classes of fork length) by the French and Spanish purse seiners during 1991.



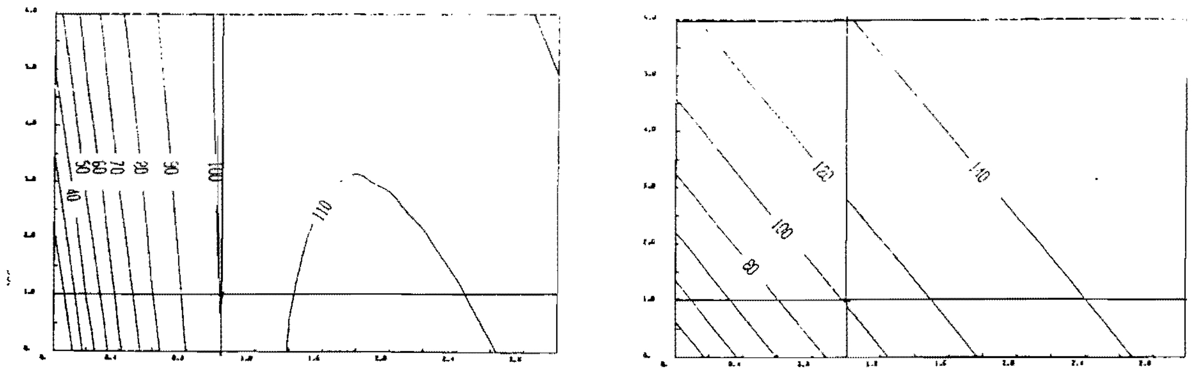
25(a) yellowfin

25 (b) skipjack

25 (c) bigeye

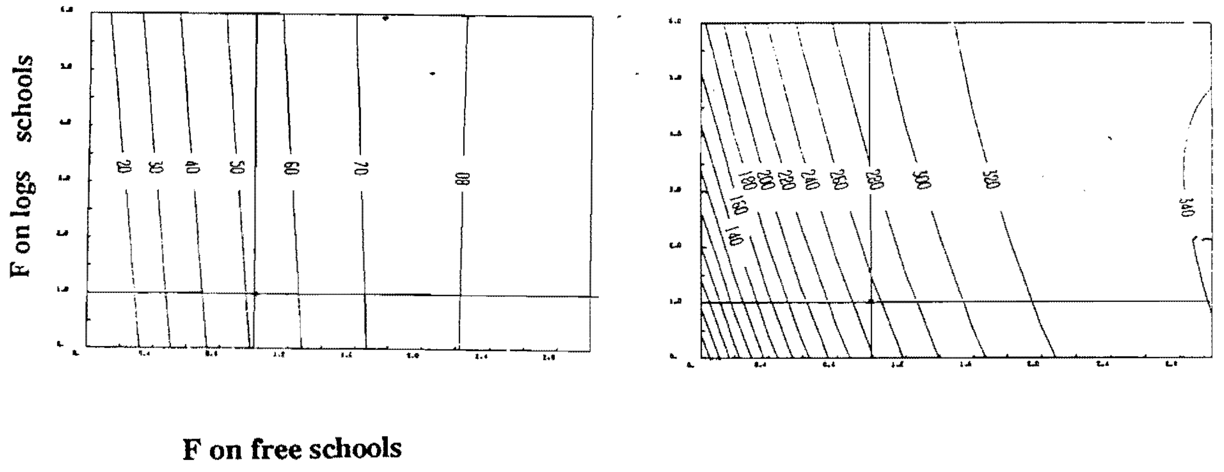
Figure 25. Fishing mortalities, total and on log associated schools, estimated for yellowfin 25 (a), skipjack 25 (b) and bigeye 25 (c).

The areas covered by the black and grey zones are proportional to the relative Fishing mortalities on logs and on free swimming schools (the cumulated F by the two fishing modes is the total F by age).



(A) YELLOWFIN

(B) SKIPJACK



(C) BIGEYE

(D) TOTAL

Figure 26. Multigear yield diagrams (yield per recruit multiplied by average recruitment) calculated for yellowfin (a), skipjack (b), bigeye (c) and total of the three species (d) for variable fishing mortalities multipliers of the log school fishery (vertical axis) and of the other fisheries (horizontal axis) (a multiplier = 1.0 correspond to the present fishery patterns).

AN OVERVIEW OF THE TUNA FISHERY IN THE SOUTHERN CARIBBEAN SEA

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ABSTRACT

In the southern Caribbean Sea, over half of the sets were made on tuna schools associated with whales or whale sharks, while the rest of the sets were made on non-associated schools ("school sets"). An analysis of data collected between 1987 and 1991 showed that sets on tunas associated with whales shifted from November to July from one year to the next, whereas sets on tunas associated with whale sharks occurred consistently between December and January. Sets on schools of tunas associated with flotsam represented less than 1% of all observations. The low percentage of observations on tunas associated with flotsam may be a result of the location of the fishing grounds with respect to terrestrial sources of flotsam and ocean circulation patterns.

Comparisons of size-frequency distributions for yellowfin and skipjack tuna associated with whales and whale sharks suggest that there is a difference in the seasonal size composition between these two tuna species. Comparisons of frequency distributions of catch per set of all tunas, by set type, did not show any significant differences. Contingency tables of the number of sets were analyzed using log-linear models. The results suggest that there may exist complex interactions between the factors analysed: season, dominant tuna species in the set, set type, proportion of unsuccessful sets, size of the tunas, and effect of chumming by baitboats during the set. However, the low number of samples in our database for which the set type could be clearly identified, and the absence of large yellowfin in this surface fishery may have affected our results.

INTRODUCTION

In the world oceans, fisherment know that tunas are associated with floating objects in srface waters. These floating objects can be other marine animals or inanimate objects carried by oceanic currents. The Venezuelan tuna surface fishery. Developed in the 1980's, use these peculiar associations on the fishing grounds in the southern part of the Caribbean Sea and the western Atlantic.

The goal of this study is briefly describe the main associations observed between tropical tunas and floating objects in the area. A hypothesis will be presented to explain the absence of other associations whaich are more frequent in other oceans.

THE ENVIRONMENT

The environment of the southern Caribbean Sea is influenced by two important factors: 1) the discharges of the Amazon and Orinoco Rivers, the world's first and third largest rivers, providing nearly 20% of the fresh water to the world's oceans, and 2) the numerous upwelling cells along the Venezuelan coast that bring nutrients to the surface waters.

Researchers have disagreed about the influence of the Amazon and Orinoco Rivers on the salinity and primary production in this region. Contrary to previous belief it appears that the influence of the Orinoco is greater than that of the Amazon, because although the general sense of the transport of the Guayana and North Equatorial currents is towards the Caribbean Sea, the influence of the Amazon on the Caribbean Sea is limited to the period February through May. Coastal Zone Color Scanner images and observations of drifting buoys (Muller-Karger, McClain and Richardson, 1988) indicate that between June and January the discharge of the Amazon is carried offshore because of recirculation in the North Brazil Current. These waters rejoin the North Equatorial Countercurrent which is directed towards the east. The maximum discharge of the Amazon occurs between May and June (Dessier, 1990), which would indicate that floating objects carried in these waters likely travel for several months before reaching the Caribbean Sea.

As the influx of Atlantic water into the southern Caribbean Sea decreases in the second part of the year, Orinoco waters (whose maximum discharge occurs between July and September, Fig. 1) are observed drifting toward the northern Caribbean Sea (Muller-Karger *et al.* 1989) offshore of the fishing grounds of the Venezuelan purse seiners. During the first part of the year, the Orinoco plume may remain along the coast and could add its nutrient effects to the numerous upwelling cells induced by the winds which blow along the Venezuelan coast between 60° and 67° W, and the Colombian coast, between 72° and 75° W (Aparicio, 1989). In Venezuelan waters, upwelling reaches maximum intensity between January and April (Fig. 2).

THE SURFACE TUNA FISHERY

Although exploratory fishing began in 1972, the Venezuelan surface tuna fishery (baitboats and purse seiners) did not become fully developed until the early 1980s. After maximum tuna catches in 1983 and 1984 of around 50,000 Mt (metric tons) per year, Venezuelan catches in the western Atlantic Ocean have dropped sharply (as a result of relocation of the majority of fishing effort to the eastern Pacific), and stabilized between 15,000 and 20,000 Mt per year. The deeper thermocline and oxycline to the north limit the fishing grounds of the surface fishery to the southeastern margin of the Caribbean Sea (Fig. 3). For this reason, purse seiners enlist the assistance of bait boats to maintain tuna schools near the surface during fishing operations. This fact explains why in this part of the Atlantic Ocean more than half of the sets continue to be made with the help of bait boats. Figure 3 shows the location of the fishing grounds in 1983-1985. Since then, the fishery has progressively abandoned the fishing grounds offshore of the Guyanas because of the strong currents which predominate in this area for more favorable waters situated near the coast of Venezuela. As was mentioned above, this point could explain the low percentage of sets made on tunas associated with flotsam in this fishery.

Types of Associations

The percentage of sets and of total catch by set type indicate a preponderance of school sets (although these schools were not found swimming with other marine animals, 90% of them were accompanied by birds), followed by sets on tunas associated with whale sharks, and next by sets on tunas associated with whales (Table 1). The number of sets on tunas associated with flotsam were practically null within the present fishing grounds (the results were probably different prior to 1986, when the fishery operated regularly in the waters offshore of Guayana). With the exception of unsuccessful sets, the minimum sampling size required to obtain a precision at the 5% level on each proportion (multinomial populations) is reached. Tortora (1978) claims than for four categories (as in the present case) this parameter is 1.66 times higher than the same obtained by the binomial approach of Cochran (1963), for an alpha of 0.05.

In a previous study, Medina-Gaertner and Gaertner (1991) observed that close to 80% of "pure" schools of skipjack were found as free schools whereas "pure" schools of yellowfin tuna were more frequently associated with whales or with whale sharks (52% for both) ; “pure” schools contain a predominant species comprising at least 80% of the school. However, the species composition by weight, obtained by catch sampling fo wells where the three main set types are well-identified, does not appear to agree with the above results (Table 2). (No school data were available for flotsam sets because of the limited number of flotsam observations.) Specifically, the proportion of skipjack catch was higher in sets with whales and with whale sharks than in school sets. However, the problem of bias of catch composition which exists in logbooks (analyzed in this previous study), the low number of schools sampled and retained in the present study (only samples taken from the same well and for which the set type was clearly identified were used) could explain this apparent contradiction. In other words, this difference could be just the demonstration that biases exist in the logbook catch composition.

Seasonality of the Associations

The average number of sets per fishing day by month for each set type are presented in Figure 4. Although there appear to have been seasonal patterns in the average number of sets by month on whales and whale sharks, these patterns are unlikely to be significant due to considerable variability in the data (Table 3). One can observe only that the average number of whale sets per day by month, which showed a general decrease between 1987 and 1991 (without taking into account the absolute abundance of whales in this region), was very low at the beginning of each year and that the period of peak fishing on tunas associated with whales appears to have shifted from November in 1987 to July-August in 1991.

Several species of large and medium-sized whales occur in the Lesser Antilles area (Northridge, 1984). In particular, there are resident populations of Bryde's whales (*Balaenoptera edeni*), humpback whales (*Megaptera novaeangliae*) who migrate into the Carribean during the winter, sperm whales (*Physeter macrocephalus*) generally observed between October and March, and the lesser-known ziphiid whales such as Gervais' beaked whale (*Mesoplodon europaeus*), True's beaked whales (*M. mirus*), and Cuvier’s beaked whale (*Ziphius cavirostris*).

The average number of sets per day by month made on tuna associated with whale sharks, very likely *Rhincodon typus*, were very few during March-April, but were abundant in December-January (Fig. 4). Sets on tuna associated with flotsam were too scarce to be analyzed.

Set Type and Tuna Size

The Kolmogorov-Smirnov two sample test was used to compare the size frequency distribution of tuna within each season (defined as dry from December-May and as rainy from June-November) by set type for both yellowfin and skipjack tunas. With the exception of skipjack (dry season, school sets and schools associated with whale sharks), the tests were significant at the 1% level (Table 4, Figs. 5-6). However, the small number of fishes sampled prevents drawing definitive conclusions. We can just observe that yellowfin caught as school sets during the dry season were in the aggregate smaller than fish caught with whale sharks, but on the other hand were larger than fish caught in association with whale sharks (and whales) during the rainy season.

Set Type and School Size

To evaluate a possible effect of the size of the purse-seine vessel on the frequency distribution of total catch per set, histograms of catch per set for each of three purse-seiner categories were compared, two by two, using a one-tailed Kolmogorov-Smirnov test (if differences exist, one would expect, *a priori*, the differences to be always in the same direction). The different purse seiner categories used in this analysis were: 1) small purse seiners (PS), under 300 Mt carrying capacity; 2) medium purse seiners (PM), between 301 Mt and 650 Mt; and 3) large purse seiners (PG), greater than 650 Mt. Results indicate that total catches per set made by large purse seiners were generally greater than those made by small and medium purse-seiners (Table 5). For this reason, large purse seiners were not included in the present analysis, and the catch-per-set data for small and medium purse-seiner classes were pooled. The analysis was further restricted to sets in the pooled data for which more than 80% of the catch was either yellowfin or skipjack ("pure" schools). Histograms of catch per set for pure schools were constructed for the three types of sets (Fig. 7). Contrary to the results of an earlier study (Medina-Gaertner and Gaertner, 1991) which did not take into consideration the dominant tuna species in the catch, there were no significant differences in catch per set between the different set types for either yellowfin or skipjack (Table 6).

STATISTICAL ANALYSES

Multidimensional contingency tables have the advantage of summarizing data into an easily accessible format, but these tables can be difficult to interpret. The loglinear model (Knoke and Burke, 1990; Agresti, 1990) is one method for examining relationships between variables corresponding to the dimensions of a contingency table. For example, the loglinear model for a 2x2 contingency table, under the assumption of independence of the row and column variables, expresses the natural logarithm (ln) of the expected counts in a given cell using analysis-of-variance-like notation as:

$$\ln(F_{ij}) = \mu + \tau_i + \tau_j; \qquad i,j = 1,2;$$

where F_{ij} = expected count in cell ij;

μ = grand mean of the logarithms of the expected counts;

τ_i, τ_j = "main effects" (*i.e.*, $\mu + \tau_i$ = mean of the logarithms of the expected counts in the j cells at level i, and $\mu + \tau_j$ = mean of the logarithms of the expected counts in the i cells at level j); and

i,j = levels of the two variables represented in the table.

It is worth noting that, unlike classical analysis-of-variance models, loglinear models for contingency tables make no distinction between dependent and independent variables.

In this section, we consider two more complicated models: 1) a loglinear model for the expected number of sets classified by set type (I), season (S) and tuna species (E) (a 3x3 contingency table) and 2) a loglinear model for expected number of sets as classified by set type, tuna species, season and weight per fish (C) (a 4x4 contingency table). The expected counts (expected number of sets) in each cell were estimated with the help of the program OCTA (Dallal, 1987) which uses the Deming-Stephan Iterative Proportional Fitting algorithm. The odds ratio (a familiar concept used in gambling), which can be defined as the probability of being in a particular cell divided by the probability of not being in that cell (Knoke and Burke, 1990; Agresti, 1990), was computed for the observed and for the estimated expected cell frequencies. Because expected cell counts can be expressed as the product of the total sample size and the cell probabilities, the loglinear model can be viewed as a model for describing variability in the odds ratio (Knoke and Burke, 1990).

A likelihood-ratio statistic $L^2 = 2\,\Sigma\, f_{ij} \bullet \ln(f_{ij} / \hat{F}_{ij})$ (where f_{ij} = observed count for cell ij and $\hat{F}_{ij}$ = estimated expected count for cell ij) was used to evaluate the fit of each model to the data. If the model is correct, L^2 will follow an approximate Chi-square distribution, where the number of degrees of freedom (df) are determined as the number of cells less the number of fitted parameters. The larger the value of L^2 (for a given number of degrees of freedom), the greater the discrepancy between observed counts and estimated expected counts. In what follows we will use the notation S, I, E and C to denote "main effects" and combinations of these letters to denote "interaction terms". For example, the notation (IE) denotes a model with main effects I and E, and the first order interaction term IE: $\ln(F_{ij}) = \mu + \tau_i + \tau_j + \tau_{ij}$, where F_{ij} = expected number of sets in cell ij, and i = 1, ..., number of levels of factor I and j = 1, ..., number of levels of factor E. (Similarly, (SEI) denotes a model with main effects S, E, and I; first order interaction terms SE, SI, and EI; and the second order interaction term SEI.)

1) The first analysis was of the number of sets as classified by species of tuna ("pure" schools of yellowfin or skipjack, using the greater than 80% criterion), by season (dry, rainy), and by set type (school sets, whale sets, whale shark sets) (Table 7). In order to decide which model provided the best fit to the data, we began with a simple model and then evaluated whether the fit improved with a more complex alternative model (*i.e.*, whether a more complex model led to a significant reduction in the value of the L^2 statistic). The simplest model which gave a satisfactory fit to the data was the model (SI)(E)(model 7, Table 8). Of the two possible

interactions with the species factor (E), only the season (S) (Cf. model 9) leaded to a significant improvement using an alpha = 0.05 (L2 = 5.96, df = 1). Addition of an interaction term for the set type and the species of tuna (model 10) did not improve the fit. Hence, odds ratios calculated with model 9 (last column in Table 7) cannot be useful to determine if a set associated with a whale has a higher probability (or not) of catching skipjack than a set made on a school set (the same for yellowfin tuna).

2) In the second analysis, we tested whether the weight of the tuna (reported in the logbooks) was dependent on the set type, the species of tuna and the season (Table 9). The tuna weights were stratified into two size categories: less than 6 kg, and greater than or equal to 6 kg for yellowfin tuna (weight corresponding at the transition between the slow-growth stanza and the fast-growth stanza, in the West Atlantic Ocean, Gaertner and Pagavino, 1991) and similarly, a more arbitrary boundary of 3 kg was set for skipjack. Under this hypothesis, the simplest loglinear model which allows for estimation of the "effects" of the three first factors on the last variable is (SEI)(C):

$$\ln (F_{ijkl}) = \mu + \tau_i^{S} + \tau_j^{E} + \tau_k^{I} + \tau_{ij}^{SE} + \tau_{ik}^{SI} + \tau_{jk}^{EI} + \tau_{ijk}^{SEI} + \tau_l^{C}.$$

The simplest model which gave a satisfactory fit to the data (P=0.707) was: (SEI) (SEC) (IC) (L^2 = 3.78, df = 6). More complex models (SEI) (SEC) (EIC) and (SEI) (SEC) (SIC) improved the fit (L^2 = 1.45 and 2.39, respectively; df = 4), but not significantly (Chi-square test with df = 2). Thus, the simpler model was used to calculate the odds ratios (Table 9). To summarize, we found: 1) an interaction between Season (S), the species of tuna (E) and the set type (I); 2) an interaction (SEC), Season*Species of tuna*weight category; and 3) an interaction (IC), in which addition of (E), or (S), did not significantly improve the fit.

No loglinear model described in a satisfactory manner the effect of the set type and baitboat cooperation on the probability of an unsuccessful set (Table 10). Even if this latter factor has an evident effect on this parameter (in the aggregate, the percentage of unsuccessful sets , or sets without catch, dropped from 41 to 12% with cooperation of baitboats), the different interactions between all the factors prevented the use of a log-linear model.

CONCLUSIONS

In spite of the proximity of the most important terrestrial source of flotsam, the Amazon and Orinoco Rivers, tunas are not fished frequently with logs in the southern Caribbean Sea. The location of the Venezuelan fishing grounds and ocean circulation patterns may explain this fact.

In this fishery, where baitboats continue to help purse seiners during fishing operations, over 50% of the sets are made on tuna schools unassociated with floating objects. For the other observations, tuna schools were associated with whales and whale sharks. The peak seasons for sets on these two floating objects were in summer-autumn and winter, respectively.

The loglinear models used in this study to describe relationships between tuna schools and floating objects, or the rates of successful sets, are not easy to interpret. In the majority of cases, numerous interactions between seasons, floating objects, dominant tuna species in the set, size category of tuna, and assistance given by a baitboat had to be included in the model to reach a satisfactory fit.

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LITERATURE CITED

Agresti, A. 1990. Categorical Data Analysis. Ed. John Wiley and Sons, New York. 287 pp.

Aparicio, R. 1989. Meteorological and oceanographical conditions along the southern coastal boundary of the Caribbean Sea, 1951-1986. Implications of climatic changes in the wider Caribbean region; Unit. Nat. Environ. Progr. IOC, G. A. Maul (Ed.): 101-117.

Cochran, W. G. 1963. Sampling Techniques, 2nd ed., John Wiley & Sons.

Dallal, G. E. (1987). OCTA: A program for the log-linear analysis of multidimensional contingency tables. The American Statistician 41: 328.

Demaris, A. 1991. A framework for the interpretation of first order interaction in logit modeling. Psychological Bulletin 110(3): 557-570.

Dessier, A. 1990. L'impact des effluents fluviatiles sur les ecosystmes marins-L'Amazone et l'Atlantique Tropical Nord-Ouest. Unpublished, 44 pp.

Evans, R. H., McLlain, D. R., and Bauer, R. A. 1981. Atlantic skipjack tuna: Influences of mean environmental conditions on their vulnerability to surface fishing gear. Mar. Fish. Rev. 43 (6): 1-11.

Gaertner, D., Medina-Gaertner, M. and Pagavino, M. 1989. Distribución de las capturas de superficie de Venezuela y evaluación de las potencialidades de captura del atún aleta amarilla, en el Atlantico Oeste. Col. Doc. Cien. ICCAT, 30(1): 150-158.

Gaertner, D. and Pagavino, M. 1991. Observations sur la croissance de l'albacore (Thunnus albacares) dans l'Atlantique ouest. Col. Doc. Cien. ICCAT, Inf. del Programa Año del Rabil, 36: 479-505.

Knoke, D. and Burke, P. J. 1990. Log-Linear Models. Sage University Paper series on Quantitative Applications in the Social Sciences, 07-020. Beverly Hills and London, Sage Pubns., 80 pp.

Medina-Gaertner, M. and Gaertner, D. 1991. Factores ambientales y pesca atunera de superficie en el Mar Caribe. Col. Doc. Cien. ICCAT, Inf. Del Programa Año del Rabil, 36: 523-550.

Muller-Karger, F. E., McClain, C. R. and Richardson, P. L. 1988. The dispersal of the Amazon's water. Nature, 333 (6168): 56-59.

Muller-Karger, F. E., McClain, C. R., Fisher, T. R., Esaias, W. E. and Varela, R. 1989. Pigment distribution in the Caribbean Sea: Observations from space. Prog. Oceanog., 23: 23-64.

Northridge, S. P. 1984. World review of interactions between marine mammals and fisheries. FAO Fish. Pap. (251) 190 pp.

Tortora, R. D. 1978. A note on sample size estimation for multinomial populations. The American Statistician, 32(3): 100-102.

Table 1. Statistics by sighting indices for Venezuelan purse seiners in Caribbean waters (1987-1991). Total sets and total catches correspond to a subset of data. Total number identified is a subset of the former total where sighting indices were reported. Percentage values within brackets were calculated without considering the "mixed" observations; n represents the required sample size (multinomial estimate, from Tortora, 1978) for an absolute precision of 5% for each proportion (α = 0.05).

	Total Sets Recorded	**Total Sets Identified**	**School Sets**	**Whales Sets**	**Whale Shark Sets**	**Flotsam Sets**	**Mixed Sets**	**n**
No. Successful sets	2,493	1,979	871	363	601	8	136	635
%	(47.26)	(19.70)	(32.61)	(0.43)				
No. Unsuccessful sets	814	604	187	110	269	1	37	635
%	(32.98)	(19.40)	(47.44)	(0.18)				
Total Sets	3,307	2,583	1,058	473	870	9	173	627
%	(43.90)	(19.63)	(36.10)	(0.37)				
Total Catch.	45,606	34,101	14,526	6,930	9,999	175		
%	(45.95)	(21.91)	(31.61)	(0.55)				
Average catch By set (TM)	16.68	19.09	16.64	21.86				

Table 2. Percentage composition in weight obtained by multi-species sampling for Venezuelan purse seiners (1987-1991) when set types were identified. The weighting factor (W), used to estimate annual value, is proportional to total catch by season.

Set Types	**Season**	**W**				**Species**			**No. Sets Sampled**
			YFT	**SKJ**	**FRI**	**ALB**	**BET**	**BLF**	
	Dry	0.4	80.6	11.8	3.7	0.2	0.4	3.3	10
Schools	Rainy	0.6	86.1	8.2	3.0	0	0	2.7	6
	Annual	83.9	9.6	3.3	0.08	0.16	2.9	16	
	Dry	0.4	-	-NO DATA		-	-	-	0
Whales	Rainy	0.6	65.1	18.8	5.2	0	0	11.0	5
	Annual	65.1	18.8	5.2	0	0	11.0	5	
Whale Sharks	Dry	0.4	71.0	14.4	6.0	0.8	0.8	6.9	7
	Rainy	0.6	75.4	15.4	2.6	0	0.4	6.2	9
	Annual	73.6	15.0	4.0	0.32	0.6	6.5	16	

Table 3. Source of variation (in percentage) for the Trend-Seasonal-Noise (TSN) analysis for sighting indices used in this study. TSN analysis means that yearly, seasonal and unexplained variabilities were evaluated.

Source of Variation	**School Sets**	**Whale Sets**	**Whale Shark Sets**	**Flotsam Sets**
Trend	4.23	10.29	1.58	13.08
Seasonal	17.72	5.98	41.17	16.02
Noise	78.05	83.73	57.25	70.89

Table 4. Values of Dmax of Kolmogorov-Smirnov test and sample sizes for comparison between size distributions according to the set type by species and by season. NS = not significant; ** = significant at α = 0.01; n1 & n2 = numbers of fishes in the corresponding samples.

Species	Season	Set Type	School Sets	Whale Sets	Whale Shark Sets
YFT	Dry	Schools	---	---	0.2003 **
		n1 & n2			(976)(470)
	Rainy	Schools	---		
		Whales	0.2283 **	---	
		n1 & n2	(348)(527)		
		Whale Sharks	0.1390 **	0.1124 **	---
		n1 & n2	(709)(527)	(709)(348)	
SKJ	Dry	Schools	---	---	0.0830 NS
		n1 & n2			(630)(462)
	Rainy	Schools	---		
		Whales	0.1926 **	---	
		n1 & 2	(390)(427)		
		Whale Sharks	0.2819 **	0. 1883 **	---
		n1 & n2	(572)(427)	(572)(390)	

Table 5. Values of Dmax of Kolmogorov-Smirnov test and sample sizes for comparison between size distributions according to purse seiner size (small, medium or large). NS = not significant; ** = significant at a = 0.01.

	Small	Medium	Large
Small	---		
Medium	0.052 NS	---	
Large	0.148 **	0.122 **	---

Table 6. Values of Dmax of Kolmogorov-Smirnov test and sample sizes for comparison between size distributions according to the set type by species. NS = not significant; n1 & n2 = numbers of fish in the corresponding samples.

Species	**Set Type**	**School Sets**	**Whale Sets**	**Whale Shark Sets**
	Schools	---		
YFT	Whales	0.05728 NS	---	
	n1 & n2	(121)(364)		
	Whale Sharks	0.0282 NS	0.05731 NS	---
	n1 & n2	(212)(364)	(212)(121)	
	Schools	---		
SKJ	Whales	0.13241 NS	---	
	n1 & n2	(154)(120)		
	Whale Sharks	0.06324 NS	0.06917 NS	---
	n1 & n2	(68)(120)	(68)(154)	

Table 7. Analysis of factors connected with dominant species in the set (in which the dominant species comprised 80% or more of the total catch of the set). The two last columns represent observed odds and estimated odds following the best log-linear model (see model 9 in Table 8).

				Odds	
Season	**Set Type**	**Dominant Species in the set**		**No. sets with YFT**	**Observed No. sets**
		YFT	**SKJ**	**Observed**	**with SKJ estimated**
	Schools	179	38	4.71	3.80
Dry	Whales	20	9	2.22	3.80
	Whale Sharks	143	43	3.33	3.80
	Schools	221	96	2.30	2.66
Rainy	Whales	110	41	2.68	2.66
	Whale Sharks	134	38	3.53	2.66

Table 8. Some log-linear models used to fit the data in Table 7; Factors are: S = seasonal, E = Species, I = Set Type.

Model	Fitted Marginals	L2	d.f.	p
1	(S) (E)	266.43	9	0
2	(I) (E)	123.52	8	0
3	(S) (I) (E)	82.91	7	0
4	(IE)	121.74	6	0
5	(IE) (S)	81.13	5	0
6	(SE) (I)	76.95	6	0
7	(SI) (E)	13.55	5	0.019
8	(SI) (IE)	11.77	3	0.008
9	(SI) (SE)	7.59	4	0.108
10	(SI) (SE) (IE)	6.9	2	0.031

Table 9. Analysis of factors connected with size class in the schools (for YFT large are > 6 Kg and for SKJ large are > 3 Kg). The dominant species comprised 80% or more of the total catch of the set. The two last columns represent observed odds and calculated odds following the best log-linear model (SEI SEC IC).

Season	Dominant Species	Set Type	No. sets with dominant size class		Odds	
			Small	Large	No. sets with small Observed	No. sets with large Estimated
Dry	YFT	Schools	6	173	0.035	0.041
		Whales	1	19	0.053	0.044
		Whale Sharks	6	137	0.044	0.037
	SKJ	Schools	29	9	3.222	3.472
		Whales	6	3	5.000	3.663
		Whale Sharks	34	9	3.778	3.064
Rainy	YFT	Schools	32	189	0.169	0.184
		Whales	21	89	0.236	0.194
		Whale Sharks	18	116	0.155	0.162
	SKJ	Schools	57	39	1.462	1.233
		Whales	21	20	1.050	1.302
		Whale Sharks	18	20	0.900	1.088

Table 10. Analysis of factors associated with unsuccessful sets. No log-linear model gave a satisfying fit to these data.

Baitboat Assistance	**Set Type**	**No. of sets**		**% Unsuccessful Sets**
		Successful	**Unsuccessful**	
YES	Schools	750	81	9.75
	Whales	258	41	13.71
	Whale Sharks	276	55	16.62
NO	Schools	121	106	46.70
	Whales	105	69	39.66
	Whale Sharks	325	214	39.70

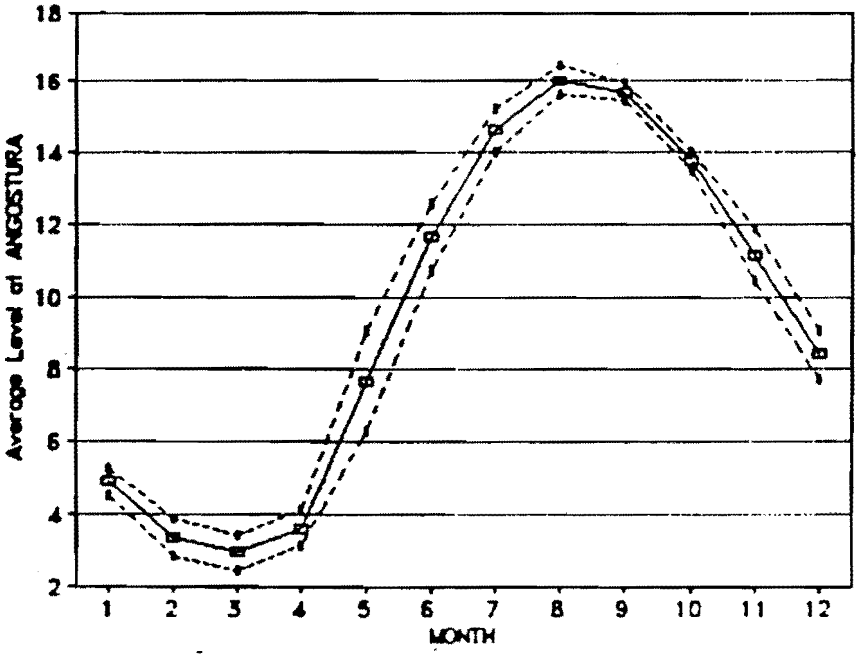

Figure 1. Seasonal pattern of the level of the Orinoco River (monthly average between 1977-1986) at the city of Angostura (R. Aparicio, IOV-UDO, pers. comm.). Dashed lines represent confidence intervals at a 5% level.

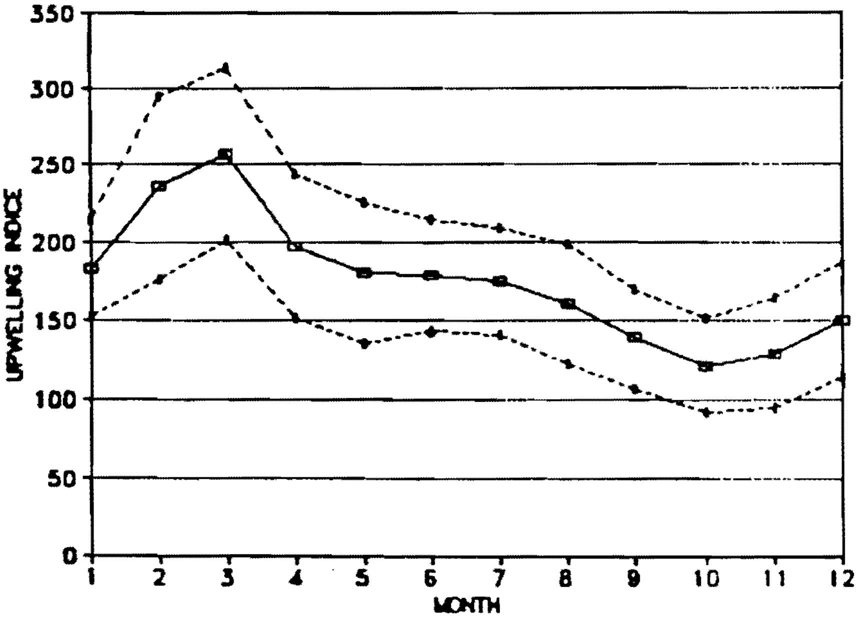

Figure 2. Seasonal pattern of the upwelling index (monthly average wind index between 1979-1988) at the city of Maiquetia (R. Aparicio, IOV-UDO, pers. comm.). Dashed lines represent confidence intervals at a 5% level.

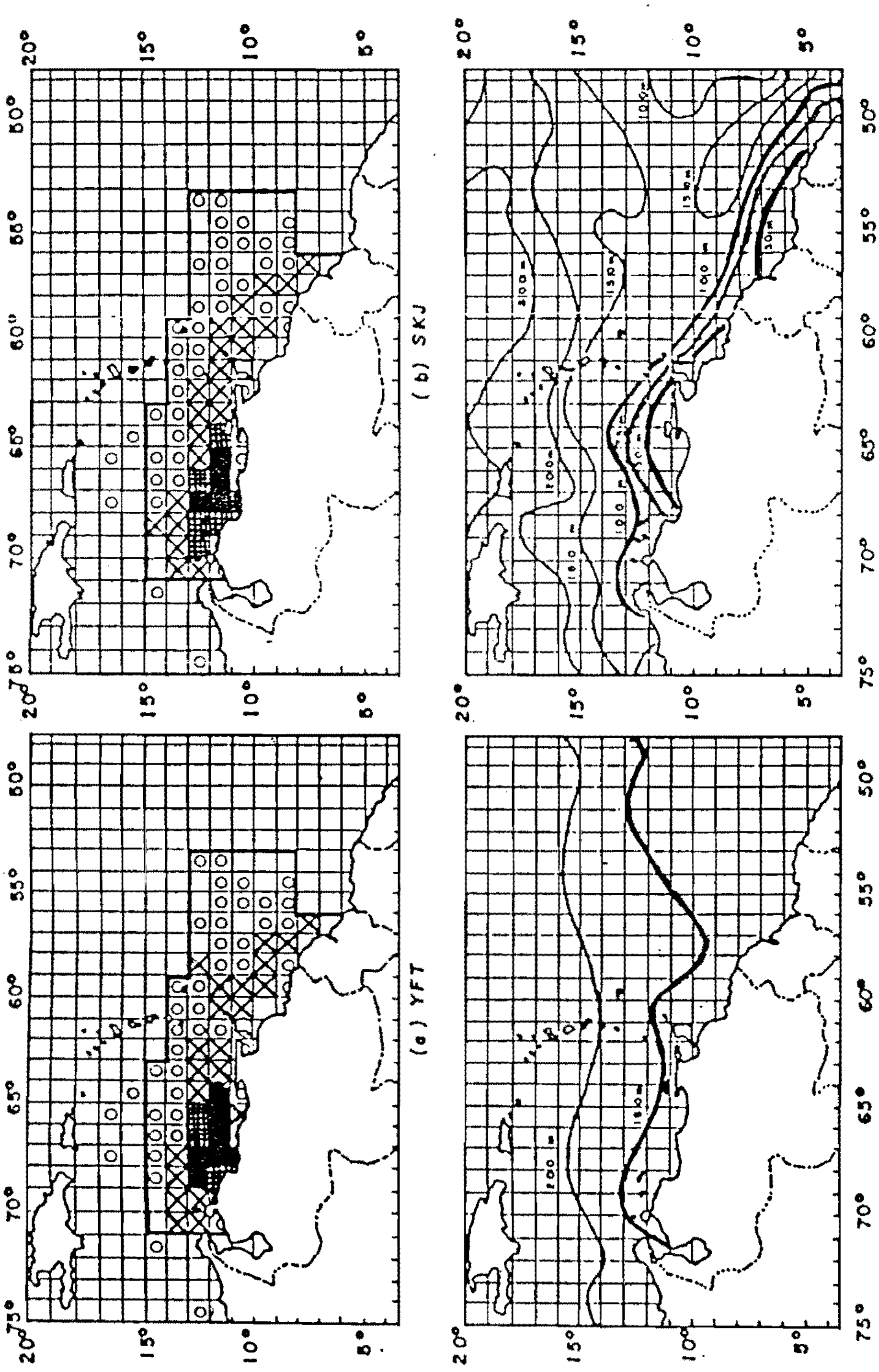

Figure 3. Location of the Venezuela surface catches for yellowfin (a) and skipjack (b), above; yearly average between 1983 and 1985: squares with circles = 0-40 Tm, squares with x's = 41-400 Tm, hatched squares = 401-900 Tm, filled squares = 901+ Tm (from Gaertner *et al.*, 1989). Bathymetric limit of the isotherm 18°C (c) and bathymetric limit of the dissolved oxygen concentration of 3.5 ml/l (d), below (from Evans *et al.*, 1981).

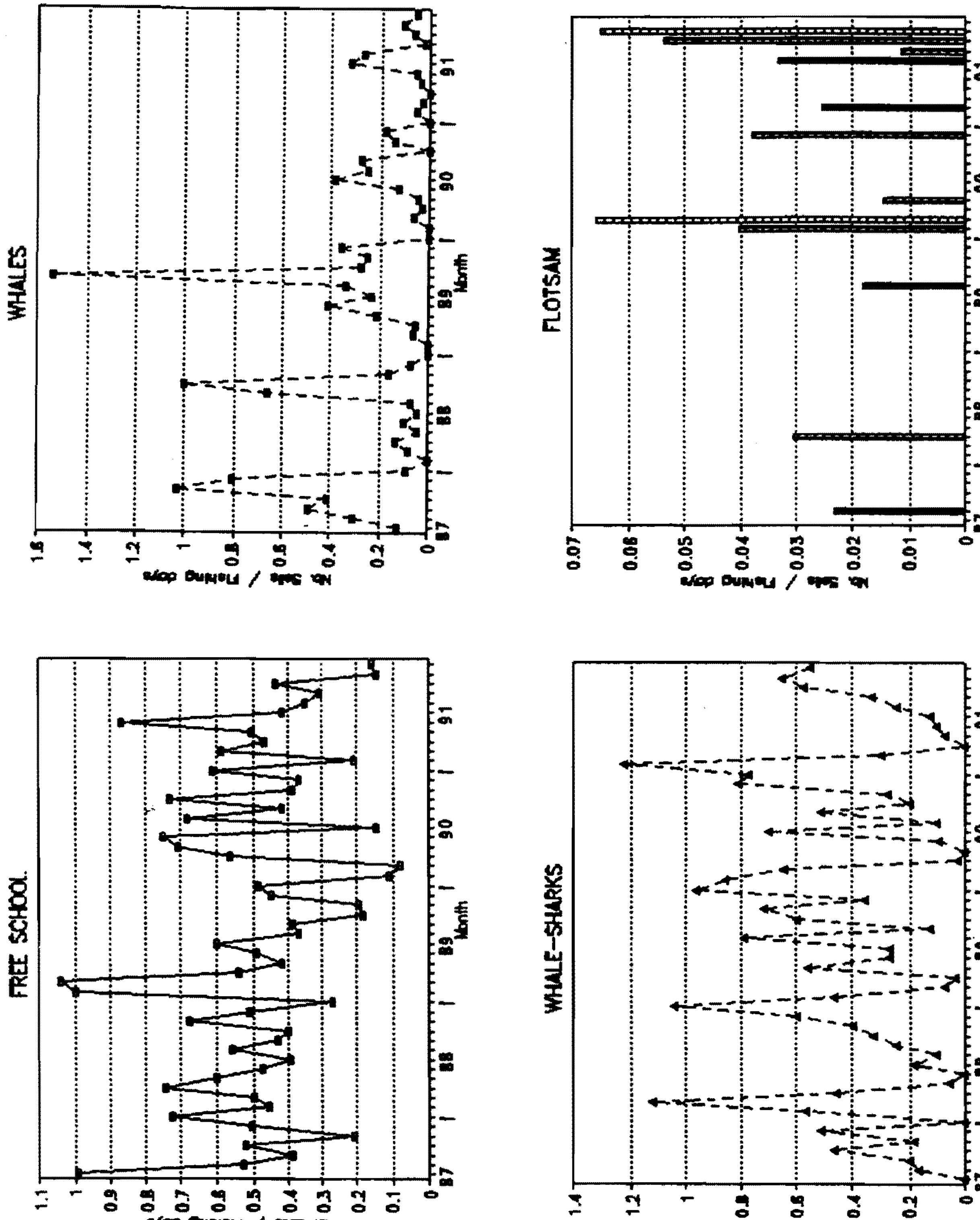

Figure 4. Monthly occurrence index (No. of sets / fishing days with set) for the different set types on tunas in the southern Caribbean Sea.

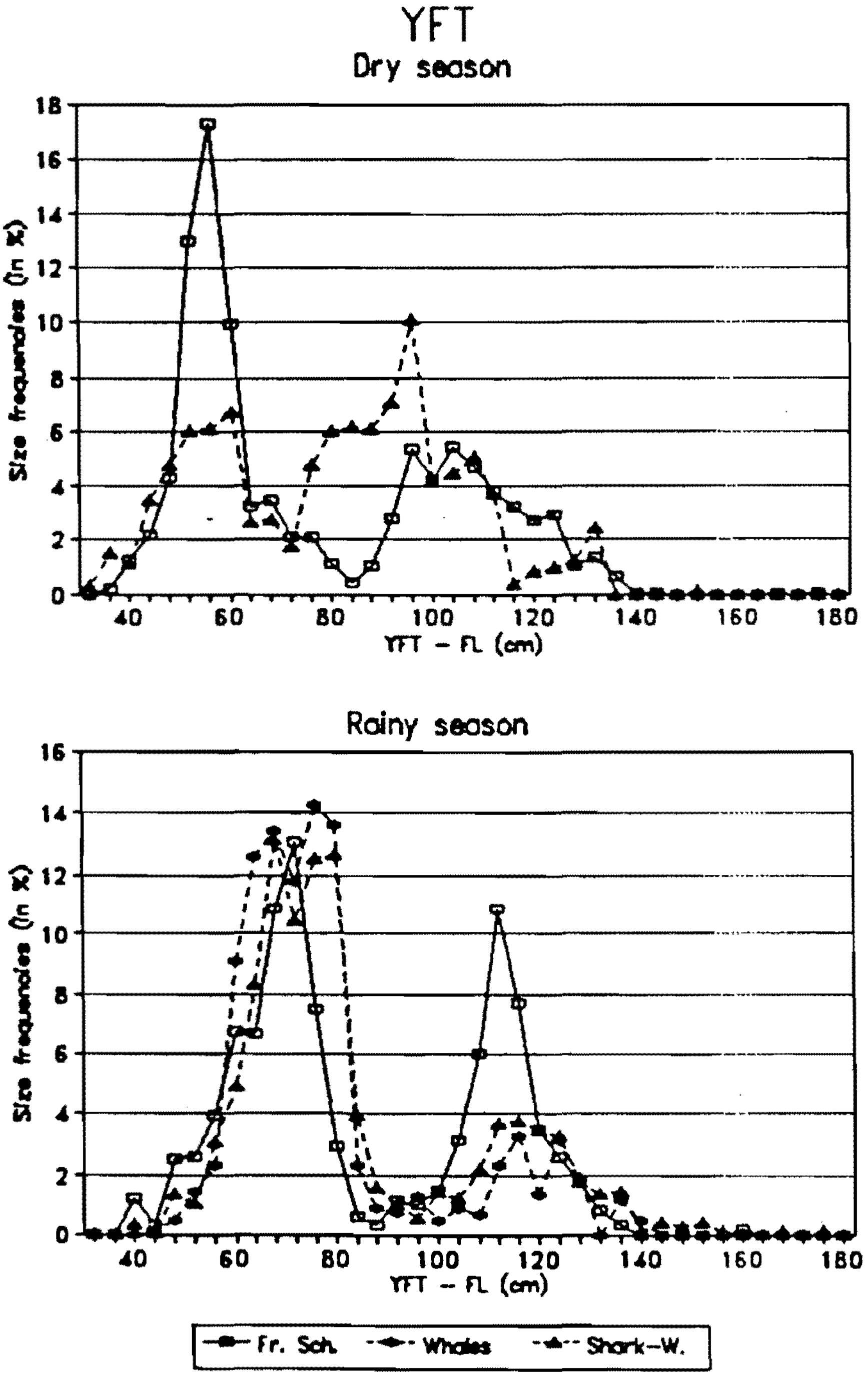

Figure 5. Size-frequency distributions of yellowfin tuna (fork length in cm) associated with free schools, whales and whale sharks during the dry season (December-May) above and the rainy season (June-November) below.

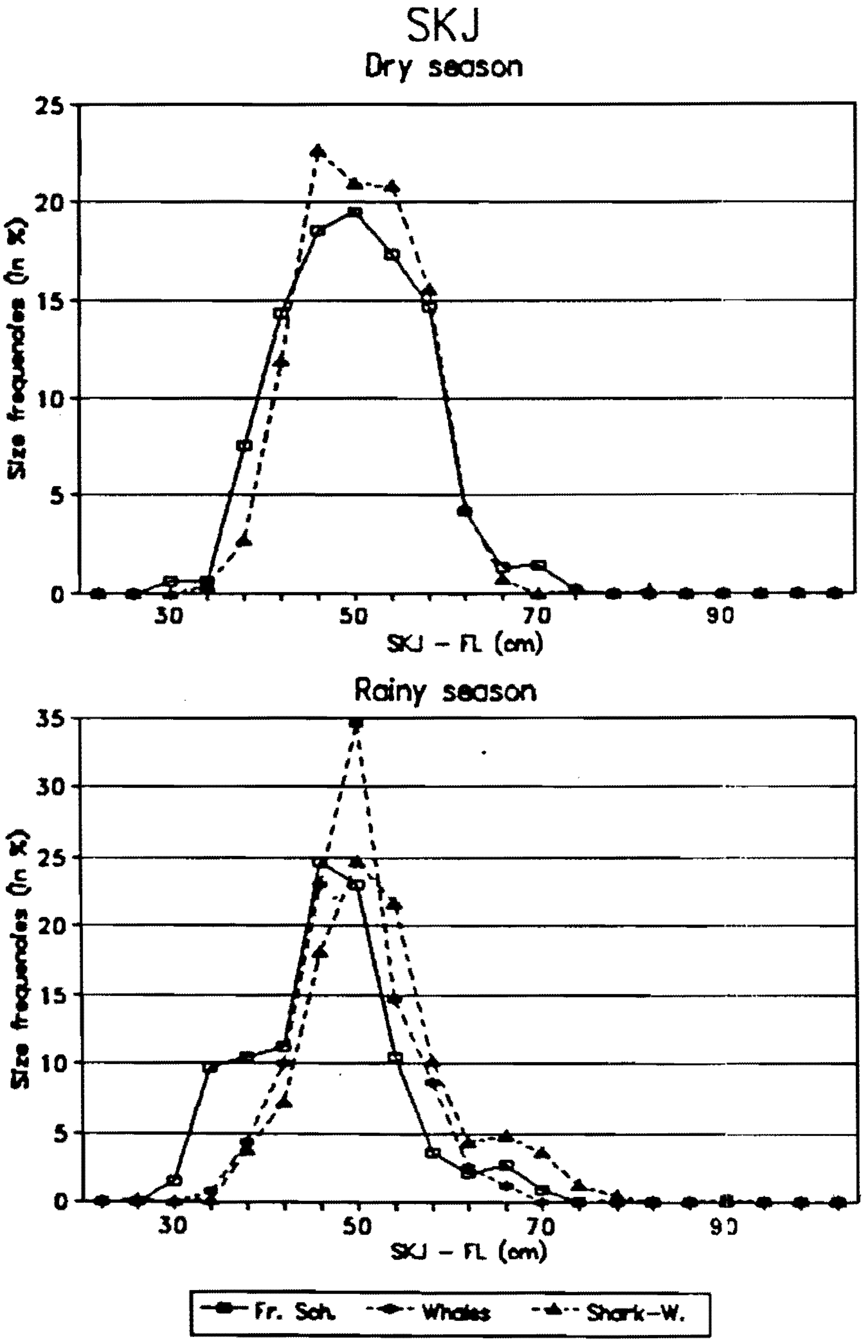

Figure 6. Size-frequency distributions of skipjack (fork length in cm) associated with free schools, whales and whale sharks during the dry season (December-May) above and the rainy season (June-November) below.

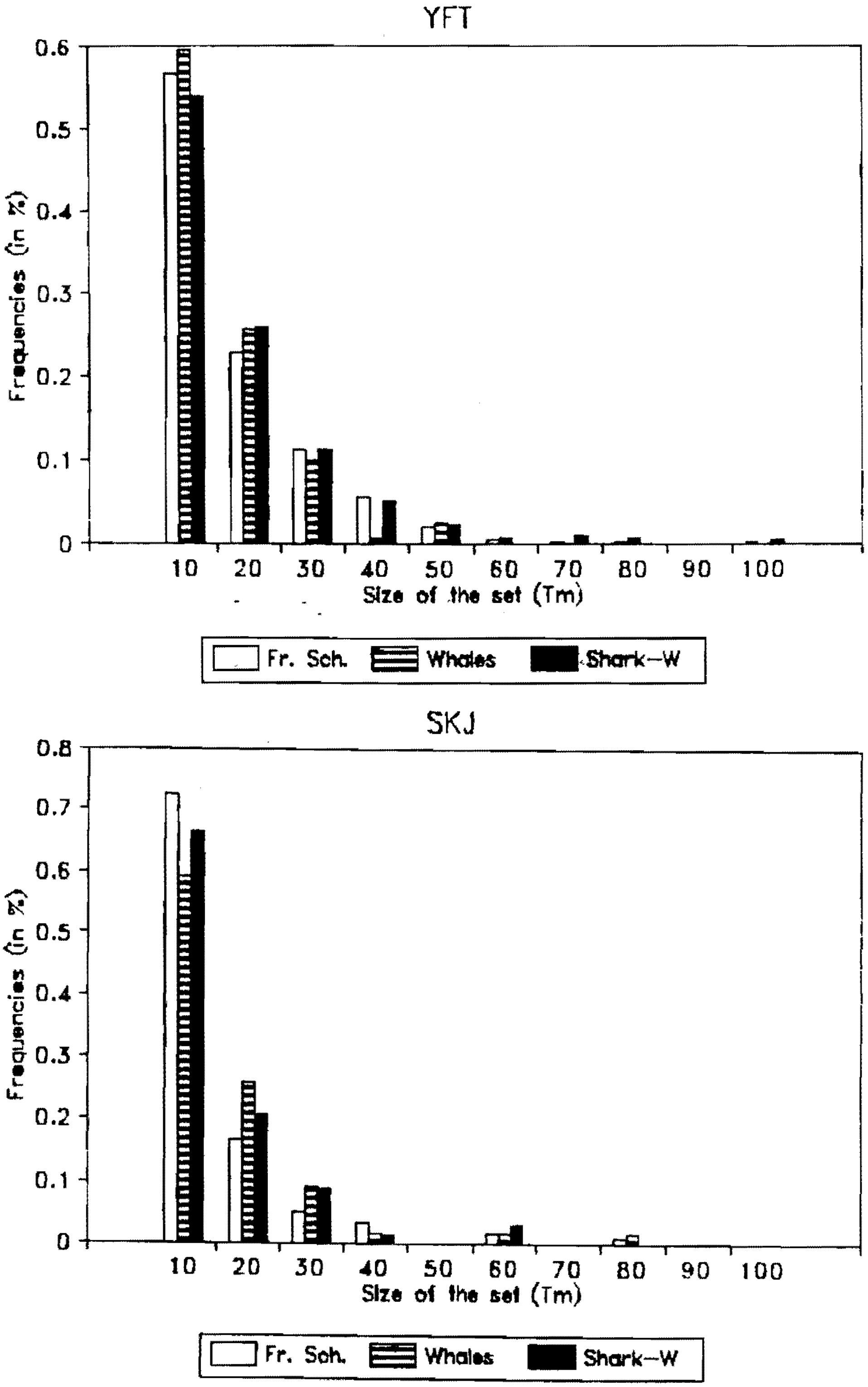

Figure 7. Histograms of the frequency of the weight of the set ("yellowfin" sets above, "skipjack" sets below) according to the set type for Venezuelan purse seiners less than 650 Mt in the Caribbean Sea.

THE ASSOCIATION OF TUNAS WITH FLOATING OBJECTS AND DOLPHINS IN THE EASTERN PACIFIC OCEAN: A REVIEW OF THE CURRENT PURSE-SEINE FISHERY

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ABSTRACT

In tropical (and some temperate) regions of the eastern Pacific Ocean schools of tropical tunas (mainly yellowfin tuna, *Thunnus albacares*, and skipjack tuna, *Katsuwonus pelamis*) are known to form associations with floating objects and with dolphins, in addition to forming unassociated schools. These behaviors have given rise to three modes of purse seining for tunas. An analysis of the relative importance of the three fishing modes for the purse-seine fishery between 1980 and 1990 is presented. Spatial and temporal variability in fishing effort, measured in terms of number of sets, and average catches of yellowfin and skipjack tuna are described. A brief review of the physical and biological characteristics of the eastern tropical Pacific Ocean is provided, and the effects of the environment on fishing operations and tuna associations are discussed.

INTRODUCTION

The eastern Pacific Ocean (EPO) (Fig. 1) from Baja California (30°N) to Peru (20°S) and from the coast to 150°W is one of the world's most productive regions for tunas. In 1988, the fishery for tunas in the EPO produced approximately 33% of the world catches of yellowfin tuna, *Thunnus albacares* (Anonymous, 1994). Lesser tonnages of skipjack tuna (*Katsuwonus pelamis*) and bigeye tuna (*Thunnus obesus*) also are harvested in these waters. A considerable proportion of the catch currently is taken in association with floating objects or with dolphins (see below). The EPO tuna fishery began early in this century, using poles and lines and live bait. Over the years, the ever-increasing demand for tuna, coupled with technological advances, led to the development of the two fishing techniques that currently dominate the fishery: purse seining and longlining. There are still some pole-and-line operations with live bait, and some small purse-seine vessels, but large purse seiners with capacities greater than 400 short tons produce the vast majority of the surface catch. (Hereforth in this report "tons" refers to short tons.) Larger, more valuable fish are caught by longlining, but the amounts taken are far less.

The longline fishery operates mostly in deeper, colder waters south of 10°N, and targets not only yellowfin, but also other large tunas, particularly bigeye and albacore (*Thunnus alalunga*), and billfishes (Kume and Joseph, 1969; Shingu *et al.*, 1974; Miyabe and Bayliff, 1987; Nakano and Bayliff, 1992). Skipjack are seldom captured with this type of gear. Japanese vessels predominate in the longline fishery in the EPO; their activities during 1971-1987 have been reviewed by Miyabe and Bayliff (1987), and Nakano and Bayliff (1992). Even though the purse-seine and longline fisheries are widespread over most of the EPO, the areas of heaviest exploitation by the two gears do not overlap. The two major fishing grounds for the longline fishery (around the Marquesas Islands, about 10°S-140°W, and off Peru) lie south of the major surface-fishing grounds.

At the surface, the presence of a school of tunas is often betrayed by disturbances on the surface of the water, especially when the fish are feeding and/or by the presence of sea birds just above the surface of the water (Scott, 1969). However, from the early years of the fishery the fishermen observed that tunas were frequently close to floating objects of different types drifting in the currents. They also noticed yellowfin tunas swimming among or near groups of dolphins, and used these observations to make the task of detecting schools of tunas easier. When purse-seine nets were adopted by the fishery, this knowledge gave rise to the three basic modes of purse seining in use today: 1) Fishing "on logs," in which the net is set on a school of tunas associated with a floating object; 2) Fishing "on schools," in which the school of tunas is detected through signs of its presence on the surface of the water; and 3) Fishing "on dolphins," in which the tunas are detected while associated with herds of dolphins of various species. This terminology, although used by both fishermen and scientists, is somewhat misleading because tuna schools are the targets in all cases.

It is not known why yellowfin and skipjack associate with floating objects and dolphins, but understanding their adaptive value could be useful to the management of both tuna and dolphin populations. Biological synopses of the species and reviews of the fishery can be found in Cole (1980), Forsbergh (1980), Punsly (1987), and Wild (1994a); for a recent update on the fishery, see Anonymous (1994). In this manuscript we present a brief description of the fishery and a summary of the spatial and temporal distributions of sets and catches. Similarities and differences among the three main modes of purse- seining for tunas are reviewed and we discuss the effect of environmental factors on tunas, dolphins, floating objects and fishing operations, and on the associations.

CLIMATOLOGY AND OCEANOGRAPHY OF THE EASTERN PACIFIC OCEAN

Precipitation patterns and river runoff

The Pacific coast of the Americas receives a great amount of precipitation, particularly along the coasts of Central America and northern South America. The relatively dry coast of Mexico can receive 400 to 600 mm of rain in any given month during the rainy season, mostly in the form of short tropical storms. Coastal areas south of about 10°S receive little precipitation annually. At the other extreme, the Pacific coasts of Colombia, northern Ecuador, Costa Rica and Panama, and the Guatemala-Mexico highland are areas of high annual precipitation, receiving over 3200 mm per year (Hoffman, 1975; Anonymous, 1976; Steinhauser, 1979; Fig. 2). With the exception of northern Colombia, where rain occurs year-round, precipitation is seasonal throughout most of Mexico, Central and northern South America along the Pacific coast, occurring mostly during May through October. Exceptions to this are northern Mexico, where rainfall is heaviest in September and October, and southern Colombia and Ecuador, where rainfall is greatest in February and March.

Although the largest rivers in the region discharge into the Caribbean Sea or the Atlantic Ocean, many smaller rivers discharge into the Pacific, and river runoff can be significant during the rainy season. For example, salinity in the coastal waters is low, especially in the Panama Bight, due to the influence of rivers of Colombia and Panama (Bennett, 1966a; Forsbergh, 1969). River flow in Mexico and Central America is greatest from about August to November, closely matching the rainy season patterns of this region. Peak runoff generally occurs between about December and March along the Pacific coast of northern South America, however, in some highland areas of Colombia and Ecuador, river transport is high throughout most of the year.

Water circulation

Circulation of water in the eastern tropical Pacific Ocean (ETP) is dominated by the equatorial components of the subtropical wind-driven anticyclonic gyrals of the eastern, northern and southern Pacific, with contributions from eastern boundary currents flowing along the continental margins (Fig.1). There are four major equatorial currents in the ETP. Flowing from east to west at the surface are the South Equatorial Current, from about 10°S to 4°N, and the North Equatorial Current (NEC), located from about 10°N to 15°N. Between the South and North Equatorial Currents is the North Equatorial Countercurrent (NECC) flowing from west to east at or near the surface. Subsurface at the equator, the Equatorial Undercurrent (also known as the Cromwell Current) flows in a narrow jet toward the east near the equator. Along the continental margins, the eastern boundary currents (California Current along the coast of North America and Peru Current along the coast of South America) flow toward the equator, and then turn west and join the east-west circulation which is characteristic of the central tropical Pacific. The NECC contributes to the warm nature of the ETP north of the equator. Although relatively narrow, the NECC extends across the tropical Pacific, and has a significant impact on upwelling in the coastal regions of Central American and southern Mexico.

The relative strengths of these currents and their contributions to the general ETP circulation fluctuate seasonally with the strength of the trade-wind system (Wyrtki, 1967). When the northeast trades are strong and extend toward the equator during the first half of the year, the NEC is strong and the NECC is weak. When the trades are usually weaker and recede northward during the second half of the year, the NECC is stronger (Wyrtki, 1974). The Equatorial Undercurrent, which is fully developed between August and December may appear at the surface, but disappears from the surface between February and April. The effect of strong winds is particularly significant close to the coast, where wind-driven upwelling episodes occur quite frequent, especially offshore of mountain passes in Mexico and Central America (Bennett, 1966a; Legeckis, 1986). Reviews of water circulation in the eastern tropical Pacific can be found in Wooster and Cromwell (1958), Wyrtki (1965, 1966, 1967), Yoshida (1967) and Tsuchiya (1970, 1974, 1982).

Physical and chemical characteristics

For the past thirty years the Inter-American Tropical Tuna Commission has monitored sea surface temperatures in the ETP. Over the past decade, surface and subsurface temperatures have been monitored extensively in global-scale oceanographic programs such as TOGA (Tropical Oceans and Global Atmosphere) and WOCE (World Ocean Circulation Experiment) (Pazan and White, 1988; Cole and McLain, 1989), and by satellite imagery analysis, in particular in relation to the El Niño (Legeckis, 1986). The ETP is characterized by a well-developed, relatively shallow (usually less than 100m) permanent thermocline. The topography of the thermocline, which is related to the currents in the surface layer, is characterized by ridges (rising thermocline with depth < 100m) and troughs (deeper thermocline with depth >100m) oriented east-west (Fig. 3). Other salient thermal features in the ETP include a tongue of cold surface water off the coast of Peru and localized areas of cooler waters in the Panama Bight, along the coast of Central America, and at the Costa Rica Dome (9°N, 89°W; Wyrtki, 1964) resulting from periodic upwelling events. Upwelling is frequently most intense during strong northerly winds in the Gulf of Tehuantepec from about November to March, the Gulf of Panama from about February to April, and at the Costa Rica Dome from about December to May (Legeckis, 1986). Descriptions of the thermal characteristics of the ETP can be found in Cromwell (1958), Wyrtki (1964), and Robinson and Bauer (1971); maps of the thermal structure can be found in Hansen and Herman (1988) and Halpert and Ropelewski (1989).

Salinity shows typical maxima for the tropics, with a minimum in equatorial surface waters. In the central ETP, seasonal variation in salinity can be large, especially in the Gulf of Panama and off the coasts of Colombia and northern Ecuador, where salinity decreases from 34 to less than 30 at the end of the rainy season (Bennett, 1966b). Low salinity, due to excess precipitation and river runoff over evaporation, together with high temperatures, characterize the Tropical Surface Water Mass, a large water mass centered along 10°N (Fig. 4). Major highly saline water masses in the ETP include the generally warm Subtropical Surface Water Mass of the South Pacific Gyre, and the Equatorial Surface Water Mass whose properties are determined by seasonal advection of cooler water from the Peru Current and by equatorial upwelling. The cool, low-salinity waters of the California Current and the Peru Current can also be distinguished as separate water masses in the ETP. Water masses in the ETP have been described by Wyrtki (1967).

The upper boundary of the oxygen minimum layer (Fig. 5) is found at depths of less than 50 m off Central America, and less than 100 m along 10°N as far offshore as 150°W and the coastal regions of Peru and northern Chile. The oxygen minimum layer is more than 200 m deep off Mexico and Central America to the west of 120°W, and more than 300 m deep offshore from Peru west of 80°W. Dissolved oxygen can be as low as 0.1 ml/l at depths of less than 400 m in these two areas, and increases to 3 ml/l with distance from the coast. Along the coasts of Ecuador and Colombia the depth of the oxygen minimum layer varies from 600 m to 1000 m, and along the equator the variation is less than 300 m in depth.

Biological productivity

Maps of nutrient distribution (Thomas, 1977) show that the surface water in most of the ETP is poor in nutrients; the exceptions are in the Peru Current, the equatorial upwelling zone, the intertropical convergence zone located between the NECC and the NEC, and the seasonal local upwellings of the Gulf of Tehuantepec, the Costa Rica Dome and the Panama Bight and the Gulf of Guayaquil (Figure 6). However, despite nutrient-poor surface water over large regions of the ETP, primary production is high when compared with the rest of the open ocean. Phytoplankton production tends to be maximal during March and April and minimal in October; the range of primary productivity varies from 127 to 318 mg C/m-2/yr-1, with an average of 75 mg C/m-2/yr-1 (Owen and Zeitzchel, 1970). Geographic and seasonal variation in primary production are reflected in the distribution and abundance of herbivorous invertebrates and carnivorous zooplankton and micronekton. The zooplankton distribution closely matches productive areas along the equator and 10°N (Blackburn *et al.*, 1970). The number of species and biomass of copepods in the ETP have been shown to be greater in upwelling areas than in open water (Sameoto, 1986). The vertical distribution of zooplankton and micronekton is also greatly influenced by the depth of the thermocline and the depth of the oxygen-minimum layer. For example, the distribution of many copepod species is truncated in the region of the oxygen minimum. Overall, standing stocks of phytoplankton, zooplankton, and micronekton show similar geographic distributions: a general decrease from east to west, and higher production in areas where the thermocline is permanently or seasonally close to the surface.

El Niño Episodes

Periodically, the ETP is affected by a large-scale atmosphere/ocean abnormalities known as an El Niño, characterized by the presence of abnormally- warm surface water. This phenomenon is associated with changes in atmospheric surface-pressure centers over the central and western South Pacific known as the Southern Oscillation. The two phenomena are referred to by some researchers as El Niño-Southern Oscillation. In the 1982-1983 El Niño event, the strongest recorded this century, the ecological make-up of the ETP changed drastically as the equatorial currents first weakened and then became much stronger than normal, while changes in atmospheric circulations brought drought to Central America and heavy rain and floods to the coastal areas of South America. These events led to the appearance of warm-water species in high latitudes, the collapse of several major fisheries, and the enhancement of others. General descriptions can be found in Nicholls (1987) and Graham and White (1988). A review of the 1982-1983 El Niño event and some of its consequences can be found in Anonymous (1983; 1984; 1985), Halpern (1983), Wooster and Fluharty (1985), and Glantz *et al.* (1987); reviews of local physical and biological impacts in the ETP can be found in Anonymous (1985), Arntz *et al.* (1985), Wooster and Fluharty (1985), Jordán (1987), Kwiecinski and Chial (1987), and Vega (1987).

THE PURSE-SEINE FISHERY FOR TUNAS IN THE EASTERN PACIFIC OCEAN

Data sources and sample sizes

The analyses presented in this manuscript are based on data collected by the staff of the Inter-American Tropical Tuna Commission (IATTC) in the course of its research and assessment activities. The three sources of data were: 1) the observer database; 2) the logbook database; and 3) the length-frequency database. The observer database (ODB) contains information recorded by observers assigned to tuna boats as part of the IATTC's Tuna-Dolphin Program (for a detailed description see Anonymous, 1989). The ODB covers the period from 1979 to the present, with varying levels of sampling, generally less than 25% of trips (Table 1). Since 1986, all nations involved in the fishery have cooperated with the program; coverage has increased gradually, and is estimated to have been 41% in 1990. For purse-seine vessels with carrying capacities of 400 or more short tons, the ODB contains data on vessel and gear characteristics, vessel activities, locations of sets, gear malfunctions, environmental conditions, amounts of each species of tuna caught, incidental mortality of dolphins, dolphin rescue operations by crew members, and sightings of marine mammals and sea turtles. Since late 1987, additional data on the characteristics of floating objects (Hall, *et al.*, this volume) and on the quantities and species of bycatch (Arenas *et al.*, this volume) have also been collected. In general, the number of sets in the ODB is substantial. Table 2 shows the number of sets in the ODB with non-zero catches of tunas (yellowfin, skipjack, bigeye, and all tunas) for the 1980-1990 period by the three modes of purse seining (described in the Introduction). Most of the analyses presented in this manuscript are based on data from the ODB and we assume that data from the ODB are representative of the fishery as a whole. Whenever necessary, ODB data were complemented with information from the other databases.

The logbook database (LDB) contains information recorded by fishermen in logbooks provided by the IATTC. It includes, for each set, the location, date, species and weight of fish caught, and type of set, plus other information relevant to fishing operations. Over 90% of all trips are represented in this database, which covers the period from 1959 to the present. This database has been described in detail by Everett *et al.* (1989). Data from 1980 to 1990 from the LDB were used in the analyses presented in this report.

The length-frequency database (LFQDB) contains data on the distribution of length frequencies of yellowfin and skipjack collected by IATTC staff from tuna vessels at the time of loading. Additional data available include information on the areas and dates of capture and the modes of purse seining. Details of the sampling design and a complete description of this database are given by Hennemuth (1957), Tomlinson *et al.* (1992), and Wild (1994b). This database covers the period 1955 to the present. Data from 1980 to 1990 were used in analyses presented in this report.

Definition of tuna catch per set

Not all sets are successful. In many cases, the vessel fails to encircle the fish, or the fish escape after encirclement. An unsuccessful set was defined as one resulting in a catch of 0.5 or less short tons. This is an arbitrary definition; from the operational point of view, even a set with a catch of one or more tons can be considered a failure, if it is likely that most of the school escaped. Table 3 shows the percentages of unsuccessful sets for 1980 to 1990 by set types.

Traditionally, in fisheries science, measures of catch per unit of effort (CPUE) have been used as indices of abundance (*e.g.*, Gulland, 1964; Paloheimo and Dickie, 1964). In the case of tunas, measures such as catch per day at sea or catch per hour (or mile) searched have been used, with various adjustment factors (Pella and Psaropulos, 1975; Allen and Punsly, 1984; Punsly, 1987). Average catch per set is clearly not a measure of CPUE, and is therefore seldom studied. However, it is of ecological interest because it reflects, to some extent, changes in the size of tuna schools. It is not a precise measure because in some cases the fishermen do not catch the whole school, and there are no data available for estimating what proportion was caught (Pella and Psaropulos, 1975). Unless otherwise specified, all catch-per-set values used in the text represent the average catch in successful sets (CSS), computed as the sum of all catches in successful sets divided by the number of successful sets.

In addition, not all the fish captured in the net are loaded into the vessel's wells. Undersized fish of the target species, or fish of other species with low market value, are usually discarded during loading. Table 4 shows the amount of yellowfin caught, the amount actually loaded, and the percentage kept onboard (100 x loaded weight/catch weight) by year for each mode of purse seining. Table 5 shows the equivalent values for all species of tunas combined.

In general, the percentage of the tuna catch that was kept on board exceeded 90%. Prior to 1985, the percentage of the catch kept on board was high, but has since increased, due to the introduction of a differential in the price paid for large and small yellowfin. From the biological point of view, catch weights are more meaningful than loaded weights, and will therefore be used in our analyses.

Another problem in the analysis of time series of catches is that fishing technology evolves, and frequently technical developments (*e.g.*, deeper nets, higher vessel speeds) affect the average catch per set (Pella and Psaropulos, 1975; Allen and Punsly, 1984; Punsly, 1987). However, we believe there are clear changes in the time series, described below, that cannot be explained simply by technological improvements.

Modes of purse seining for tunas

There are three modes of purse seining for tunas in use today: 1) fishing "on logs" (log fishing, log sets), 2) fishing "on schools" (school fishing, school sets), and 3) fishing "on dolphins" (dolphin fishing, dolphin sets). We briefly describe each of these modes of fishing below.

1) Log fishing. The terms "log" and "floating object" are used interchangeably, and refer to any type of inanimate flotsam on the surface of the water, slow-swimming marine mammals (*e.g.*, whales), whale sharks and sea turtles. In this mode of fishing, the fishermen search for floating objects under which a school of tunas is gathered and then set the net around the floating object, thus capturing the fish. A detailed description of the characteristics of floating objects can be found in Hall *et al.* (this volume). Between 1980 and 1990, tree trunks, or logs, were among the most common floating objects observed in the EPO (Table 6), although many floating objects, such as dead marine animals, discarded fishing gear or pieces of plywood, can attract and aggregate tunas (Greenblatt,1979).

Between 1980 and 1990, observed log sets generally yielded less yellowfin tuna than the other two modes of purse seining for tunas, but yielded the majority of skipjack caught in the EPO tuna fishery (Table 7). On average, 10 to 15% of all observed log sets were unsuccessful sets (Table 3). A preliminary analysis of the tuna catch in log sets suggests that the most important factors affecting catch are the location of the set and the time of year (Hall *et al.*, this volume), rather than the characteristics of the log. Logs were often accompanied by a wide diversity of associated fauna including billfish, dorado, wahoo, sharks, trigger fish, other species of large and small fishes and several species of birds (Table 8). As a result, log sets produce a significant amount of non-tuna bycatch generally not present in the other two modes of purse seining (Hall, 1992; Joseph, 1994). A detailed discussion of the faunal aggregations associated with floating objects is given in Arenas *et al.* (this volume).

2) School fishing. School fishing refers to all sets on tunas not associated with floating objects or dolphins. The tunas are detected from signs on the surface of the water (Scott, 1969), visible from the vessel or helicopter. Frequently, a school of tunas feeding, or swimming rapidly

close to the surface, will disturb the water's surface; their presence may also be betrayed by a flock of birds, or the fish may be seen jumping. The percentage of unsuccessful school sets was two to three times those for the other two modes of purse seining (Table 3). School sets are more likely to be unsuccessful because the school is more likely to separate into smaller groups of tunas during the chase and encirclement phases of the set.

3) Dolphin fishing. This mode of fishing takes advantage of the association of large yellowfin tuna with herds of dolphins. By detecting the easily-visible, surface-swimming dolphins, approaching and chasing them, and then maneuvering them into the net, the fishermen capture the tunas; the tuna are retained and the dolphins released (Coe and Sauza, 1972; Francis *et al.*, 1992). In dolphin sets, the tuna school is so closely associated with the dolphins that it stays with them throughout the chase and encirclement phases of the set. The incidental dolphin mortality resulting from this mode of fishing has given rise to the "tuna-dolphin problem," which has played a major role in the evolution of this fishery (Perrin, 1968, 1969; Francis *et al.*, 1992; Joseph and Greenough, 1979; Joseph, 1994). Dolphin sets yielded the majority of yellowfin caught in observed sets (Table 6) and accounted for over 50% of the number of sets (Table 1). On average, between 11 and 15% of dolphin sets were unsuccessful (Table 2).

Herds of dolphins associated with tunas can be unispecific or multispecific. Between 80 and 90% of the observed sets (and of the catch) were made on herds containing spotted dolphins (*Stenella attenuata*), with over 50% of the sets (and catch) involving pure herds of spotted dolphins (Table 9). Spinner dolphins (*S. longirostris*) were also found in association with tunas in mixed herds with spotted dolphins. Spinner dolphins have been divided into two main stocks: eastern spinner dolphins and whitebelly spinner dolphins (Perrin, 1990; Perrin *et al.*, 1991). The relative proportions of the sets on these two stocks varied over time; in some years the ratio of observed sets on spotted and whitebelly spinner herds to those on spotted and eastern spinner herds was 4 to 1, while in other years it was less than 0.5 to 1. The third important species is the common dolphin (*Delphinus delphis*). Several other species of dolphin were found associated with tunas, but much less frequently. These included the striped dolphin (*S. coeruleoalba*), the rough-toothed dolphin (*Steno bredanensis*), the bottlenose dolphin (*Tursiops truncatus*), and Fraser's dolphin (*Lagenodelphis hosei*). The spatial distributions of spotted, spinner, and common are shown in Figure 7. The spatial distribution of dolphin stocks has been reviewed by Perrin *et al.* (1983), Au and Perryman (1985), Scott and Chivers (1990), Reilly (1990), Dizon *et al.* (1994).

The proportion of observed successful sets for all tunas that were dolphin sets varied from a low of 46% in 1980 to a high of 82% in 1985 (Table 1). The average number of observed successful sets for all tunas that were dolphin sets for the 1985-1990 period is considerably greater than for that of 1979-1984, the main reasons for this being that (1) higher prices were paid for large yellowfin, which are caught in dolphin sets, than for small yellowfin and skipjack, which are caught in school and log sets and (2) large yellowfin were unusually abundant, due to reduced fishing effort during 1980-1984. Most of the increase in dolphin sets was at the expense of log sets, which decreased from a maximum of 35% in 1982 to a minimum of 8% in 1985 (Table 2); school sets showed no trend.

The proportion of the observed catch of yellowfin taken in dolphin sets varied from 86% in 1985 to 57% in 1988 (Table 7). In most recent years the average was about 75%, as compared to 65% in earlier years. This increase in observed catch in dolphin sets was largely at the expense of log sets, which declined over the same period from about 20% to less than 10% of the catch (although this trend appears to have reversed in 1990).

Spatial and temporal distributions of sets

The spatial distributions of individual purse-seine sets on floating objects, schools, and dolphins from 1980 to 1990 are presented in Figure 8. Sets on floating objects occurred predominantly in the coastal and inshore waters of Central America. However, along 10°N fishing on logs extended offshore from the coast to 145°W. There was very little log fishing off most of the mainland of Mexico or the Baja California peninsula, where there are few rivers and forests, and hence few logs.

The spatial distribution of school sets (Fig. 8) is similar to that of floating objects, with the exception that there was only limited school fishing offshore along 10°N. Most sets were made in coastal areas, particularly along the coasts of Colombia and Ecuador, and especially in and near the Gulf of Guayaquil. There was also an important school-fishing area off the west coast of Baja California and at the entrance of the Gulf of California. The area of high concentration of school sets off Central America was somewhat similar to the area where most log sets were made, but the main school-fishing area was even more restricted to the coastal areas and extended further south along the Ecuadorian coast.

While the overall distribution of sets on dolphins (Fig. 8) is similar to that of log and school sets in the coastal regions, and similar to log sets offshore along 10°N, the dolphin-fishing area was slightly larger, and the areas of high exploitation were quite different. The number of sets was also greater. There were two main areas of intense exploitation by dolphin fishing: one extended from the coast to 112°W along 10°N, and the other lies offshore, centered at about 8°N and 128°W. There was also a narrow area of high concentration of dolphin sets from the central coast of Mexico to the entrance to the Gulf of California. Other smaller areas of exploitation occurred near the Costa Rica Dome, at the Revillagigedo Islands, southwest of Baja California, and off Peru at about 12°S. It appears that few purse-seine sets of any type occurred between 6° and 7°N and 115° and 120°W.

Annual variation

Table 10 shows the numbers of 1-degree areas in which the various fishing modes were used during each year of the 1980-1990 period. The fishery on dolphins was the most widespread of the three modes. The area with school sets was comparable in size to the area with log sets and both were roughly comparable in size to the area with dolphin sets prior to 1983. After that, however, the area with dolphin sets remained approximately constant, while the areas with the other two set types, log sets in particular, decreased in size. In recent years, the dolphin-fishing area was twice as large as those of the other two set types.

Log sets: Figure 9 shows the annual distribution of log sets. Consistent with the trend in Table 10, the charts show a general decreasing tendency in the area exploited by log sets. The coastal areas of Central America (in particular, the Panama Bight and the Gulf of Tehuantepec) were heavily exploited by log fishing in all years. The offshore fishing area, where the dolphin fishery traditionally took place, was occasionally productive for log fishing prior to 1984.

School sets: Figure 10 shows the annual distributions of school sets. Although the school-fishing area and the log-fishing area overlapped considerably, the annual patterns were quite different. In general, the annual variability in spatial distribution was greater for school sets than for log sets. The western coast of Baja California and the mouth of the Gulf of California were consistently fished for schools, and were heavily exploited in 1980-81 and 1989. The Gulf of Guayaquil was also consistently fished for schools, even in years with low overall exploitation. Except for these two areas, no clear patterns are evident: areas of importance in some years were only lightly exploited in other years. The offshore region was seldom exploited by the fishery on schools, although 1980, 1981 and 1983 were exceptions.

Dolphin sets: Figure 11 shows the annual distribution of dolphin sets. As indicated in Table 10, the area exploited by dolphin sets was greater than that for either log or school sets. Two readily apparent and generally consistent characteristics are the lack of high numbers of sets in the coastal areas, especially the Panama Bight, and the significance of the offshore region (both in contrast to log sets and school sets). However, the coastal and nearshore regions became more important in recent years: during 1985 many dolphin sets were made off the Gulf of Tehuantepec, and in more recent years more sets were made in the productive nearshore areas along 10°N and fewer sets south of 5°N.

Seasonal variation

Table 11 shows the monthly frequency of observed sets by mode of purse seining. For log and school sets, peak numbers of sets by month occurred in the first part of the year. However, for all three modes of fishing, no clear seasonal trends are apparent. Dolphin sets accounted for between 51 and 70% of the sets observed each month, and log sets for between 11 and 19%.

Log sets: Figure 12 shows the spatial distribution of log sets by month. Eight well-defined area-season strata for log fishing (Fig. 13) can be identified:

1) Northern Panama Bight. Log fishing intensity was high in this area from April to August, with a peak during May-June, although some log fishing took place in this area during most of the year. These data are in agreement with earlier observations of tuna abundance which showed that tuna were most abundant in the northern part of the Panama Bight in April and May (Forsbergh, 1969).

2) Southern Panama Bight. This was one of the most important areas for log fishing, in terms of number of sets. The log-fishing season in this area extended from April to December, but was most intense from June to August.

3) Offshore of Costa Rica. Fishing on logs occurred in this area throughout most of the year, but was most intense from February to May, and in November.

4) Offshore of Nicaragua. This area was heavily exploited during April, and particularly during May, and was fished only sporadically during the rest of the year, although there was a slight increase in fishing activity during October and November.

5) Offshore of the Gulf of Tehuantepec. The log-fishing season in this area is short, beginning in January and peaking in February and March.

6) South of the Revillagigedo Islands. Log-fishing takes place in this area only during March and April.

7) Offshore. The number of sets made on logs in this area is low relative to the number of sets made on dolphins, but during June-August, the number of log sets made in the area is greater than in other months.

8) Offshore of Peru. Log-fishing in this area took place primarily between December and April.

School sets: Figure 14 shows the spatial distribution of school sets by month. The pattern of fishing seems to be more scattered during the winter. The principal areas were (Fig. 15) as follows:

1) West coast of Baja California. Fishing intensity was greatest in this area between May and August. A moderate number of sets occurred here between September and December.

2) Mouth of the Gulf of California. This area was fished heavily for unassociated schools of tuna between December and June, with a peak in fishing intensity in March.

3) Off the Gulf of Tehuantepec. This area extends further from the coast than any of the other areas in which the number of sets on unassociated schools was high. It was most productive at the beginning of the year, particularly during February and March.

4) Coast of Central America. The school-fishing season in this narrow area peaked between March and May, following the marked peak of the fishery off the Gulf of Tehuantepec (see Forsbergh, 1969).

5) Gulf of Panama and Panama Bight. Fishing intensity on unassociated schools of tunas was high in this area throughout the year, particularly from March to May (see Forsbergh, 1969). As noted above, this area is also heavily fished year-round for tunas associated with floating objects.

6) Gulf of Guayaquil. This area is one of the most important fishing grounds for school fishing. Fishing intensity was concentrated around the mouth of the Guayas River, where log and dolphin sets were rare. The area was heavily fished from September to December, with a peak in the number of school sets during October and November.

7) Offshore. The numbers of school sets are less than the numbers of log sets in this area. School fishing in this area was primarily important during June to August.

Dolphin sets: Figure 16 shows the spatial distribution of the number of dolphin sets by month, and Figure 17 shows the main dolphin-fishing areas. In general, the total area exploited increased during May through August with the addition of offshore regions. The principal area-seasons were, in descending order of importance (Fig. 17):

1) Offshore off southern Mexico and northern Central America. Sets on dolphins were frequent throughout the year, with a low between May and July, coinciding with the peak in the Offshore area (see below). Additionally, fishing intensity was low in this area between December and January.

2) Offshore. This area was heavily exploited during the northern summer, as was the case with log and school fishing, particularly from June to August, although there was some fishing from May to October.

3) Northwest coast of Mexico. Fishing took place throughout most of the year in this area, and most of the sets were made on common dolphins. Effort on dolphins has decreased in recent years in this area.

4) Offshore of Costa Rica. This area was exploited during the first half of the year, with a peak in the number of dolphin sets occurring between January and March. The fishing intensity on dolphins has decreased notably in recent years.

5) Revillagigedo Islands. Fishing intensity in this area was high from April to August, with a peak in the number of dolphin sets occurring between April and June.

6) Southern Area. The number of dolphin sets in this area was high from November to March, with a weak peak during December through February.

The seasonality in the spatial distribution of dolphin sets resulted in a seasonal component in the species composition of dolphin herds captured in dolphin sets. While observed sets on pure spotted dolphin herds were predominant in every month of the year, with relatively little variation, observed sets on mixed herds of spotted and eastern spinner dolphins, and spotted and whitebelly spinner dolphins showed greater variability (Table 12). The coincidence of the lowest value for the former with the peak for the latter in June-July reflects the movement of the fleet to the offshore area during May-August. Fishing intensity on common dolphins, as a proportion of the total number of sets on dolphins, was greatest in April-May and lowest in August-September (Table 12).

Spatial and temporal distribution of catches

The patterns for yellowfin in log sets (Fig. 18) and school sets (Fig.19) were similar, with high CSSs in the coastal area and at the southern edge of the fishery. CSSs in school sets were also high south of the tip of Baja California (Fig. 19). The pattern of catches in dolphin sets (Fig.

20) followed the same overall distribution, with the exception of the coastal area off Central America.

The patterns for skipjack in log sets (Fig. 18) and school sets (Fig. 19) were also similar, with the largest areas of high CSSs occurring in a band along roughly 0-5°N from the coast to 110°W and from south of Baja California to about 10°N-125°W. These patterns are clearly different to those for yellowfin, for which high CSSs tended to occur in more coastal waters. The area of the fishery south of 10°S between 80° and 90°W produced high CSSs per sets of both species.

Annual variation

Figure 21 shows that the CSS of yellowfin tuna in school sets was relatively stable between 1980 and 1982; it started increasing during 1983 and continued until 1985, when it averaged close to 30 tons per set. It then declined from 1985 to 1988, and leveled off in 1989-1990 at around 20 tons per set. School sets were the most productive type of set when successful, but as noted in Table 2, they also had the highest failure rate. The pattern for the CSS of yellowfin tuna in dolphin sets and log sets is similar to that for school sets, but the increase and the decline started one year later, in 1983 and 1986, respectively. Dolphin sets produced greater average catches than log sets in almost all years; both averages show increases between 1983 and 1986.

In the case of skipjack tuna (Fig. 22), log sets produced the greatest catches per successful set (CSSs), reaching a maximum of almost 38 tons in 1985. A marked increase during 1982-1985 was followed by a stabilization at 24-29 tons in 1986-1990. School set CSSs increased between 1981 and 1985, declined until 1988, and then leveled off. Dolphin sets showed the lowest values, ranging from 3 to 7 tons, with no clear pattern. The similarity of the fluctuations in CSSs for skipjack and yellowfin may indicate that the CSS of both species was affected by factors other than abundance, for example, by prey abundance or patchiness. The R^2 from a least-squares fit of CSS of skipjack to CSS for yellowfin was 0.79 for log sets and 0.90 for school sets.

Seasonal variation

In order to describe the seasonal distribution of CSS, we used monthly CSS data for 10 selected areas (Fig. 23), chosen on the basis of the spatial characteristics of the fishing modes, described above. CSS data were pooled across mode of purse seining because we were attempting to describe the change in average tuna school size, regardless of the method of capture. Table 13 shows, for each area, the number of successful sets and the corresponding CSSs for yellowfin and skipjack.

Area 1 (south of Baja California). Yellowfin: the number of sets was greatest in March to May, and least in December and January. CSS values were high in April to July (16.3-17.5 tons). Skipjack: the number of sets also peaked in April-May, with the lowest values in August-September and December-January. Highest CSS values were in April (33.9 tons), September (31.0 tons), July (29.8 tons), and May (28.8 tons).

Area 2 (offshore dolphin area). Yellowfin: sets were concentrated in May to August, with June and July having by far the greatest values. There was practically no fishing between December and April. Highest CSS values are in May (24.4 tons) and June (21.7 tons), with another peak in September (20.3 tons) and October (22.9 tons). Skipjack (not a main target species in this area): sets followed a similar pattern. The highest CSS values occurred in October (17.5 tons) and November (17.4 tons).

Area 3 (inshore dolphin area). Yellowfin: sets were frequent in February- April, and also in September-November. Greatest CSS values were in February (17.5 tons) and August-October (16.5-17.4). Skipjack: the peak period was also February-April, with the highest CSS value in March-April (19.1 and 18.6 tons, respectively).

Area 4 (Central American coast). Yellowfin: number of sets was high from February to July, with a peak in March and another in November. CSS values were high during May to September (22.1-23.9). Skipjack: sets were frequent in February-March and in September-November. Highest CSS values were in August to October (18.8-24.0 tons).

Area 5 (centered on 1°N and 125°W). Yellowfin: very little effort, concentrated in March-May, with CSS of 20-25 tons. Skipjack: insufficient data.

Area 6 (centered on 1°S and 108°W). Yellowfin: very little effort, concentrated in November-February, peaking in December, when CSS values reached 26.1 tons. Skipjack: insufficient data.

Area 7 (centered on 9°S and 95°W). Yellowfin: very little effort, with the peak in January, followed by December; CSS values were 17.5 and 21.7 tons, respectively. Skipjack: insufficient data.

Area 8 (centered on 12°S and 85°W). Yellowfin: low number of sets concentrated in December-February. CSS was very high in December (35.5 tons) and lower in January-February (22.3 and 20.0 tons, respectively). Skipjack: some sets, especially during January and March, with high CSS (32.0 and 39.0 tons, respectively).

Area 9 (off Guayas River). Yellowfin: sets concentrated in August to December, peaking in October, with CSSs of 15.9-21.9 tons, highest in August. Skipjack: sets concentrated in September-December, with peak in October; CSS values ranged from 8 to 14 tons.

Area 10 (Panama Bight area). Yellowfin: sets frequent in March-May, with peak in May. Highest CSS values were in November (19.8 tons) and September (18.6 tons). Skipjack: number and distribution of sets similar to yellowfin; CSSs values were highest in August-November (26.1-35.4 tons), with a peak in August.

Summarizing, the major features for the fishery for yellowfin are : a) effort moves offshore during May-August; b) effort moves to the southern edge of the fishing area in November-February; c) effort in the inshore area off Mexico is high all year except during May-August, when the effort moves offshore; d) effort is high off Central America all year, with a slight increase during February-August and an isolated peak in November; e) effort in the Panama Bight has two peaks, the main one in March-May and the second in October-December; f) effort in the area off Ecuador shows a clear seasonality, with the peak during August-December.

Tuna catch and dolphin herd type

The CSSs of yellowfin tuna on the various types of dolphin herds found in the EPO during 1980-1990 are shown on Figure 24. Sets on mixed herds of offshore spotted and whitebelly spinner dolphins were the most productive, averaging more than 14 tons in 1980-1983, and increasing to an average of close to 25 tons in 1984-1990. These averages are about one-third higher than those for sets on herds of common dolphins and on herds composed only of spotted dolphins, which were the least productive. Sets on mixed spotted and eastern spinner herds showed intermediate values. Because these species or stocks of dolphins are similar in size and swimming speed, two possible explanations for the differences in CSSs among stocks are 1) spatial differences (some of the species or stocks are found offshore while others are more coastal) and/or 2) differences in average herd size (if the "attraction" of the herd is a function of its size).

Figure 25 shows average herd size (average number of animals in the net when the net was pursed) for the main herd types during 1980-1990. The most productive herd type (spotted and whitebelly spinner) also showed the greatest average size, varying from about 800 in 1980-1983 to about 1100 in 1989-1990. Mixed herds of spotted and eastern spinner dolphins and pure herds of common dolphins were similar in size, and remained stable at around 500-700 animals. Pure herds of spotted dolphins had the lowest average size, usually 300-400 animals, and also remained fairly stable during 1980-1987, with a possible increasing trend in recent years.

In order to explore the possibility that herd size determined average tuna catch, the relationship between these two factors was examined. Herd size for each of the main herd types discussed above were grouped into the following intervals: < 300, 300-600, 601-900, 901-1200, 1201-1500, 1501-1800, 1801-2100, and > 2100 animals. Figure 26 shows the CSS of yellowfin for the main herd types by average herd group size (average of the herd sizes within each size interval), pooled over years. CSSs were very similar for similar-sized herds of all stocks except common dolphins, which produced much lower CSSs. Differences in herd size could therefore explain most of the differences in CSSs among the species and stocks, except common dolphins. The R^2 values between CSS of yellowfin and herd size for the various herd types were: pure spotted dolphins, 0.92; spotted and eastern spinners, 0.89; spotted and whitebelly spinners, 0.96; and common dolphins, 0.69. The distribution of sets on common dolphins was more coastal than that of the other species, and occurred in three discrete areas (Figs. 27-30), which may explain the remaining difference. It should be noted that the average offshore CSS figures may be slightly biased, due to the fact that only large vessels fished offshore, whereas both large and small vessels fished in the coastal areas. However, the predominance of large vessels was so great that bias, if it exists, should not be important. Figure 31 shows the relationship between herd size and CSS of yellowfin, using yearly averages for 1980-1990 (a composite of Figures 24 and 25). These data appear to support the hypotheses that CSSs yellowfin increased with average dolphin herd size.

Figures 27-30 show the spatial distribution of sets on the main species or stocks of dolphins. Sets on herds of pure spotted dolphins occurred throughout the area, but were more frequent in the inshore and northern regions. Sets on herds of spotted and eastern spinner dolphins were common in the inshore area; records of sets on this combination of species south of the equator were probably the result of incorrect stock identifications, since the southern boundary for the eastern spinner stock of spinner dolphins is at the equator (Fig.7). Herds of spotted and whitebelly spinner dolphins were set on throughout the area, but predominantly offshore. Sets on common dolphins occurred in three distinct small areas relatively close to the shore.

Size of yellowfin tuna caught and set type

Figure 32 shows the percentage length-frequency distributions, in numbers of fish, of yellowfin caught in the different types of sets during 1980-90. The fish were measured from the tip of the snout to the fork of the tail. Sets on logs caught the smallest tunas (mode ~ 45 cm). Sets on schools show a similar length-frequency distribution, with a slightly larger modal size (between 50-70 cm). Since the spatial and temporal distributions of these two types of set were roughly similar, the similarity of the size distributions of the catches supports the idea that the same age classes were caught in both types of sets. Dolphin sets produced the largest yellowfin caught by the surface fishery. In general, yellowfin greater than 90 cm in length were caught in dolphin sets in greater proportions than in either school or log sets, and almost all the catch of yellowfin greater than 120 cm was taken in dolphin sets. Conversely, tunas of less than 60 cm in length were caught in significant numbers only in log and school sets. It is possible that smaller yellowfin do not associate with dolphins at all, or that only the larger fish can keep up with the dolphins either at cruising speed (Edwards, 1992) or perhaps at their escape speed when threatened. Another possibility is that the diets of large yellowfin and dolphins are similar, and that small yellowfin have different requirements that they cannot satisfy with the types of prey the dolphins seek.

Considering the frequency distributions as percentages of total weights caught (Figs. 33-34), there is a large amount of overlap, but the modes are clearly separated. Figure 33 shows the size distribution by weight of yellowfin in the three types of set during 1980-90. The mode for log sets was around 40- 50 cm, and for school sets between 60 and 75 cm. For dolphin sets the mode was around 130-140 cm, but the distribution is flat from about 90 and 120 cm.

It is interesting to compare the distributions in Figure 33 with those of the previous decade, 1969-79 (Fig. 334), when the fishery was predominantly coastal, and was expanding from north to south. The mode for log sets was slightly higher in 1969-1979 than in 1980-1990, probably a reflection of the fact that the fishery had not reached in any significant way the southern areas where most of the small yellowfin tuna caught in log sets have been found. The length-frequency distribution for school sets is much flatter for the 1980-1990 period, probably a result of a broader distribution of the sets. Dolphin sets show two clear modes in 1969-1979, compared to one asymmetric mode in 1980-1990. It is possible that the predominance of offshore sets in 1979-1988 caused the disappearance of the lower mode, which probably reflected fish caught in coastal sets.

It may be that the length-frequency distributions of the tunas caught in the three types of sets simply reflect the predominance of different types of sets in different areas: log sets tended to be more coastal than dolphin sets, and school sets fell between the two, although their geographic range was closer to that of log sets. In order to answer this question, we compared the length-frequency distributions of all set types in two selected areas, denominated A1 and A2. Area A1, which stretches from 5°N to 15°N between the coast and 100°W (area 5, Fig. 35), was intensively exploited with all three types of sets. Figure 36 shows the length-frequency histograms for the three types of sets in Area A1. The mode was around 45 cm for log sets, between 45 and 55 cm for school sets, and between 70 and 100 for dolphin sets. Most of the fish more than 100 cm long were caught in dolphin sets. In Area A2, which lies north of 20°N (Areas 1 and 8, Fig. 35), the mode was at 40-45 cm for log sets, at 50-60 cm for school sets, and at 55-80 cm for dolphin sets (Fig. 37). Not many yellowfin greater than 110 cm were caught in this area, but the larger fish were nonetheless caught in association with dolphins. These differences within areas in the length-frequency distributions of yellowfin caught in log, school, and dolphin sets support the conclusion that larger tunas associate with dolphins, regardless of the spatial distribution of the different types of sets.

Is there any difference in the sizes of the tunas associated with the various species or stocks of dolphins? To answer this question, we compared the length-frequency distributions of yellowfin caught in association with spotted and common dolphins in Areas A1 and A2; spinner dolphins were not included because in most cases they are found in mixed herds with spotted dolphins. The category "common" dolphins includes common dolphins and whitebelly spinners, although in areas A1 and A2, whitebelly spinner dolphins are not abundant (Fig. 7). This comparison within areas eliminates differences in geographical distribution among different species and/or stocks of dolphins. For both areas, the length-frequency distributions are broadly similar (Figs. 38-39); the ranges were the same and, if we ignore some spikes in the data, the most frequent sizes were the same.

Other factors, such as cannery preferences for different sizes, the condition of the stock, and the evolution of fishing gear, also play a role in the length-frequency data. One major problem with the LFQDB database is that the data were obtained from landings, and thus were not representative of the total catch. For instance, years in which more (presumably smaller) fish were discarded at sea will tend to have distributions biased toward the larger sizes.

Another comparison of interest (Fig. 40) is between the length-frequency distributions of yellowfin caught with purse-seines in dolphin sets and those caught with longlines. The average size caught with longlines was greater than that caught on dolphins, indicating perhaps that these larger yellowfin tend to swim at greater depths (Suda and Schaefer, 1965).

Diel patterns

Searching effort on dolphins and on schools occurred more or less uniformly throughout the day, and is limited only by weather and visibility. Figure 41 shows the frequency of the different types of sets by time of day. The slight dip around midday in the distribution of dolphin sets probably corresponded to reduced watches at lunch time (especially by helicopter crews). Sets on logs were made predominantly early in the morning, most of them before sunrise. The floating object is frequently detected the previous afternoon or evening, either visually or by contacting a radio buoy attached to the object. The vessel spends the night close to the object, and the set is made early the next morning. Many fishermen believe that if the set is delayed the fish will leave the log, which provides some circumstantial evidence in support of the idea that the association is nocturnal and that it is broken in the morning when the schools start foraging. This is further supported by the data shown in Figure 42, which indicate that floating objects were routinely observed (*i.e.* inspected for the presence of tuna schools) during the day, but that this seldom led to sets. In addition, Yabe and Mori (1950) found that tunas aggregated under floating objects in the evening. Given that these two modes of purse seining catch similar sizes of tunas, a possible explanation for this is that tunas rely heavily on vision when seeking prey, and may cease foraging at the end of day and seek (or merely encounter) a drifting object with which to remain until daylight returns.

The sizes of the dolphin herds and tuna schools may also exhibit diel variation. Scott and Cattanach (1998) studied tuna catches by time of day in log, school, and dolphin sets. Catches in school sets peaked early in the morning and declined during the rest of the day; in contrast, catches in dolphin and log sets increased throughout the day, reaching a maximum at about 4 p.m. Mean herd size patterns for spotted dolphins and spinner dolphins were similar, increasing during the day, peaking in the afternoon, and declining in the evening. This pattern of increasing group size during the daytime is believed to provide better protection from predators at these times, although the effects of diel changes in prey distribution cannot be discounted (Scott and Cattanach, 1998). Their data on school size supports the idea that yellowfin association with logs is nocturnal. Scott and Cattanach also examined the diel pattern of the ratio between tons of tuna caught and number of dolphins in the herd, and found that this ratio was flat during most of the day, but climbed steeply in the evening. This may indicate that the association with dolphins could loosen or break during the late evening, perhaps because dolphin herds fragment and the tunas tend to remain together, associating with one of the fragments of the original dolphin herd, or that tunas aggregate under dolphin herds late in the evening, as they do with logs.

Repeated sets on the same floating object

To investigate renewal rates at logs, data from the ODB on catches of tuna associated with floating objects in which two or more observations had been made on the same object were analyzed. The majority of these objects had two observations (or sets); only 7 objects were set on 10 or more times, and the maximum number of sets for a single log was 15. Observations were divided into two types: a "sighting," in which a floating object was observed but no set was made, and a "set," in which the net was set around the object. Figure 56 shows the frequency distribution of sightings and of sets for these objects.

There were several problems with our data collection system: 1) not all boats carried observers so, we cannot know whether an object was set on by another boat between visits from vessels with observers; 2) we have attempted to match objects described by different observers, but some mismatching may have occurred; and 3) objects can change: for example, two separate objects may be tied together by fishermen. It is unlikely that two sets would be made in one day on the same floating object by different vessels, given that most log sets were made very early in the morning and, on average, lasted over three hours. However, for any given object there was no information prior to the first record, after which there may be days without any information, days with visits and no catch, and days with visits and catch. A visit during which tuna were not found is a valuable data point, equivalent to an unsuccessful set, but the days without any information severely limit our ability to draw conclusions from these data. In order to minimize these problems, a subset of data was selected which included only complete sequences of sets made on consecutive days. If more than one set was made on the same object during the same day, the catches were added together and considered a single set. The values in Figures 43-47 and Tables 14-17 were calculated from this group of data, and with the exception of Table 15, represent data for both successful and unsuccessful sets.

There was a decline in the average total catch and in the catches of individual species in consecutive sets on the same object (Figs. 44-47 and Table 14), with a drop of 33% in total catch between the first and second sets. It should be noted that the average catch on a floating object may be overestimated from data for repeated sets, because logs with good catches were more likely to be revisited and a set is more likely to be made around a log with a large amount of fish near it than around a log with only a few fish near it. The changes in school size were equally evident when only CSS set was considered (Table 15). Our results are in agreement with the finding of others. Pallarés *et al.* (1989) followed seven consecutive sets on the same object in the eastern Atlantic. The catches fluctuated considerably, but appear to decline after the first three days. Hallier (1985, 1991) found that in 268 sequences of sets in the Indian Ocean the average total catch declined over successive sets, from 56 tons in the first set to 19 in the sixth.

The replacement of skipjack by yellowfin, described by Hallier (1991), was also seen here (Tables 16 and 17). Skipjack, dominant in the first two sets, was virtually absent by the fifth. The fact that the proportions in successive sets changed may indicate that either 1) fishing was depleting the dominant competitor for the logs (presumably skipjack) and allowing yellowfin to occupy the empty "territory," or 2) fishing in the vicinity of a log selectively removed more skipjack than yellowfin, and the catches on the log reflected the change in local species composition. For the removal to be selective, either the fishermen must fish selectively on skipjack, or skipjack must be easier to detect or catch than yellowfin. The explanation of this replacement is considerably complicated by the fact that mixed schools of both species were common. The changes in the proportions of the different types of schools are shown in Table 17. Sample sizes for the fifth day in the sequence were low, but the increase in the proportion of pure yellowfin schools and the decrease in pure skipjack schools are quite clear.

DISCUSSION

The three main components of the associations presented are tunas, dolphins, and floating objects. These components are not homogeneous: there are several species of tunas and dolphins, and many types of floating objects, but for simplicity this heterogeneity will be disregarded for now. Our main interest is not how the environment affects the distribution of tunas or dolphins, but how the environment plays a role in the development and stability of the associations between tunas and floating objects and between tunas and dolphins. We will, however, briefly describe the interactions postulated between the environment and the distributions of tunas and dolphins, discuss the effect of the environment on the distribution of floating objects, and comment on the impact of environmental factors on the associations *per se*.

Environment and tunas

The distribution of adult tunas in the EPO is affected by sea-surface temperature and the depth of the thermocline, the depth of the upper boundary of the oxygen-minimum layer, and the extent and distribution of oceanic fronts and other areas of convergence and divergence (Blackburn, 1965; Cole, 1980; Sund *et al.*, 1981; Ortiz and Guzman, 1982). Attempts have been made to describe tuna habitats in the EPO based on isotherm distribution and tuna physiology. Sharp (1978) believes there is a high correlation between tuna fishing (purse seining and longlining), the depth of the mixed layer, thermal structure, and oxygen concentrations (more important for skipjack). Other authors have proposed correlations between tuna distribution and water transparency, salinity, wind stress, and currents (used for active and passive movement) (Seckel, 1972; Williams, 1972; Sund *et al.*, 1981).

Environment and dolphins

Dolphin habitats also seem to be correlated with the environment, in particular with the depth of the mixed layer and the distribution of water masses (Au and Perryman, 1985; Reilly, 1990). It is unlikely that the oxygen- minimum layer has a direct effect on dolphins, but it may affect the distribution of their prey, particularly in coastal waters (Au and Perryman, 1985; Polacheck, 1987). Spotted and spinner dolphins seem to prefer the major divergence zone of the Tropical Surface Water Mass (Figure 4), with its characteristic shallow thermocline along 10°N and relatively minor annual variation in sea-surface temperature. Common and striped dolphins appear to prefer equatorial and subtropical waters with seasonal coastal upwelling and relatively large changes in sea-surface temperature and thermocline depth (Reilly, 1990). Recent ecological studies (Fielder and Reilly, 1994; Reilly and Fiedler, 1994) based on data from assessment cruises for dolphin stocks are improving our understanding of dolphin habitat distribution and interannual changes, and of the effect that factors such as the El Niño have upon them.

Environment and floating objects

The floating objects found in the EPO can be classified into two main types, those of natural origin and those resulting from human activities. Most natural floating objects originate in the coastal zone, so the first connection with the environment required is a source for the objects. The most common sources are areas of vegetation, such as forests and mangrove swamps; waters off desert coasts (*e.g.*, Baja California) are unlikely to have logs. Another source is the marine forests, or kelp beds, but these are much less significant. The only natural objects that can originate in the open sea are whales, whale sharks, and sea turtles, alive or dead. Most objects which are the result of human activity also enter the ocean along the coastline; these include such things as cut trees, debris from cities, and lost or discarded fishing gear and other equipment. Some of these objects can also originate in the open sea on the fishing grounds or along shipping lanes.

Natural and human factors influence the number of objects entering the ocean: production from forests and swamps can change from year to year, and logging, erosion, and pollution have intensified over the years. Most of these trends probably lead to an short-term increase in the number of floating objects produced, which in turn may affect the tuna populations and the fishery in unknown ways. In the longer term, extensive deforestation and other factors may perhaps lead to a decrease in the number of floating objects.

There are two phases in the transport of floating objects: 1) transport to the ocean, and 2) circulation in the ocean. Transport to the ocean requires the presence of river systems, and they in turn require abundant precipitation. The major sources of floating objects in the EPO coincide with areas of water surplus. Environmental factors may affect transport through modifications of the precipitation patterns: droughts and floods probably play a major role. Human activities can also affect transport through flow control measures, dams, and dredging. Also, deforestation tends to reduce precipitation.

Results of a simulation study of trajectories of floating objects in the EPO (García *et al.*, this volume) suggest that the coastal currents may retain floating objects in the coastal zone for quite some time. This pattern is important because the objects, and therefore any organism associated with them, would be retained within the rich coastal environment. Because El Niño events (such as those of 1982-83 and 1986- 87) affect the current patterns in the EPO, retention of floating objects in the coastal zone during such periods may be affected, which might, in turn, affect the distribution of the fishery for tunas on floating objects, as well as its intensity. Some floating objects must eventually become waterlogged and sink; those that remain afloat may eventually leave the coastal zone on some of the westward currents, and may aggregate in frontal areas. The objects and all their associated fauna will drift with the water mass, rich in nutrients and organic matter. This is likely to confer an adaptive advantage to the organisms which associate with the floating objects, by placing and keeping them in a relatively rich environment. In order to analyze this issue properly, it would be necessary to obtain estimates of the number and locations of floating objects present in the EPO at various times of the year. Such estimates are not available and would be difficult to obtain. However, estimates of the relative abundance of floating objects, which are more tractable, may be available shortly to allow a more thorough analysis.

Environment and fishing operations

The number of sets in an area or season is directly affected by the environment: purse seining and longlining rely on weak currents and good weather. This is the most likely explanation for the low level of fishing effort of either type along the Equator; the strength of the Equatorial Undercurrent may lead to fishing gear deployed in the area being lost (Seckel, 1985). Fishing in the offshore areas west of 120°W is most intensive during May-August, when the weather is favorable for fishing; during a good part of the rest of the year the weather makes fishing operations more difficult. The depth of the thermocline also affects the retention of fish caught in purse-seines: deeper nets are needed in areas with deeper thermoclines (Green, 1967).

The distribution patterns of both purse-seining and longlining effort can thus be explained partly in oceanographic terms. Log fishing is predominantly coastal from April to August, and is concentrated along the Central American coast, enriched by seasonal upwelling and, to a much lesser extent, by contributions from the continent. School fishing is also coastal, and covers an area similar to that for log fishing, but even more restricted to the coast, with concentrations off the Gulf of Tehuantepec and along the coast of Central America. There is some school fishing offshore, but smaller coastal areas such as the Gulf of Guayaquil and regions without large natural log sources (the mouth of the Gulf of California and the west coast of Baja California) are more important. Dolphin fishing is most common in areas where the thermocline is shallow, productivity is high due to the presence of fronts, and temperature variations are minor. The areas of high concentrations of dolphin fishing show almost no overlap with the more coastal areas for log and school fishing. The exception is the productive offshore area where, although dolphin fishing is by far the most important fishing mode, all three modes are common from July to September in some years. However, the fishing season in that area is determined by the weather patterns, which allow fishing only a few months of the year, and not by any known particular seasonality of the biological components.

Longlining occurs mostly south of 10°N. None of the areas in which large yellowfin are caught on longlines overlaps with the major purse-seine fishing grounds, with the exception of a small area off Central America. Although yellowfin catch is relatively uniform in the northern band of the longline fishery, defined above, effort and catch are usually low. Thus, most of the yellowfin caught in the Japanese longline fishery during 1971-1980 were not taken in coastal areas or the area along 10°N, where most of the purse-seine fleet fished. Kume and Joseph (1969) and Shingu *et al.* (1974) found that yellowfin catches along 10°N were higher west of 120°W during 1964-1966 and east of 105°W during 1967-1970.

Environment and the tuna-log association

The association with logs is not a requirement for the tunas. In some ocean areas, such as the Caribbean Sea and the Gulf of Mexico, yellowfin occur, and yet there is very little fishing on floating objects, and in the northern area of the purse-seine fishery in the EPO the fishermen rely almost exclusively on school and dolphin sets. We can therefore conclude that the association is not a requirement for the life cycle of yellowfin or other tunas.

The majority of the yellowfin found associated with floating objects are relatively small (<80 cm), so for the association to develop the conditions needed for both small tunas and floating objects to be present need to be satisfied. In the "natural" conditions that prevailed when this behavior likely evolved, concentrations of floating objects would be found only near the mouths of tropical rivers, so the presence of a river system within a tropical area where temperatures are suitable for these tuna species would appear to be a requirement for the association. In those areas, the association probably has adaptive value, and therefore has evolved in several species.

One important factor for which no information is available is the mechanism the tunas use to detect the objects. If it is visual, olfactory, or sonic, environmental factors, such as water clarity or wind speed, may affect the detection.

Log fishing seasons and areas can be qualitatively matched with the two apparent main periods of input of logs into the ocean, at the beginning and at the peak of the rainy season. However, in most areas the flow of material continues throughout the rainy season; this includes not only logs and other large items, but also dissolved organic material and nutrients, which enrich the waters of the continental shelf considerably. It is probable that a considerable amount of organic material accumulates on the continent during the dry season, due to natural processes and agriculture, and that this is transported to the ocean at the beginning of the rainy season, particularly in southeastern Mexico and some areas of Central America. The peak of the rainy season coincides closely in most areas with peak river runoff and transport of objects to the sea, and is especially important in Costa Rica and Panama.

Logs in the fishing areas of the Panama Bight thus probably originate along the coast of Colombia and Ecuador. They probably remain in the area for extended periods, because the Equatorial Countercurrent is usually strong and flows eastward almost to the coast, and its southern branch does not allow the logs to disperse westward. Fishing in the northern Panama Bight peaks during May and June, at the beginning of the rainy season; in the south it lasts from April to December, matching the rainy season in this part of the continent.

The log-fishing area off Costa Rica probably depends on log production at the beginning of the rainy season in May, and on floating objects transported from the Panama Bight. Logs are retained in this area by the gyral circulation around the productive area of the Costa Rica Dome, but not for as long as in the Panama Bight. The log-fishing area off Nicaragua is probably the result of transport of floating debris from the Costa Rica area, as effort peaks slightly later and local sources of logs have declined over the years due to deforestation.

The log-fishing area off the Gulf of Tehuantepec is more difficult to explain; logs in this area may come from the Nicaragua area and stay there for some time. It is also possible that there is an accumulation of material from the Mexican coast, transported when the Equatorial Countercurrent is weak and the water flows to the southwest and then west off the Gulf of Tehuantepec. Also, some logs originating in the southwestern Mexico-Guatemala rainy area during October to December may move north and then south, accumulating in this region during the first months of the year.

Finally, there is a pattern of westward transport of floating objects along 10°N to the offshore fishing area. This area is also important for dolphin and school fishing, but only during June-September. A key factor in this summer fishery could be the improved weather conditions resulting from the westward extension of the doldrum zone during this season (Seckel, 1972).

The log-fishing area off Baja California peaks in February and March. Most floating objects in the area are kelp patties transported southward by the strong California Current and accumulating around the islands and banks in the region. Some logs from Central America may also end up in this area, transported by the anticyclonic eddy that develops from February to April off Mexico.

Environment and the detection of unassociated schools

In school fishing, tunas can be detected only if they swim at or near the surface of the ocean. Because yellowfin tend to remain above the thermocline, school fishing is more likely to succeed if the thermocline is shallow (Green, 1967). Since many school sets are made while tunas are feeding, the concentration of prey items near the surface also contributes to the success of this mode of fishing, unless the tunas drive their prey to the surface from wherever they find it.

Environmental influences on water movements may affect current patterns, and through them the presence or absence of frontal zones, eddies, and other features that may affect prey distribution, patchiness, *etc*. This may in turn affect the school dynamics of tunas, resulting in greater or lesser degrees of aggregation, which may facilitate or hamper detection and capture.

Another environmental factor that affects this mode of fishing is the weather and sea state. If the strength of the wind, the swells, the turbidity of the water, and the available light are unsuitable, detecting schools may become so difficult that the fishermen may be forced to search elsewhere. The effect of these conditions on the tuna schools is unknown: their foraging may be impaired and they may have to leave the area, or they may simply change their feeding depth, or make other adjustments in order to adapt to them.

Another factor relevant to this form of fishing is the abundance of sea birds (Au and Pitman, 1988). As the presence of a school is often betrayed by the presence of a flock of sea birds, detected either visually or with a special radar, areas with low populations of sea birds will tend to have lower detection rates. Trends in the number of flocks and/or average flock size will also influence detectability, and weather conditions affecting the birds' behavior will indirectly affect tuna detection.

Environment and the tuna-dolphin bond

As stated above, for the tuna-dolphin association to develop it is necessary that the environmental requirements for both species be satisfied. Apparently these conditions are met in many regions of the world's oceans where both dolphins and yellowfin tuna are found, but the association seems to be more frequent or more stable, or both, in the EPO than in other oceans, although data from other oceans are sparse. Why this is so is one of the key questions to any understanding of the association. We believe that a shallow thermocline is important, for two reasons: 1) a shallow upper ocean layer shared by the two components of the association facilitates their encountering one another and 2) once the association is formed, the probability of the tunas and dolphins separating would be greater in a deep layer, perhaps because the different components would forage at different depths or the oxygen requirements of the tunas would prevent them from associating with the dolphins.

The association of tunas with dolphins may be an extension of their association with floating objects. It is possible that the association with objects may not be adaptive in other oceans if, for instance, the objects are not found in rich water masses, a case for which no examples are yet available, or that a weak association with objects results in a weak association with dolphins. We believe that, in general, the association with floating objects is adaptive, and that the tendency to associate with dolphins, as well, will therefore be present in other oceans, but that it is more stable in the EPO because of factors such as the shallow thermocline or the swimming depths of the main prey species. The association will therefore develop in other oceans, perhaps less frequently, but it will break more easily in environmental conditions such as deep thermoclines. During the strong El Niño event of 1982-1983, the tuna fishery in the EPO experienced a major decline; overall effort decreased, and fishing on dolphins was especially poor in some areas. One of the more evident changes in the environment was a deepening of the thermocline, and the event thus provided a large-scale natural experiment on the role of the thermocline on the tuna-dolphin bond. At least in some areas, the bond was apparently not as strong as in other years. The problem is that an El Niño event changes so many other physical and biological parameters that it is difficult or impossible to identify any one change as the cause of a particular result. However, additional evidence is supplied by the fact that the purse-seine fishery in the western Pacific, where the thermocline is much deeper than in the EPO, makes very few sets on tunas associated with dolphins. The decrease of the depth of the thermocline in the western Pacific during the 1982-1983 El Niño may have affected the tuna-dolphin bond in those waters. Regrettably, there are no data on tuna-dolphin associations in the western Pacific with which to investigate the effect of the decrease in the thermocline depth on the tuna-dolphin bond. A shallow thermocline seems to be one of the requirements for the presence of a strong tuna-dolphin bond, by either facilitating the encounter, or preserving the stability of the bond once formed, or both.

Even though a much better picture of the environment in the EPO is beginning to emerge, we are still far from understanding the multiple and complex ways in which environmental factors affect the associations of tunas with floating objects and dolphins. Given that experiments can elucidate mechanisms, but not evolutionary processes, a comparative study of different ocean areas is probably one of the best ways of approaching this subject.

Increases in catch per set

As discussed above (section on spatial and temporal distribution of catches),the CSS of yellowfin showed a marked increase between 1983 and 1985 for all three modes of fishing. Assuming that the entire school is caught, increases in CSS may result from a greater average number of fish in each school or from a greater average weight per fish, from variations in the proportion of schools caught, or from a combination of these factors. Variations in the proportion of schools caught could be due to changes in gear and fishing techniques. In addition, changes in the composition of the fleet may have occurred between 1980-90 so that the fleet may not have been homogeneous. However, the differences among years are so large that it seems unlikely that they could be explained by changes in growth rate alone, and it is therefore probable that changes in the average number of fish in a school are mainly responsible for the increases (or decreases). The abundance and/or patchiness of the schools of prey species may change from year to year, affecting the optimum size of tuna schools that exploit them.

Increases in the overall biomass of tuna, such as happened after 1983 (Anonymous, 1994: Figure 46), can result from increases in 1) the number of schools or 2) the average size of the schools, or a combination of both these factors. Predation, reproduction, and feeding are usually considered the key factors in determining the size of a school of fish (Brock and Riffenburgh, 1960; Cushing and Harden-Jones, 1968; Radakov, 1973; Shaw, 1978; Pitcher, 1986, and Norris and Schilt, 1988). Given the magnitude of the changes in CSS observed in consecutive years, it is difficult to believe that the numbers of "natural" tuna predators could change so much over such a short period, especially because many of them are long-lived and do not have the reproductive potential to adjust so rapidly to an increase in prey abundance. The purse-seine fleet, switching between the eastern and western Pacific, could cause major swings in predation rates among years, yet the direction of the changes matches changes in effort only in some cases. Effort decreased between 1980 and 1983, and then increased until the late 1980s and has recently began to decline.

The diagram below shows some of the options that can bring about an increase in biomass.

INCREASE IN BIOMASS
→ **MORE SCHOOLS**
→ **LARGER SCHOOLS**
  → **MORE INDIVIDUALS**
  → **LARGER INDIVIDUALS**

For yellowfin tuna, Broadhead and Orange (1960) found some correlation between apparent abundance and average catch per set, but they concluded that the number of schools was more sensitive to changes in abundance. However, in the period covered in their study (1946-1958), only a small and coastal portion of the current fishing grounds was exploited. Because of this, the measures of apparent abundance they used are likely to be considerably biased.

Reproductive requirements may influence the size of mature schools, but they are not likely to have a major impact on the young tunas that normally associate with logs. If the number of eggs in a batch is higher, or if their survival is increased for any reason, the initial group size will be greater, but information available from tagging (Bayliff, 1988; Hilborn, 1991) does not seem to support the idea that skipjack schools, at least, are fixed, long-lasting units. The initially larger size of a school may therefore not be reflected in its later size. The question of the permanence of membership in a yellowfin school (or dolphin herd) is pivotal to our understanding of the ecology and dynamics of tunas (and dolphins).

Feeding is therefore the only variable with a response time compatible with the observations made. The abundance, school size, and type of prey species may be affected by environmental factors, and tunas may respond to these changes by changing their average school size.

If the optimum school size is determined by ecological factors, and these had remained constant over the period in question, the larger biomass would have resulted only in more schools. For the fishing fleet this would mean a reduction in search time, but a constant CSS. The fact that the CSS in 1985 was two or three times that in 1980 (Figures 21 and 22) could indicate either a change in optimum school size or that this optimum size covers a very broad range of values, not finely tuned to the environment but grossly constrained by extreme conditions, by which only very small or very large schools are at a disadvantage.

Another interesting approach is to consider logs and dolphins as attractors, whose abundance varies, and that tunas tend to converge into larger schools when the attractors are scarce and divide into smaller ones when they abound, thus affecting catch-per-set rates. Data on some of these "attractors" is available for the period in question. Studies of dolphin populations for the 1980-1990 period (Anganuzzi and Buckland, 1989; Holt and Sexton, 1990; Anganuzzi *et al.*, 1992; Wade and Gerrodette, 1993) show no trends in abundance. Average herd size increased from 415 to 667 dolphins between 1981 and 1984, declined to 407 between

1984 and 1987, and increased steadily thereafter (to 477 in 1988, 579 in 1989, and 622 in 1990). Neither the peaks nor the trends match the fluctuations in tuna school size.

Until recently, no data were available on the abundance of floating objects, but it seems reasonable to assume that their number has increased steadily over the years, since many of them are by-products of human activities (logging and agriculture, debris, discarded fishing gear) which have intensified over the past decades. This increase in the number of attractors has not been accompanied by a reduction in average tuna school size.

This superficial analysis does not appear to indicate that the abundance of attractors is a major determinant of school size, although more information on the dynamics of tuna schools and of the attractors will be needed before we can fully understand their interaction. Any study of this question must take into account the spatial and temporal variability of both tunas and attractors.

FUTURE RESEARCH

Our principal interest is the role that these associations play in the detection and capture of the tunas and in the ecology of the various species involved, and our main objective is to understand why these associations evolved, and through that understanding perhaps develop alternative ways of fishing that can circumvent the problems caused by the incidental mortality of dolphins in the fishery. The IATTC research program on floating objects, initiated in 1987, seeks to study and describe the following, with particular reference to yellowfin tuna:

1. The main characteristics of the environment where the fishery and the multispecific aggregations take place;
2. The interactions between the continent and the pelagic environment generated by the entrance of floating objects from tropical rivers to the coastal zone, and how the life history of tunas and other species may adapt to take advantage of seasonal peaks;
3. The fate of floating objects, particularly their drift patterns and how they can affect the ecology of pelagic species;
4. The characteristics that make a floating object attractive for the epipelagic fauna of the EPO, and their possible application in the design and deployment of artificial floating objects for attracting large yellowfin and thus reduce fishing on dolphins;
5. The nature and dynamics of the pelagic communities found associated with tunas in the different types of sets;
6. Ecological aspects of the associations between tunas and floating objects and between tunas and dolphins, including their temporal and spatial characteristics;
7. The possibility that both associations have a common origin, and are variations of the same basic adaptation, the association with dolphins being an extension of the association with floating objects that develops earlier in the tunas' life cycle, and
8. The possibility that both associations--being part of different stages in the life history--suggest a yellowfin tuna movement cycle within the EPO.

LITERATURE CITED

Allen, R.L. and R.G. Punsly. 1984. Catch rates as indices of abundance of yellowfin tuna, Thunnus albacares, in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 18: 301-379.

Anganuzzi, A.A. and Buckland, S.T. 1989. Reducing bias in trends in dolphin relative abundance, estimated from tuna vessel data. Rep. int. Whal. Commn. 39:323-334.

Anganuzzi, A.A., K.L. Cattanach and S.T. Buckland. 1992. Relative abundance of dolphins associated with tuna in the eastern tropical Pacific, estimated from tuna vessel sightings data for 1990. Rep. int. Whal. Commn. 42.

Anonymous. 1976. Atlas Climatológico e Hidrográfico del Istmo Centroamericano. Publ. Instituto Panamericano de Geografia e Historia. 367 (9 maps).

Anonymous. 1983. Annual report of the Inter-American Tropical Tuna Commission 1982. 294 pp.

Anonymous. 1984. Annual report of the Inter-American Tropical Tuna Commission 1983. 272 pp.

Anonymous. 1985. Annual report of the Inter-American Tropical Tuna Commission 1984. 270 pp.

Anonymous. 1985. Taller Nacional Fenómeno El Niño 1982-83. Investigación Pesquera (Chile) 32:1-255.

Anonymous. 1989. Inter-American Tropical Tuna Commission. Dolphin Workshop held at San Jose, Costa Rica, March 14-16, 1989. (Working documents 1-4).

Anonymous. 1991. Annual report of the Inter-American Tropical Tuna Commission, 1989. 270 pp.

Anonymous. 1992. Annual report of the Inter-American Tropical Tuna Commission, 1990. 261 pp.

Anonymous. 1994. Annual report of the Inter-American Tropical Tuna Commission, 1993. 316 pp.

Arntz, W., Landa, A. and Tarazona, J. 1985. "El Niño" su impacto en la fauna marina. Bol. Inst. Mar Peru - Callao (volúmen extraordinario). 222 pp.

Au, D.W.K. and Perryman, W.L. 1985. Dolphin habitats in the eastern tropical Pacific Ocean. Fish. Bull. 83:623-643.

Au, D., and R.L. Pitman. 1988. Seabird relations with tropical tunas and dolphins. Pp. 174-212 in Seabirds and Other Marine Vertebrates, J. Burger, ed. New York: Columbia University Press.

Bayliff, W.H. 1988. Integrity of schools of skipjack tuna, (*Katsuwonus pelamis*), in the eastern Pacific Ocean, as determined from tagging data. Fish. Bull. 86:631-644.

Bennett, E.B. 1966a. Influence of the Azores high on sea-level pressure and wind, and on precipitation, in the eastern tropical Pacific Ocean. Bull. Inter-Am. Trop. Tuna Commn. 12(1): 1-23.

Bennett, E.B. 1966b. Monthly charts of surface salinity in the eastern tropical Pacific Ocean. Bull. Inter-Am. Trop. Tuna Commn. 11(1): 1-44.

Berger, W.H., Fischer, K., Lai, C., and Wu, G. 1988. Ocean carbon flux: global maps of primary production and export production. In: C. Agegian (ed) Biogeochemical cycling and fluxes between the deep euphotic zone and other oceanic realms. Symp. Series for Undersea Res. NOAA, Undersea Research Program Res. Rp. V.3(2). 131-176.

Blackburn, M. 1965. Oceanography and the ecology of tunas. Oceanogr. Mar. Biol. Ann. Rev., 3, 299-322.

Blackburn, M., R.M. Laurs, R.W. Owen and B. Zeitzschel. 1970. Seasonal and areal changes in standing stocks of phytoplankton, zooplankton and micro nekton in the eastern tropical Pacific. Mar. Biol. 7: 14-31.

Broadhead, G.C. and C.J. Orange. 1960. Species and size relationships within schools of yellowfin and skipjack tuna, as indicated by catches in the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 4:447-492.

Brock V. E., and R.H. Riffenburgh. 1960. Fish schooling: a possible factor in response to predation. J. Cons. Perm. int. Explor. Mer. 25: 307-317.

Coe, James, and George Sousa. 1972. Removing porpoise from a tuna purse seine. Mar. Fish. Rev., 34 (11-12): 15-19.

Cole, J.S. 1980. Synopsis of biological data on the yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788), in the Pacific Ocean. Inter-Am. Trop. Tuna Commn. Spec. Rep. 2:71-212

Cole, D., and D.R. McLain. 1989. Interannual variability of temperature in the upper layer of the North Pacific eastern boundary region. 1971-1987. NOAA Tech. Mem. NMFS-SWFC-125.

Cromwell, T. 1958. Thermocline topography, horizontal currents and "ridging" in the eastern tropical Pacific. Bull. Inter-Am. Trop. Tuna Commn. 3: 134-164.

Cushing, D.H., and F.R. Harden-Jones. 1968. Why do fish school? Nature 218: 918-920.

Dizon, A.E., Perrin, W.F. and Akin, P.A. 1994. Stocks of dolphins (*Stenella* spp. and *Dephinus delphis*) in the eastern tropical Pacific: A phylogeographic classification. NOAA Tech. Rpt. NMFS 119.

Edwards, Elizabeth F. 1992. Energetics of associated tunas and dolphins in the eastern tropical Pacific Ocean: A basis for the bond. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 90 (4): 678-690.

Everett, E., Hinton, M.G. and Bayliff, W.H. 1989. Procedures for collection and handling of tuna fishery data by field station personnel. Field Manual. Inter-Amer. Trop. Tuna Comm.

Fiedler, P.C. and Reilly, S.B. 1994. Interannual variability in dolphin habitats in the eastern tropical Pacific. II: Effects on abundances estimated from tuna vessel sightings, 1975-1990. Fish. Bull 92:451-463.

Forsbergh, E.D. 1969. On the climatology, oceanography and fisheries of the Panama Bight. Bull. Inter-Am. Trop. Tuna Commn. 14(2): 49-385.

Forsbergh, E.D. 1980. Synopsis of biological data on the skipjack tuna, *Katsuwonus pelamis* (Linnaeus,1758), in the Pacific Ocean. Inter-Am. Trop. Tuna Comm., Spec. Rep. 2:295-360.

Francis, Robert C., Frank T. Awbrey, Clifford L. Goudey, Martín A. Hall, Dennis M. King, Harold Medina, Kenneth S. Norris, Michael K. Orbach, Roger Payne, and Ellen Pikitch. 1992. Dolphins and the Tuna Industry. National Academy Press, Washington, D.C.: xii, 176 pp.

Glantz, M. Katz, R. and Krenz, M. 1987. The societal impacts associated with the 1982-83 worldwide climate anomalies. Nat. Center for Atmosph. Res. 105p.

Graham, N. and W. White. 1988. The El Niño cycle: a natural oscillator of the Pacific Ocean-Atmosphere system. Science 240:1293-1302.

Green, Roger E. 1967. Relationship of the thermocline to success of purse seining for tuna. Amer. Fish. Soc., Trans., 96(2): 126-130.

Greenblatt, P.R. 1979. Associations of tuna with flotsam in the eastern tropical Pacific. Fish. Bull. 77: 147-155.

Gulland, J.A. 1964. Catch per unit effort as a measure of abundance. Rapp. P.-V. Réun. Cons. int. Explor. Mer. 155: 8-14.

Hall, M.A. 1992. Atunes y delfines en el Oceano Pacífico oriental: Situación actual y perspectivas de pesca e investigación. 12a Semana das Pescas dos Acores, 16 a 20 de Marco, Horta-Faial, Portugal. Secretaria Regional da Agricultura e Pescas Direccao Regional das Pescas. pp. 221-33.

Hallier, J.P. 1985. Purse seining on debris-associated schools in the Western Indian Ocean. IPTP Collective Volume of Working Documents, Vol. 1, TWS/85/30, pp. 150-156.

Hallier, J.P. 1991. Tuna fishing on log associated schools in the western Indian ocean: an aggregation behavior. Expert consultation on stock assessment of tunas in the Indian Ocean, Bangkok, Thailand, 2-6 July 1990. Indo-Pacific Tuna Dev. and Manag. Prog. Working Documents 4: 325-342.

Halpern, D. (ed). 1983. 1982 Equatorial Pacific warm event. Tropical Ocean-Atmosphere Newsletter Special Issue, Feb. 1983. 16:1-20.

Halpert, M.S., and L.F. Ropelewski. 1989. Atlas of tropical sea- surface temperature and surface winds. NOAA Atlas No.8.

Hansen, D.V., and Herman, A. 1988. A seasonal isotherm depth climatology for the eastern tropical Pacific. NOAA Tech. Rept. 434-AOML 33 (Revised). 11p.+ 224 maps.

Hennemuth, R.C. 1957. An analysis of methods of sampling to determine the size composition of commercial landings of yellowfin tuna (*Neothunnus macropterus*) and skipjack tuna (*Katsuwonus pelamis*). Bull. Inter-Amer. Trop. Tuna Comm., 2(5):171-243.

Hilborn, R. 1991. Modeling the stability of fish schools: exchange of individual fish between schools of skipjack tuna (*Katsuwonus pelamis*). Can. J. Fish. Aquatic Sci. 98(6):1681-1691.

Hoffmann, J.A.J. 1975. Climatic Atlas of South America. I. Maps of mean temperature and precipitation. OMM.WMO.UNESCO, Paris and Cartographia, Budapest.

Holt, R.S. and S.N. Sexton. 1990. Monitoring trends in dolphin abundance in the eastern tropical Pacific using research vessels over a long sampling period: Analysis of 1988 data. Rep. int. Whal. Commn. 40:471-476.

Jordán, R. (ed). 1987. Fenómeno de El Niño 1982-1983 con particular referencia a sus efectos sobre los recursos pesqueros y las pesquerías en el Pacífico sudeste. Rev. Com. Perm. Pacífico Sur 16:1-278.

Joseph, J. 1994. The tuna-dolphin controversy in the eastern Pacific Ocean: biological, economic, and political impacts. Ocean Development and International Law 25:1-30.

Joseph, James, and Joseph W. Greenough. 1979. International Management of Tuna, Porpoise, and Billfish--Biological, Legal, and Political Aspects. University of Washington Press, Seattle and London: xv, 253 pp.

Kume, S. and J. Joseph. 1969. The Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean east of 130° W, 1964-1966. Bull. Inter-Am. Trop. Tuna Commn. 13: 275-418.

Kwiecinski, B. and Chial, B. 1987. Manifestations of El Niño in the Gulf of Panama. Tropical Ocean-Atmosphere Newsletter 45:7-9.

Legeckis, R. 1986. A satellite time series of sea-surface temperatures in the eastern equatorial Pacific Ocean, 1982-1986. J. Geophys. Res. 91: 12879-12886.

Miyabe, N. and W.H. Bayliff. 1987. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1971-1980. Bull. Inter-Am. Trop. Tuna Commn. 19: 1-163.

Nakano, Hideki, and William H. Bayliff. 1992. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1981-1987. Inter-Amer. Trop. Tuna Comm., Bull. 20(5): 185-355.

Nicholls, N. 1987. The El Niño/Southern Oscillation Phenomenon. In: pp 2-10. Glantz, M. Katz, R. and Krenz, M. (eds). 1987. The societal impacts associated with the 1982-83 worldwide climate anomalies. Nat. Center for Atmosph. Res. 105 pp.

Norris, K.S., and C.R. Schilt. 1988. Cooperative societies in three-dimensional space: on the origins of aggregations, flocks, and schools, with special reference to dolphins and fish. Ethol. and Sociobiol. 9: 149-179.

Ortiz, R.W., and R. Guzmán. 1982. Efectos metereológicos y oceanográficos en la productividad del Océano Pacífico del Este. Geofisica. 17: 23-39.

Owen, R.W. and B. Zeitzschell. 1970. Phytoplankton production: Seasonal change in the oceanic eastern tropical Pacific. Mar. Biol. 7: 32-36.

Pallarés, P., J.C. Santana, J. Ariz and A. Delgado de Molina. 1989. Explotación durante una semana de los túnidos asociados a un objeto flotante en el Atlántico intertropical. ICCAT, SCRS/89/38 (YYP/89/4).

Paloheimo, J.E., and L.M. Dickie. 1964. Abundance and fishing success. Rapp. P.-V. Réun. Cons. int. Explor. Mer. 155: 152-163.

Pazan, S.E. and W.B. White. 1988. Annual report on tropical Pacific subsurface thermal structure 1986. SIO Ref. No. 88.3.

Pella, J.J. and C.T. Psaropulos. 1975. Measures of tuna abundance from purse-seine operations in the eastern Pacific Ocean adjusted for fleet-wide evolution of increased fishing power, 1960-1971. Inter-Amer. Trop. Tuna Comm., Bull. 16: 282-400.

Perrin, W.F. 1968. The porpoise and the tuna. Sea Frontiers 14 (3).

Perrin, W.F. 1969. Using porpoise to catch tuna. World Fish. 18 (6): 42-45.

Perrin, W.F., M.D. Scott, G.J. Walker, F.M. Ralston, and D.W.K. Au. 1983. Distribution of four dolphins (*Stenella* spp., and *Delphinus delphis*) in the eastern tropical Pacific, with an annotated catalog of data sources. NOAA Tech. Memo. NMFS NOAA-TM-NMFS-SWFC-38. 65 pp.

Perrin, William F. 1990. Subspecies of *Stenella longirostris* (Mammalia: Cetacea: Delphinidae). Biol. Soc. Wash. Proc. 103 (2): 453-463.

Perrin, William F., Priscilla A. Akin, and Jerry V. Kashiwada. 1991. Geographic variation in external morphology of the spinner dolphin *Stenella longirostris* in the eastern Pacific and implications for conservation. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 89 (3): 411-428.

Pitcher, T.J. 1986. The behavior of teleost fishes. John Hopkins Univ. Press. 553 pp.

Polacheck, T. 1987. Relative abundance, distribution and inter-specific relationship of cetacean schools in the eastern tropical Pacific. Mar. Mamm. Sci. 3(1):54-77.

Punsly, R. 1987. Estimation of the relative annual abundance of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean during 1970-1985. Inter-Amer. Trop. Tuna Commn., Bull. 19: 265-306.

Radakov, D.V. 1973. Schooling in the ecology of fish. J. Wiley & Sons. New York.

Reilly, S. B. 1990. Seasonal changes in distribution and habitat differences among dolphins in the eastern tropical Pacific. Mar. Ecol. Prog. Ser. 66:1-11.

Reilly, S.B. and Fiedler, P.C. 1994. Interannual variability of dolphin habitats in the eastern tropical Pacific. I: Research vessel surveys, 1986-1990. Fish Bull. 92:434-450.

Robinson, M.K., and R.A. Bauer. 1971. Atlas of monthly mean surface and subsurface temperature and depth of the top of the thermocline. North Pacific Ocean. Fleet Num. Weather Central, Monterey, CA. 95 pp.

Sameoto, D.D. 1986. Influence of the biological and physical environment on the vertical distribution of mesozooplankton and micronekton in the eastern tropical Pacific. Mar. Biol. 93: 263-279.

Scott, J.M. 1969. Tuna schooling terminology. Calif. Fish Game 55:136-140.

Scott, M.D., and S.J. Chivers. 1990. Distribution and herd structure of bottlenose dolphins in the eastern tropical Pacific Ocean. pp. 387-402 In: Leatherwood, S., and Reeves, R. (eds): The bottlenose dolphin. Academic Press, San Diego.

Scott, M.D. and K.L. Cattanach. 1998. Diel patterns in aggregations of pelagic dolphins and tunas in the eastern Pacific. Mar. Mamm. Sci. 14(3): 401-428.

Seckel, G.R. 1972. Hawaiian-caught skipjack tuna and their physical environment. Fish. Bull. 72: 763-787.

Seckel, G. R. 1985. Currents of the tropical and subtropical North Pacific Ocean. pp 461-482. In R.S. Shomura and H.O. Yoshida (eds.). Proceedings of the workshop on the fate and impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Comm., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Sharp, Gary D. 1978. Behavioral and physiological properties of tuna and their effects on vulnerability to fishing gear. pp 397-449. In: Sharp, Gary D. and Dizon, Andrew E. The Physiological Ecology of Tunas. Academic Press, Inc.

Shaw, E. 1978. Schooling fishes. Am. Sci., 66: 166-175.

Shingu, C., P.K. Tomlinson and C.L. Peterson. 1974. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1967-1970. Bull. Inter-Am. Trop. Tuna Commn. 16: 67-230.

Steinhauser, F. 1979. Climatic Atlas of North and Central America. I. Maps of mean temperature and precipitation. OMM.WMO,UNESCO, Paris and Cartographia, Budapest.

Suda, A. and M.B. Schaefer. 1965. General review of the Japanese tuna long-line fishery in the eastern tropical Pacific Ocean 1956-1962. Inter-Amer. Trop. Tuna Comm. Bull. 9: 305-464.

Sund, P.N., M. Blackburn and F. Williams. 1981. Tunas and their environment in the Pacific Ocean: a review. Oceanogr. Mar. Biol. Ann. Rev. 19: 443-512.

Tsuchiya, M. 1970. Equatorial circulation of the south Pacific. In: Wooster, W. (ed) Scientific exploration of the south Pacific. Natl. Acad. Sci., Wash. D.C. p. 69-74.

Tsuchiya, M. 1974. Variation of the surface geostrophic flow in the eastern intertropical Pacific Ocean. Fish. Bull. 72: 1075-1086.

Tsuchiya, M. 1982. On the Pacific upper-layer water circulation. J. Mar. Res. (Suppl.) 40:777-799.

Thomas, W.H. 1977. Nutrient-phytoplankton interrelationships in the eastern tropical Pacific Ocean. Bull. Inter-Am. Trop. Tuna Commn. 17(3): 172-212.

Tomlinson, P.K., Tsuji, S., and Calkins, T.P. 1992. Length-frequency estimation for yellowfin tuna (*Thunnus albacores*) caught by commercial fishing gear in the eastern Pacific Ocean. Bull. Inter-Amer. Trop. Tuna Comm. 20(16): 357-398.

Vega, N. 1987. The effects of El Niño in Costa Rica, 1982-83. Tropical Ocean Atmosphere Newsletter 39:1.

Wade, P.R. and T. Gerrodette. 1993. Estimates of cetacean abundance and distribution in the eastern tropical Pacific. Rep. int. Whal. Commn. 43:477-493.

Wild, A. 1994a. A review of the biology and fisheries for yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean. FAO Fish. Tech. Pap. 336 (2): 52-107.

Wild, A. 1994b. An evaluation of length-frequency sampling procedures and subsequent data analysis for purse-seine-caught yellowfin tuna in the eastern Pacific Ocean. Bull. Inter-Amer. Trop. Tuna Comm. 21(1): 1-70.

Williams, F. 1972. Consideration of three proposed models of the migration of young skipjack tuna (*Katsuwonus pelamis*) into the eastern Pacific Ocean. Fish. Bull. 70: 741-762.

Wooster, W., and T. Cromwell. 1958. An oceanographic description of the eastern tropical Pacific. Bull. Scripps Inst. Ocean. 7:169-282.

Wooster, W., and Fluharty, S. (eds). 1985. El Niño north: Niño effects in the eastern subarctic Pacific Ocean. Washington Sea Grant Program, Univ. Washington, Seattle. 312 pp.

Wyrtki, K. 1964. The thermal structure of the eastern Pacific Ocean. Deutsche Hydrogr. Zeits., Erganzungsheft. p. 1-84.

Wyrtki, K. 1965. Surface currents of the eastern tropical Pacific Ocean. Bull. Inter-Am. Trop. Tun. Comm. 5: 269-304.

Wyrtki, K. 1966. Oceanography of the eastern equatorial Pacific Ocean. Oceanogr. Mar. Biol. Ann. Rev. 4: 33-68.

Wyrtki, K. 1967. Circulation and water masses in the eastern equatorial Pacific Ocean. Int. J. Oceanol. Limnol. 1(2): 117-147.

Wyrtki, K. 1974. Equatorial currents in the Pacific 1950 to 1970 and their relations to the trade winds. J. Phys. Oceanogr. 4: 374-380.

Yabe, H. and T. Mori. 1950. An observation on a school of skipjack and kimeji accompanying a drift log. Bull. Jap. Soc. Sci. Fish. 16(2): 35-39.

Yoshida, K. 1967. Circulation in the eastern tropical oceans with special references to upwelling and undercurrents. Jap. J. Geophys. Res. 4:17-29.

Table 1. Sampling coverage of the international fleet by IATTC observers, for 1980 through 1990. Estimates are based on data presented in Anonymous (Table 1, Appendix I, 1989; Table 15, 1991; Table 15, 1992).

Year	Approximate Coverage
1980	12%
1981	13%
1982	14%
1983	15%
1984	8%
1985	12%
1986	23%
1987	26%
1988	33%
1989	36%
1990	41%

Table 2. Number of sets with catch of yellowfin, skipjack, bigeye, and all tunas, by year and mode of purse seining, 1980-90. The "All tunas" column represents the number of sets with any catch of yellowfin, skipjack or bigeye tuna.

	Yellowfin			**Skipjack**			**Bigeye**			**All tunas**		
Type of set:	**Log**	**School**	**Dolphin**	**Log**	**School**	**Dolphin**	**Log**	**School**	**Dolphin**	**Log**	**School**	**Dolphin**
1980	512	245	1,070	739	310	198	34	82	2	800	463	1,076
1981	612	314	1,346	769	312	60	27	53	1	860	508	1,358
1982	509	146	1,012	642	217	28	45	13	0	715	291	1,016
1983	262	166	826	347	101	81	52	30	3	399	235	829
1984	57	118	513	93	70	34	18	16	3	105	166	515
1985	75	72	1,322	97	115	8	35	9	4	125	160	1,327
1986	286	218	2,274	270	158	63	7	3	1	339	266	2,279
1987	343	548	3,150	304	364	77	14	12	0	435	731	3,154
1988	506	1508	2,810	537	675	238	48	23	5	669	1,801	2,819
1989	570	857	4,170	629	735	175	16	4	1	751	1,422	4,174
1990	836	834	4,238	675	570	207	51	36	0	948	1,211	4,263
Totals:	4,568	5,026	22,731	5,102	3,627	1,169	347	281	20	6,146	7,254	22,810
Species totals:		32,325			9,898			648			36,210	

Table 3. Percentages of unsuccessful sets, by mode of purse seining and year, 1980-90.

	Log sets	**Schools Sets**	**Dolphin Sets**
1980	10.5	42.9	15.0
1981	13.0	38.9	11.0
1982	11.7	44.6	14.3
1983	12.3	36.5	10.9
1984	13.2	28.4	6.5
1985	16.7	32.8	14.1
1986	14.0	34.8	13.9
1987	11.6	36.9	15.2
1988	11.2	31.9	15.4
1989	10.9	30.2	11.4
1990	8.9	37.6	11.5

Table 4. Comparison of tonnage of yellowfin loaded (LWTS) with tonnage caught (CWTS), by mode of purse seining and year, 1980-90.

	Log sets			School sets			Dolphin sets		
	CWTS	**LWTS**	**Ratio**	**CWTS**	**LWTS**	**Ratio**	**CWTS**	**LWTS**	**Ratio**
1980	4,979	4,934	99.10	2,466	2,444	99.11	11,582	11,577	99.96
1981	5,004	4,981	99.54	4,809	4,809	100.00	17,663	17,655	99.95
1982	4,637	4,618	99.59	1,577	1,570	99.56	12,154	12,154	100.00
1983	2,097	2,087	99.52	3,330	3,140	94.29	10,363	10,337	99.75
1984	694	688	99.14	2,523	2,523	100.00	9,059	9,020	99.57
1985	1,840	1,576	85.65	2,247	2,141	95.28	25,458	25,161	98.83
1986	6,900	4,973	72.07	5,204	4,879	93.75	51,024	50,689	99.34
1987	6,754	5,905	87.43	12,822	12,132	94.62	56,786	56,545	99.58
1988	7,023	6,590	93.83	29,719	28,796	96.89	48,175	47,754	99.13
1989	8,623	7,439	86.27	16,856	16,554	98.21	78,830	78,235	99.25
1990	1,626	14,154	87.04	17,790	16,783	94.34	83,449	82,847	99.28
Totals:	64,812	57,945	89.40	99,343	95,771	96.40	404,543	401,974	99.36

Table 5. Comparison of tonnage of all tunas loaded (LWTS) with tonnage caught (CWTS), by mode of purse seining and year, 1980-90.

	Log sets			School sets			Dolphin sets		
	CWTS	**LWTS**	**Ratio**	**CWTS**	**LWTS**	**Ratio**	**CWTS**	**LWTS**	**Ratio**
1980	23,307	21,743	93.29	8,121	7,985	98.33	12,372	12,365	99.94
1981	22,760	19,571	85.99	9,571	9,464	98.88	17,984	17,955	99.84
1982	17,077	15,243	89.26	6,030	5,442	90.25	12,357	12,350	99.94
1983	10,536	9,708	92.14	5,554	5,236	94.27	10,703	10,677	99.76
1984	3,777	3,718	98.44	4,423	4,406	99.62	9,192	9,150	99.54
1985	7,164	6,432	89.78	6,298	6,088	96.67	25,702	25,405	98.84
1986	15,037	11,240	74.75	10,315	9,244	89.62	51,468	51,071	99.23
1987	17,643	12,809	72.60	20,633	19,172	92.92	57,100	56,822	99.51
1988	26,039	19,744	75.82	43,305	40,909	94.47	49,875	49,412	99.07
1989	32,768	24,627	75.16	35,440	33,336	94.06	79,893	79,260	99.21
1990	37,281	29,672	79.59	31,108	29,295	94.17	84,505	83,869	99.25
Totals:	213,389	174,507	81.78	180,798	170,557	94.34	411,151	408,336	99.32

Table 6. Types of floating objects observed in the eastern Pacific Ocean between 1987-90, from Hall, *et al.* (this volume). A sighting is an observation that did not lead to a set.

	Sightings % (n = 2723)	**Sets % (n = 2491)**	**Median catch per successful set (tons) (1st, 3rd quartiles)**		
Type of object			**All tunas**	**Yellowfin**	**Skipjack**
a) Plant material	48.2	47.2	25 (11, 50)	8 (3, 20)	8 (3, 25)
Unidentified tree	44.4	44.0			
Palm tree	1.0	0.7			
Banana tree	0.1	0.1			
Mangrove tree	0.3	0.3			
Bamboo	1.5	1.7			
Cane	0.8	0.4			
Hay/straw	<0.1	<0.1			
Fruits	0.1	0.0			
b) Kelp	5.5	0.8	10 (2, 25)	6 (2, 10)	6 (2, 17)
c) Wooden man-made	16.9	17.8	28 (12, 61)	10 (3, 22)	12 (4, 34)
Boats and boat parts	0.9	1.0			
Pallets	6.6	8.3			
Planks	5.8	5.1			
Plywood	1.7	1.8			
Cable drums	1.9	1.7			
d) Dead animals	4.8	3.2	23 (10, 45)	7 (2, 17)	11 (3, 22)
Whale	2.6	2.4			
Other animals	1.1	0.6			
Unidentified turtle	1.0	0.1			
Olive ridley	0.1	0.0			
e) Discarded equipment	13.7	11.8	32 (15, 57)	9 (3, 19)	17(5, 44)
Rope	3.3	6.2			
Fishing gear	3.6	2.2			
Buoy	5.7	2.9			
Life preservers	0.3	0.0			
Rafts	0.2	0.1			
Other	0.6	0.3			
f) Non-wooden man-made	5.9	5.8	30 (12, 60)	7 (2, 20)	16(2, 42)
Tires	0.1	0.5			
Foam	0.9	0.2			
Plastic drums	1.2	1.8			
Other plastic	1.8	2.1			
Trash	0.4	0.2			
Metal drums	1.4	0.3			
Research buoys	0.1	0.7			
g) FADs	3.1	12.6	25 (12, 44)	11 (5, 32)	8 (3, 20)
h) Others and unidentified	1.7	0.7	26 (8, 70)	13 (2, 25)	2 (1,10)
Other objects	1.6	0.7			
Unidentified	0.1	<0.1			

Table 7. Catches of yellowfin, skipjack, and all tunas, by mode of purse seining and year, 1980-90.

	Yellowfin			Skipjack			All tunas		
Type of set:	**Log**	**School**	**Dolphin**	**Log**	**School**	**Dolphin**	**Log**	**School**	**Dolphin**
1980	4,966	2,466	11,582	16,760	3,847	770	23,274	8,118	12,372
1981	5,004	4,809	17,663	14,241	3,405	292	22,754	9,569	17,984
1982	4,587	1,561	12,154	9,443	3,313	196	16,966	6,013	12,357
1983	2,084	3,312	10,363	7,289	1,689	305	10,431	5,498	10,703
1984	694	2,523	9,059	2,696	1,378	121	3,876	4,362	9,192
1985	1,804	2,247	25,443	3,635	3,538	271	7,115	6,298	25,777
1986	6,876	5,204	51,024	6,811	4,455	347	14,944	10,315	51,468
1987	6,497	12,670	56,786	7,722	7,167	291	17,164	20,323	57,100
1988	7,195	29,659	48,185	13,417	10,413	1,520	25,969	43,270	49,875
1989	8,536	16,825	78,825	18,271	14,224	968	32,334	35,312	89,888
1990	16,239	17,755	83,449	15,939	9,863	960	37,237	30,842	84,505
Totals:	64,482	99,031	404,533	116,224	63,292	6,041	212,064	179,920	421,221

Table 8. Biota associated with floating objects in the eastern Pacific Ocean from observations made between 1987-90, from Arenas *et al.* (this volume).

		Number of observations
Tuna		
Yellowfin	*Thunnus albacares*	2,422
Skipjack	*Katsuwonus pelamis*	2,310
Bigeye	*Thunnus obesus*	146
Black skipjack	*Euthynnus lineatus*	1,092
Bullets	*Auxis* spp.	907
Bonito	*Sarda* spp.	37
Billfish		
Marlin	*Makaira* spp.	654
	Tetrapterus spp.	
Sailfish and	*Istiophorus platypteras*	170
Swordfish	*Xiphias gladius*	
Other Fish		
Dorado	*Coryphaena* spp.	3,099
Wahoo	*Acanthocybium solandri*	916
Rainbow runner	*Elagatis bipinulatus*	672
Yellowtail	*Seriola* spp.	
Other large fish[1]		290
Triggerfish	Balistidae	1,638
Small forage fish[2]		1,687
Other small fish[3]		587
Sharks and Rays		
Blacktip shark	*Carcharhinus limbatus*	487
Whitetip shark	*Carcharhinus longimanus*	170
Hammerhead	*Sphyrna* spp.	141
Other Shark	*Carcharhinus* spp.	260
Unidentified shark[4]	*Carcharhinus* spp.	1,672
Manta ray	Mobulidae	140
Sting ray	Rajidae, Dasyatidae	
Other Fauna		
Sea turtles[5]	Chelonidae, Dermochelydae	745
Marine mammals	*Stenella* spp., *Delphinus* spp.	24
Invertebrates[6]		73

Sea Birds		
Red-footed boobies	*Sula sula*	113
Masked boobies	*Sula dactylatra*	502
Brown boobies	*Sula leucogaster*	433
Unidentified booby	*Sula* spp.	351
Shearwaters	*Puffinus* spp.	279
Terns	*Sterna* spp. *Chlidonias* spp.	189
Frigate bird	*Fregata* spp.	675
Petrels	*Pterodroma* spp.	66
Other birds[7]		93
Unidentified bird		325
Epibiota		
Acorn barnacles	Balanomorpha	1,120
Gooseneck barnacles	Lepadomorpha	1,312
Crabs	Decapoda	544
Seaweed		837
Other epibiota		475

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[1] Includes sea bass and cabrilla (Serranidae), and jacks (Carangidae)

[2] Small fishes, usually very abundant. Several families, including: Engraulidae, Clupeidae, Kyphosidae, Haemulidae

[3] Other small fishes not considered baitfish by fishermen such as flying fish (Excocoetidae), small cabrillas (Serranidae) and small scombrids

[4] The most common shark in the tuna fishing grounds is the silky shark (*Carcharhinus falciformis*), but it is difficult to identify.

[5] The most common sea turtle in the EPO is the olive ridley (*Lepidochelyis olivacea*).

[6] Usually squids (Cephalopoda), and jellyfish (Scyphozoa)

[7] Mostly coastal birds such as gulls (Laridae), pelicans (Pelecanidae), and cormorants (Phalacrocoracidae)

Table 9. Number of successful sets and tons of yellowfin tuna by dolphin herd type, 1980-90. Numbers of sets are in parentheses.

	Pure spotted	**Eastern and spotted**	**Whitebelly and spotted**	**Common**
1980	6,295 (627)	99 (91)	3,271 (237)	357 (34)
1981	9,220 (797)	1,682 (158)	5,049 (263)	296 (22)
1982	5,452 (534)	1,593 (110)	3,502 (254)	16 (5)
1983	3,677 (364)	1,416 (116)	4,334 (272)	42 (5)
1984	4,651 (284)	722 (32)	3,074 (163)	-
1985	11,182 (650)	5,739 (305)	4,920 (182)	827 (53)
1986	21,299 (1138)	10,885 (410)	9,902 (332)	2,510 (151)
1987	25,559 (1655)	13,883 (669)	9,567 (405)	1,855 (128)
1988	22,800 (1529)	11,880 (572)	5,930 (271)	3,269 (198)
1989	31,499 (1963)	16,297 (909)	18,984 (701)	5,002 (282)
1990	39,189 (2301)	11,881 (617)	24,437 (896)	1,603 (94)

Table 10. Number of 1-degree areas exploited by the purse-seine fishery by mode of purse seining and year, 1980-90.

	Log	**School**	**Dolphin**
1980	656	632	822
1981	646	588	876
1982	606	516	881
1983	462	381	649
1984	332	346	716
1985	221	341	739
1986	271	296	750
1987	306	331	820
1988	381	398	813
1989	421	508	870
1990	397	424	836

Table 11. Number of sets on different species of tunas, by mode of purse seining and month of the year, 1980-90.

	Log	**School**	**Dolphin**
Jan	315	664	1,843
Feb	569	916	2,069
Mar	872	833	2,993
Apr	861	1,195	2,425
May	616	1,399	2,101
Jun	549	520	2,475
Jul	660	467	2,110
Aug	424	459	2,060
Sep	295	644	1,848
Oct	462	869	1,884
Nov	703	751	2,439
Dec	493	776	1,889

Table 12. Percentages of sets on dolphins, by herd type and month, 1980-90.

	Herd type				
Month	**Spotted**	**Spotted + eastern spinner**	**Spotted + whitebelly spinner**	**Common**	**Total sets**
January	50.24	15.19	15.19	5.26	1,843
February	49.15	19.90	11.91	2.18	2,045
March	53.49	16.81	8.32	3.91	2,993
April	52.37	16.41	9.73	7.30	2,425
May	46.98	17.69	14.31	6.80	2,103
June	43.11	11.36	29.98	5.64	2,482
July	40.26	11.20	31.29	6.14	2,116
August	46.09	17.00	21.16	1.40	2,070
September	51.90	21.82	8.63	1.18	1,865
October	49.71	22.35	7.03	3.59	1,893
November	47.93	16.25	10.56	5.44	2,462
December	51.98	9.76	20.05	3.69	1,895

Table 13. Number of successful sets (in parentheses) and CSS for yellowfin and skipjack for 1980-90 by month and area.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Area 1												
Yellowfin	11.0	13.6	12.4	16.3	17.5	16.8	17.1	15.3	13.6	13.7	8.8	10.6
	(60)	(113)	(217)	(333)	(281)	(165)	(145)	(111)	(120)	(126)	(154)	(63)
Skipjack	21.3	14.1	17.0	33.9	28.8	19.4	29.8	5.8	31.0	25.2	17.3	21.3
	(10)	(79)	(81)	(163)	(153)	(63)	(30)	(14)	(13)	(38)	(69)	(20)
Area 2												
Yellowfin				16.4	24.4	21.7	18.5	17.4	20.3	22.9	18.9	4.8
	(0)	(0)	(0)	(13)	(435)	(1225)	(1130)	(624)	(157)	(137)	(37)	(9)
Skipjack					12.9	14.7	14.5	14.2	5.8	17.5	17.4	42.3
	(0)	(0)	(0)	(0)	(71)	(198)	(240)	(107)	(9)	(39)	(19)	(6)
Area 3												
Yellowfin	13.9	17.5	13.3	13.3	14.8	13.0	14.3	17.4	16.5	16.5	15.7	15.9
	(479)	(950)	(1192)	(802)	(282)	(98)	(116)	(495)	(854)	(768)	(821)	(424)
Skipjack	15.3	12.7	19.1	18.6	15.2	4.2	9.3	9.6	16.2	13.7	10.6	8.1
	(54)	(311)	(316)	(215)	(82)	(11)	(4)	(16)	(66)	(27)	(44)	(23)
Area 4												
Yellowfin	18.1	18.3	20.2	19.9	23.9	22.9	22.2	22.1	23.5	20.4	17.3	16.9
	(270)	(435)	(662)	(437)	(463)	(424)	(441)	(380)	(298)	(285)	(614)	(341)
Skipjack	15.5	16.3	14.7	18.2	10.6	9.1	13.0	18.8	19.0	24.0	14.9	11.9
	(57)	(183)	(151)	(91)	(50)	(73)	(91)	(89)	(105)	(116)	(174)	(93)

Table 13. (continued).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Area 5												
Yellowfin	7.0	7.5	25.3	26.6	22.5	23.9	15.1	24.2	12.9	9.0	17.1	22.0
	(2)	(2)	(72)	(47)	(46)	(18)	(11)	(23)	(15)	(1)	(21)	(15)
Skipjack			2.5	2.7	16.8	1.0					25.8	2.5
	(0)	(0)	(6)	(3)	(4)	(1)	(0)	(0)	(0)	(0)	(4)	(4)
Area 6												
Yellowfin	28.9	27.3	15.2	23.3	28.0	21.7	12.5	26.0	6.0	13.6	21.9	26.1
	(47)	(62)	(29)	(4)	(4)	(6)	(2)	(3)	(1)	(11)	(63)	(158)
Skipjack	28.8	66.7	5.5		3.0			11.8		20.0	11.3	13.4
	(9)	(3)	(2)	(0)	(1)	(0)	(0)	(5)	(0)	(1)	(3)	(11)
Area 7												
Yellowfin	21.7	11.7	12.3	5.6	17.6	14.0		14.0	24.8		13.9	17.5
	(101)	(34)	(4)	(8)	(5)	(7)	(0)	(2)	(28)	(0)	(22)	(78)
Skipjack	21.4	7.0	17.3	47.2							10.0	13.2
	(14)	(2)	(3)	(6)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(14)
Area 8												
Yellowfin	22.3	20.0	30.3	19.6	35.1	40.2			26.7	12.0	18.9	35.5
	(237)	(73)	(56)	(23)	(22)	(18)	(0)	(0)	(3)	(1)	(25)	(86)
Skipjack	32.0	16.1	39.0	56.5							15.2	43.2
	(76)	(16)	(41)	(15)	(0)	(0)	(0)	(0)	(0)	(0)	(6)	(17)

Table 13. (continued).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Area 9												
Yellowfin	12.7	8.4	20.0	18.0	8.4	26.0	21.8	21.9	21.1	20.0	17.7	15.9
	(6)	(10)	(1)	(1)	(5)	(2)	(29)	(83)	(121)	(281)	(195)	(157)
Skipjack	22.7	10.1	77.0	20.7	21.3	76.0	17.2	28.7	13.4	10.8	9.5	8.4
	(3)	(9)	(1)	(18)	(7)	(2)	(5)	(24)	(86)	(151)	(110)	(89)
Area 10												
Yellowfin	17.7	16.7	15.0	16.0	14.7	17.7	12.5	15.5	18.6	13.8	19.8	15.7
	(64)	(129)	(377)	(478)	(586)	(43)	(64)	(63)	(76)	(138)	(280)	(244)
Skipjack	17.4	14.1	14.3	18.0	16.4	24.0	22.4	35.4	26.1	31.0	26.3	19.9
	(36)	(83)	(276)	(420)	(496)	(42)	(77)	(65)	(78)	(164)	(240)	(208)

Table 14. Description of catches per set (including unsuccessful sets) in series of consecutive sets on a floating object (all sets, regardless of whether the species is present). Q1 = first quartile; Q3 = third quartile; Q3-Q1 = interquartile range; Max = maximum value.

	N	Mean	S.E.	Q1	Median	Q3	Q3-Q1	Max
				YELLOWFIN				
Day 1	361	19.06	1.41	1	8.0	25	24	176
Day 2	361	14.50	1.46	1	6.0	18	17	342
Day 3	88	17.90	3.04	1	7.5	20	19	165
Day 4	22	13.36	3.43	3	9.5	18	15	75
Day 5	7	9.14	2.59	4	10.0	15	11	20
				SKIPJACK				
Day 1	361	29.48	2.39	1	11	40	39	402
Day 2	361	20.45	1.81	0	6	22	22	208
Day 3	88	14.53	3.77	0	2	18	18	300
Day 4	22	7.64	2.36	0	2	10	10	39
Day 5	7	0.71	0.71	0	0	0	0	5
				OTHERS				
Day 1	361	10.54	1.25	0	1	10	10	180
Day 2	361	4.78	0.65	0	0	5	5	140
Day 3	88	3.95	0.89	0	0	4	4	50
Day 4	22	2.55	1.20	0	0	1	1	22
Day 5	7	4.43	2.94	0	0	10	10	20
				ALL TUNAS				
Day 1	361	59.08	2.92	20	45.0	88	68	402
Day 2	361	39.72	2.45	10	25.0	50	40	362
Day 3	88	36.39	4.93	8	24.0	45	37	300
Day 4	22	23.55	4.06	8	19.5	40	32	75
Day 5	7	14.29	4.06	5	11.0	24	19	30

Table 15. Description of CSSs in series of consecutive sets on a floating object. Q1 = first quartile; Q3 = third quartile; Q3-Q1 = interquartile range; Max = maximum value.

	N	**Mean**	**S.E.**	**Q1**	**Median**	**Q3**	**Q3-Q1**	**Max**
					YELLOWFIN			
Day 1	312	22.06	1.57	4	12.0	28	24	176
Day 2	307	17.05	1.67	2	9.0	21	19	342
Day 3	76	20.72	3.41	3	12.0	26	23	165
Day 4	22	13.36	3.43	3	9.5	18	15	75
Day 5	7	9.14	2.59	4	10.0	15	11	20
					SKIPJACK			
Day 1	303	35.12	2.73	5.0	17.0	50	45	402
Day 2	298	24.78	2.11	2.0	10.0	30	28	208
Day 3	70	18.27	4.65	2.0	8.0	21	19	300
Day 4	16	10.50	2.95	1.5	7.0	20	18	39
Day 5	2	2.50	2.50	0.0	2.5	5	5	5

Table 16. Percentages of the catch of various species in consecutive sets.

	Yellowfin	**Skipjack**	**Other**
Day 1	32.3	49.9	17.8
Day 2	36.5	51.5	12.0
Day 3	49.2	39.9	10.9
Day 4	56.7	32.4	10.8
Day 5	64.0	5.0	31.0

Table 17. Proportions of school types in the catches per set in consecutive sets.

	Day				
	1 **(n = 361)**	**2** **(n = 361)**	**3** **(n = 88)**	**4** **(n = 22)**	**5** **(n = 7)**
SCHOOL TYPE					
Pure yellowfin	7.2	7.5	10.2	27.3	42.9
Pure skipjack	6.9	8.0	6.8	0.0	0.0
Yellowfin + skipjack	24.7	29.1	21.6	36.4	14.3
Other tunas	1.9	1.1	0.0	0.0	0.0
Yellowfin + other tunas	6.9	8.9	10.2	0.0	28.6
Skipjack + other tunas	4.7	5.8	6.8	0.0	0.0
Yellowfin + skipjack + other tunas	47.6	39.6	44.3	36.4	14.3
Schools with skipjack	83.9	82.5	79.5	72.8	28.6
Schools with yellowfin	86.4	85.1	86.4	100.0	100.0

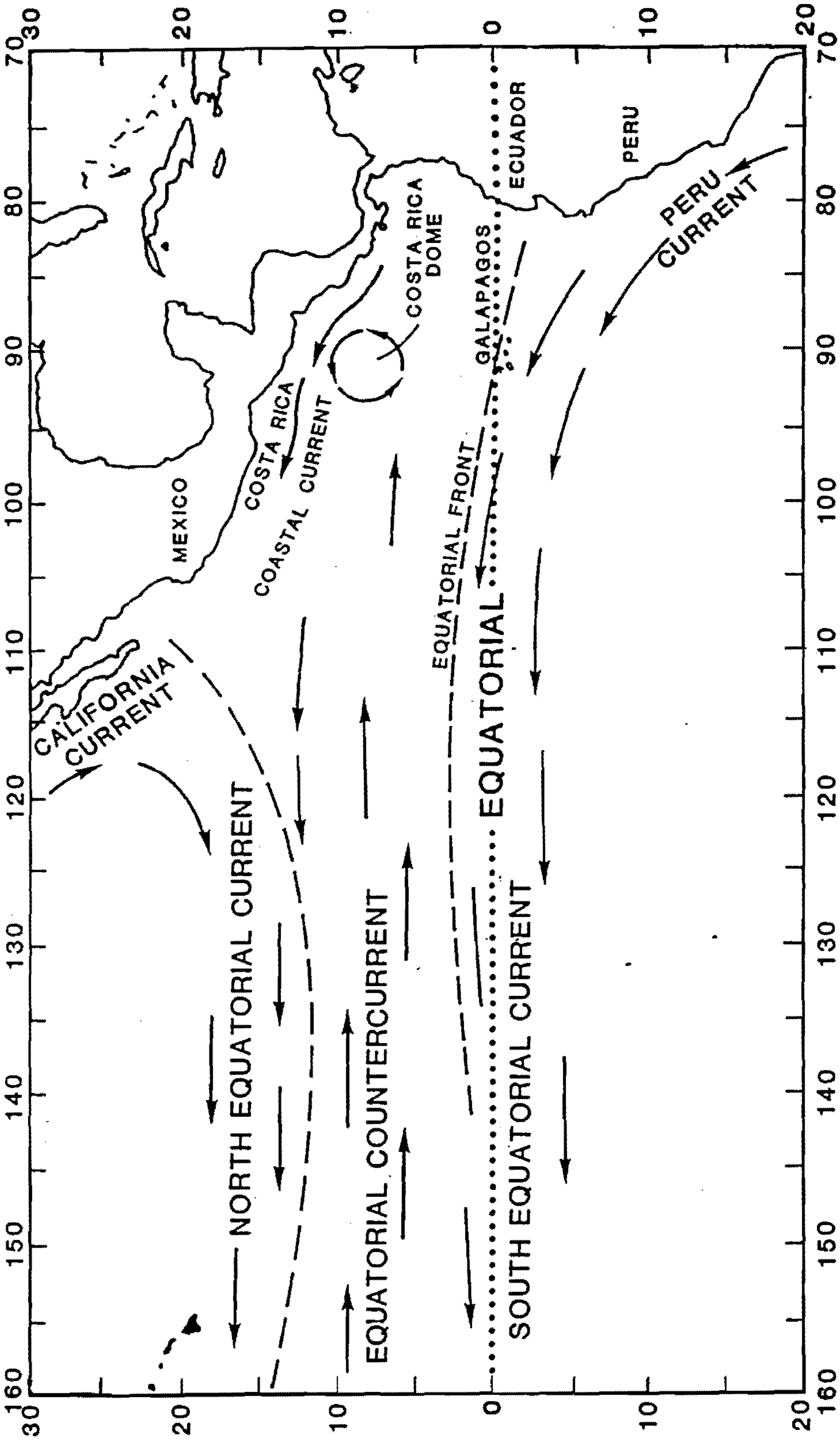


Figure 1. The eastern Pacific Ocean. Circulation patterns based on Wyrtki (1974).

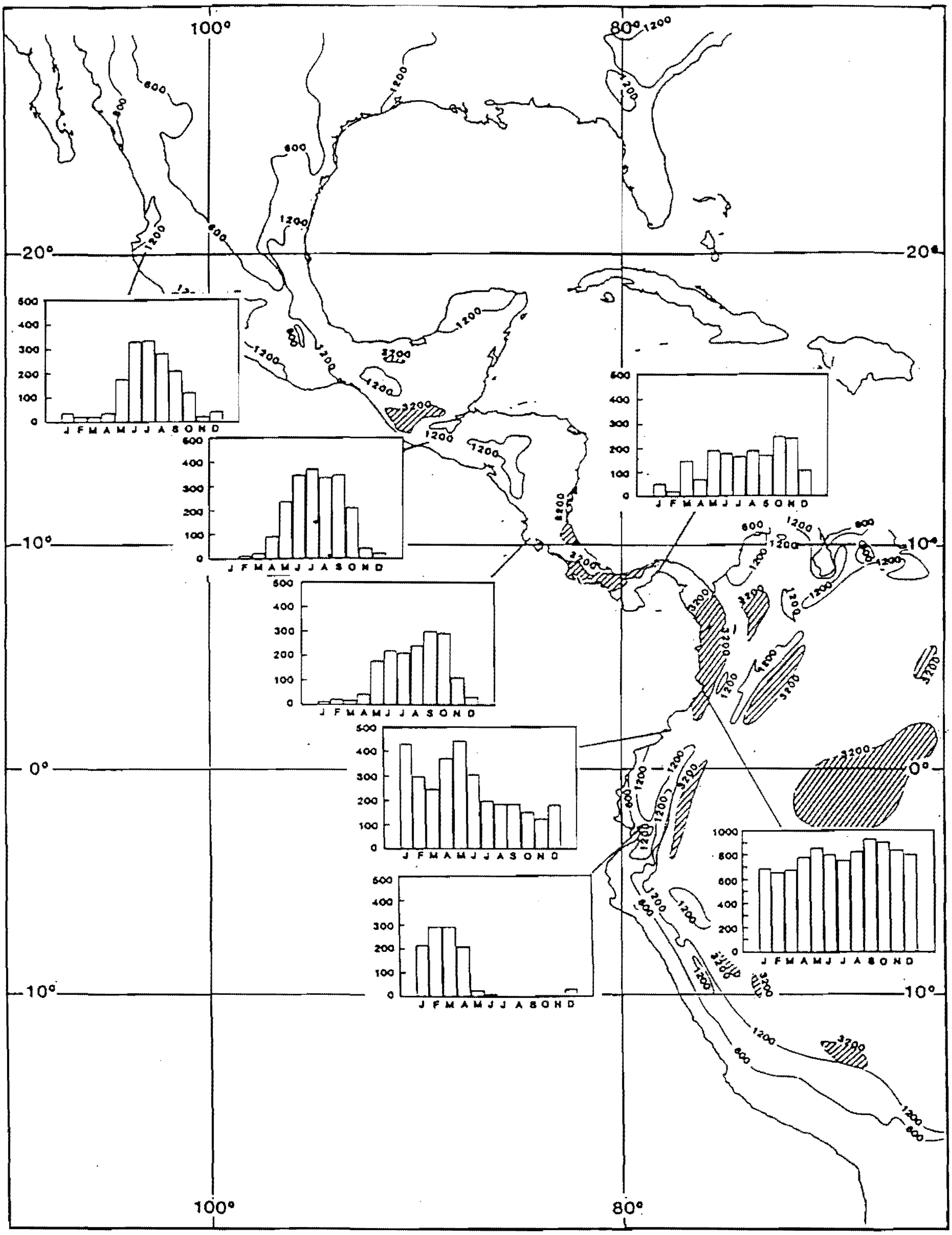


Figure 2. Average annual precipitation (mm) over the continent and average monthly precipitation (mm) at selected stations. Shaded areas indicate areas of high precipitation. Based on Hoffman (1975), Anonymous (1976) and Steinhauser (1979).

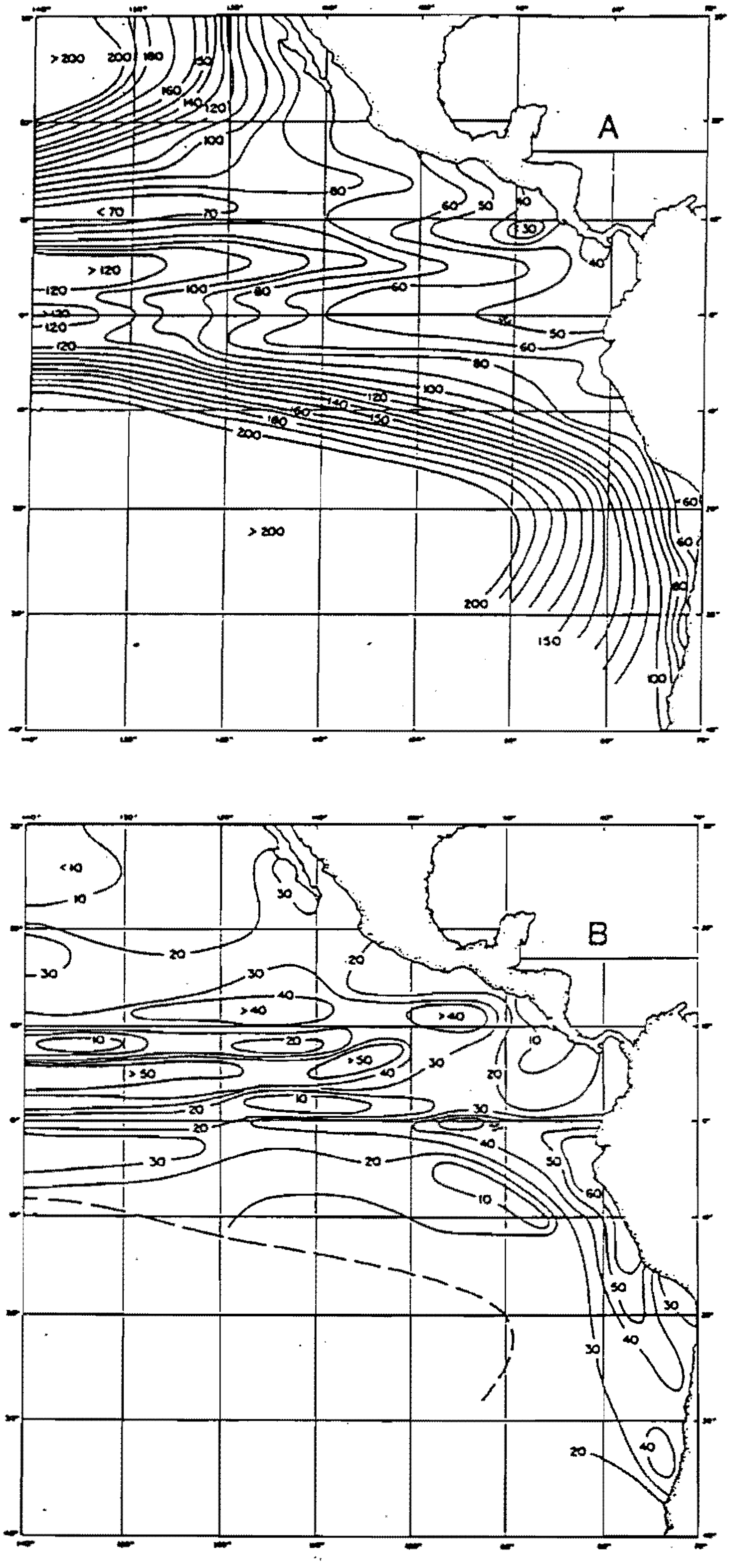


Figure 3. Average depth (m) and annual variations (m) of the center of the permanent thermocline, from Wyrtki (1964).

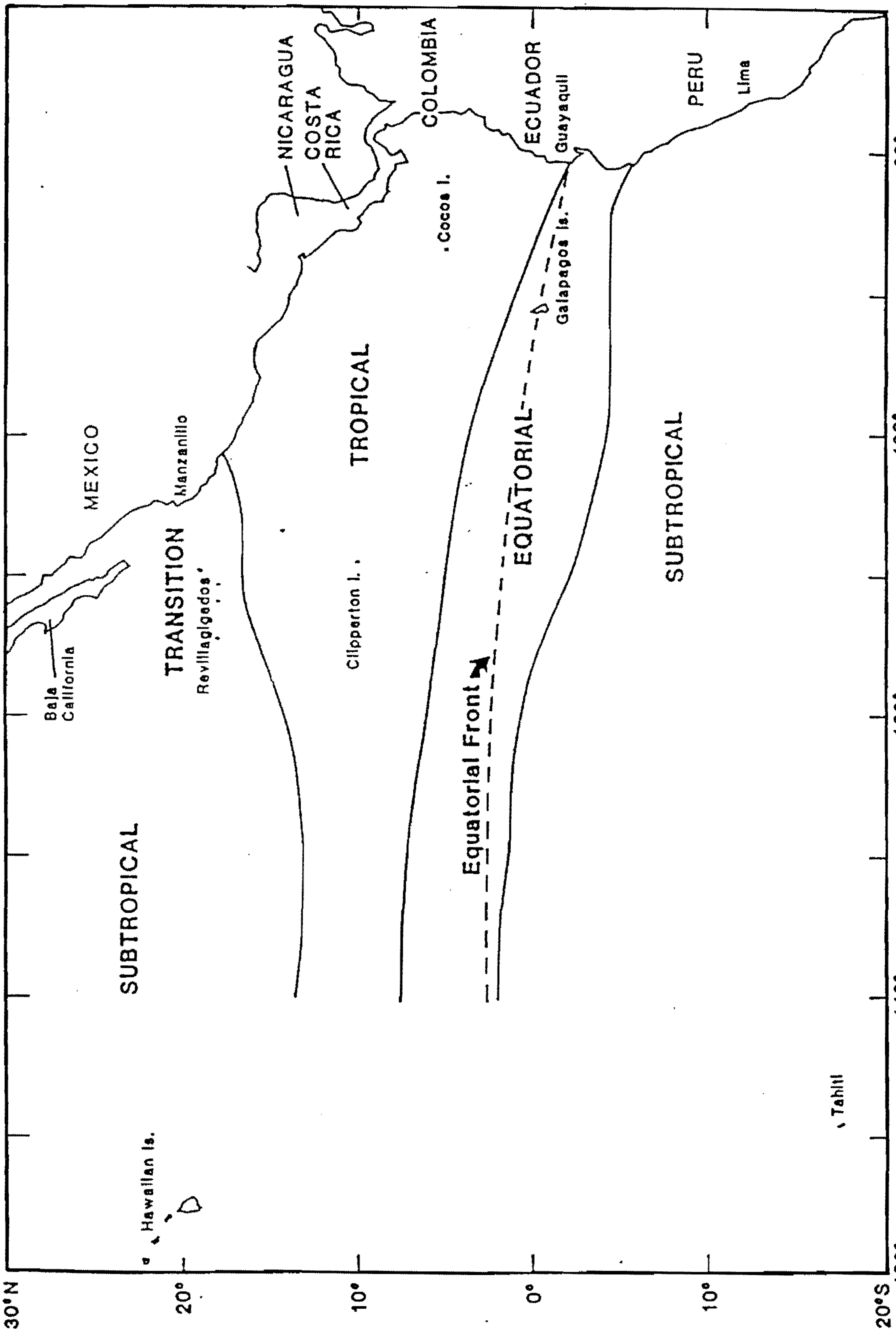


Figure 4. Surface water masses of the eastern tropical Pacific Ocean, from Wyrtki (1967).

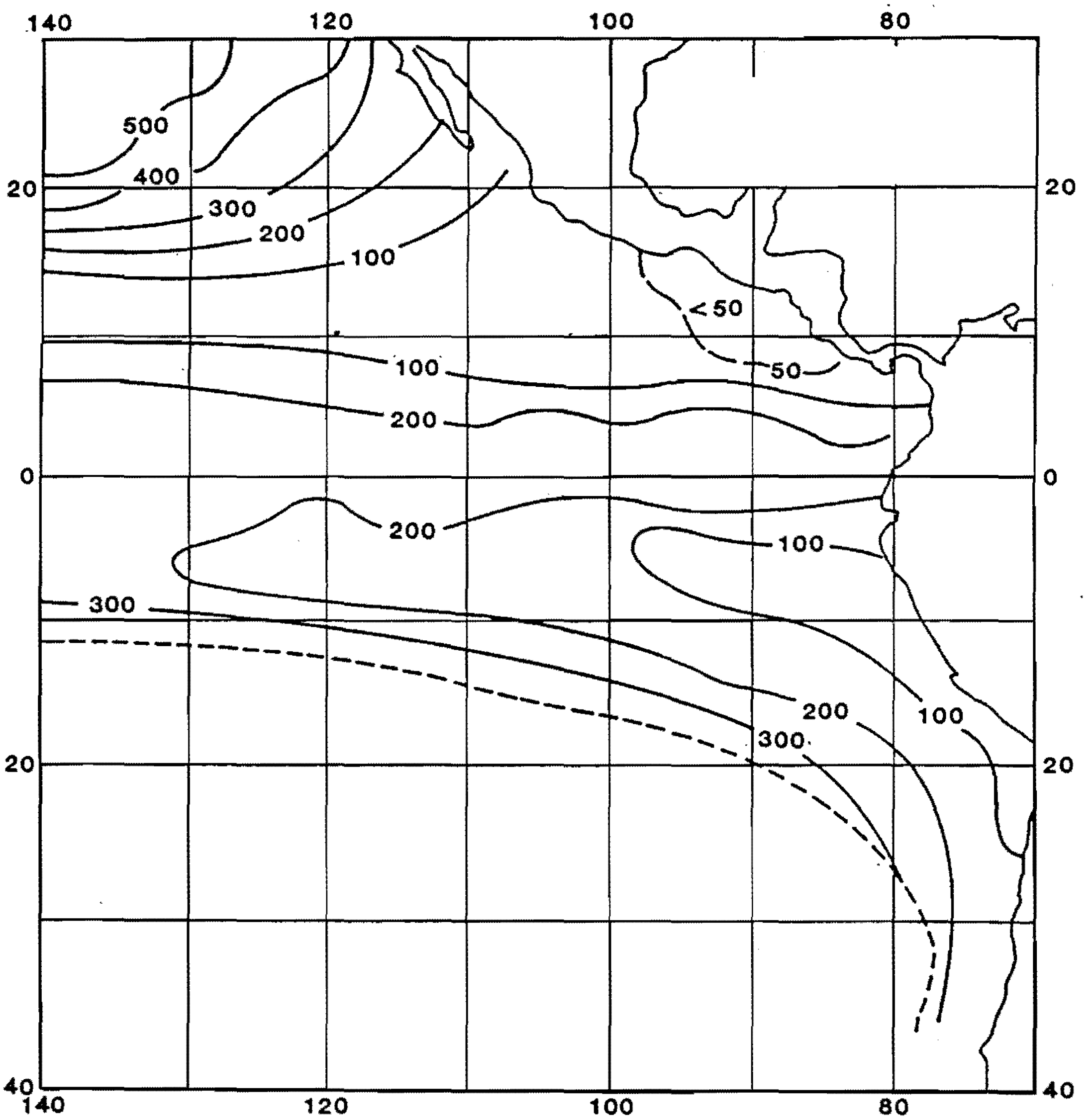


Figure 5. Depth (m) of the upper boundary of the oxygen minimum layer, from Wyrtki (1967).

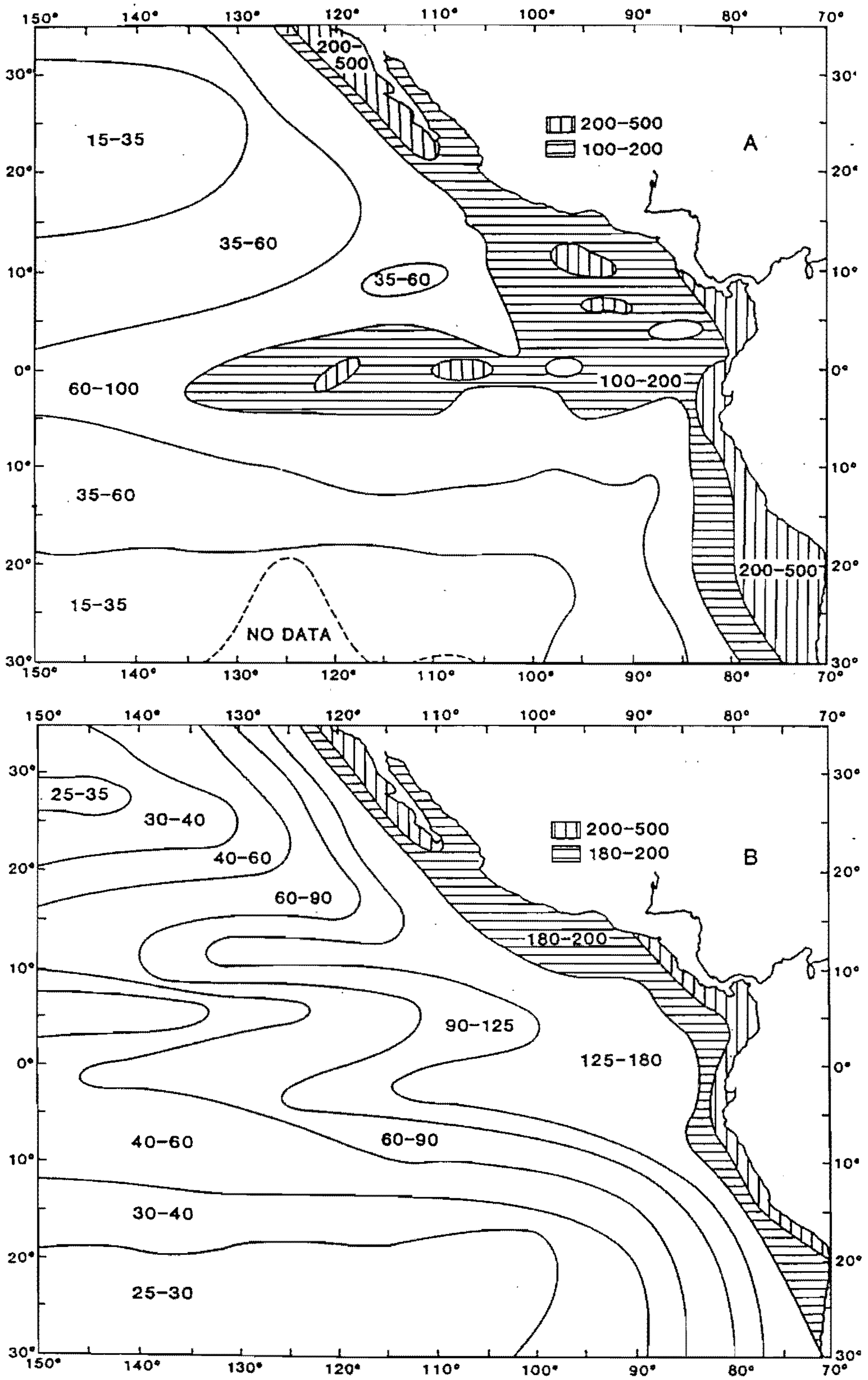


Figure 6. Average (A) and synthetic (B) primary productivity (gC/M2/yr). Redrawn from Berger *et al.* (1988).

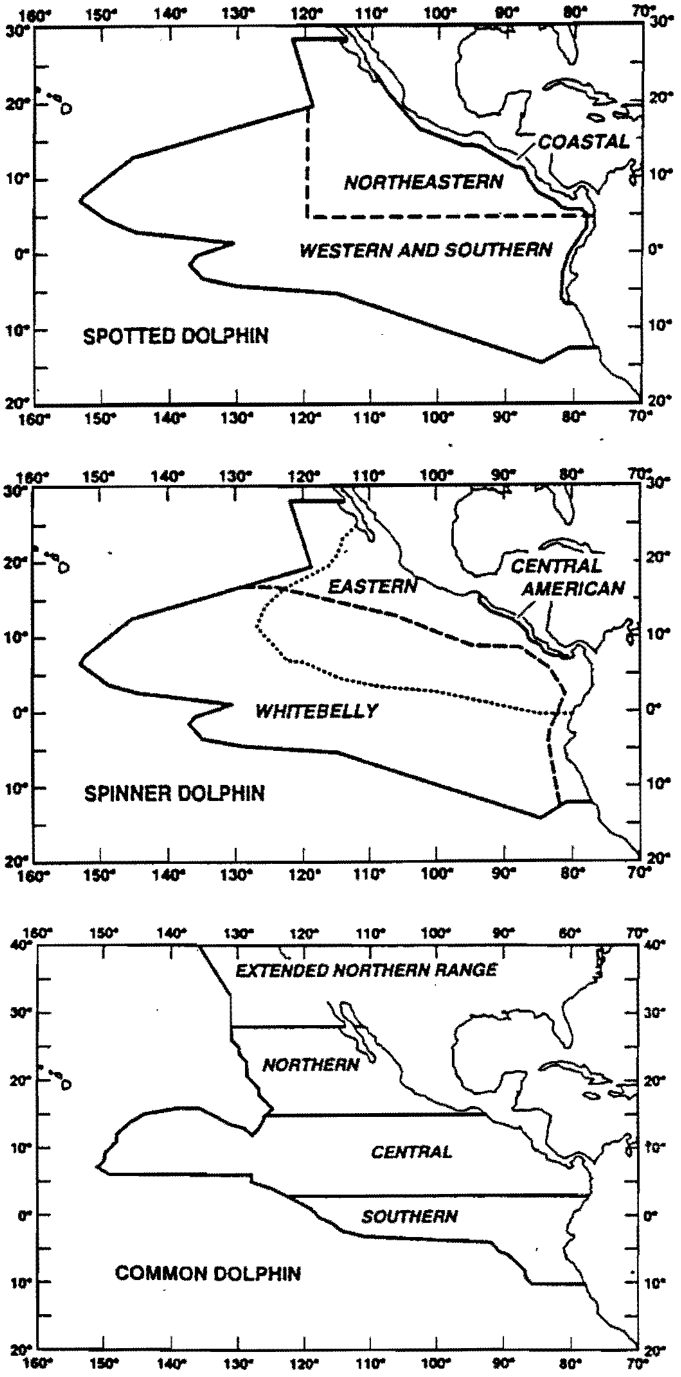


Figure 7. Geographical distribution of the stocks of spotted, spinner, and common dolphins in the eastern Pacific Ocean, from Anonymous (Figure 33, 1994).

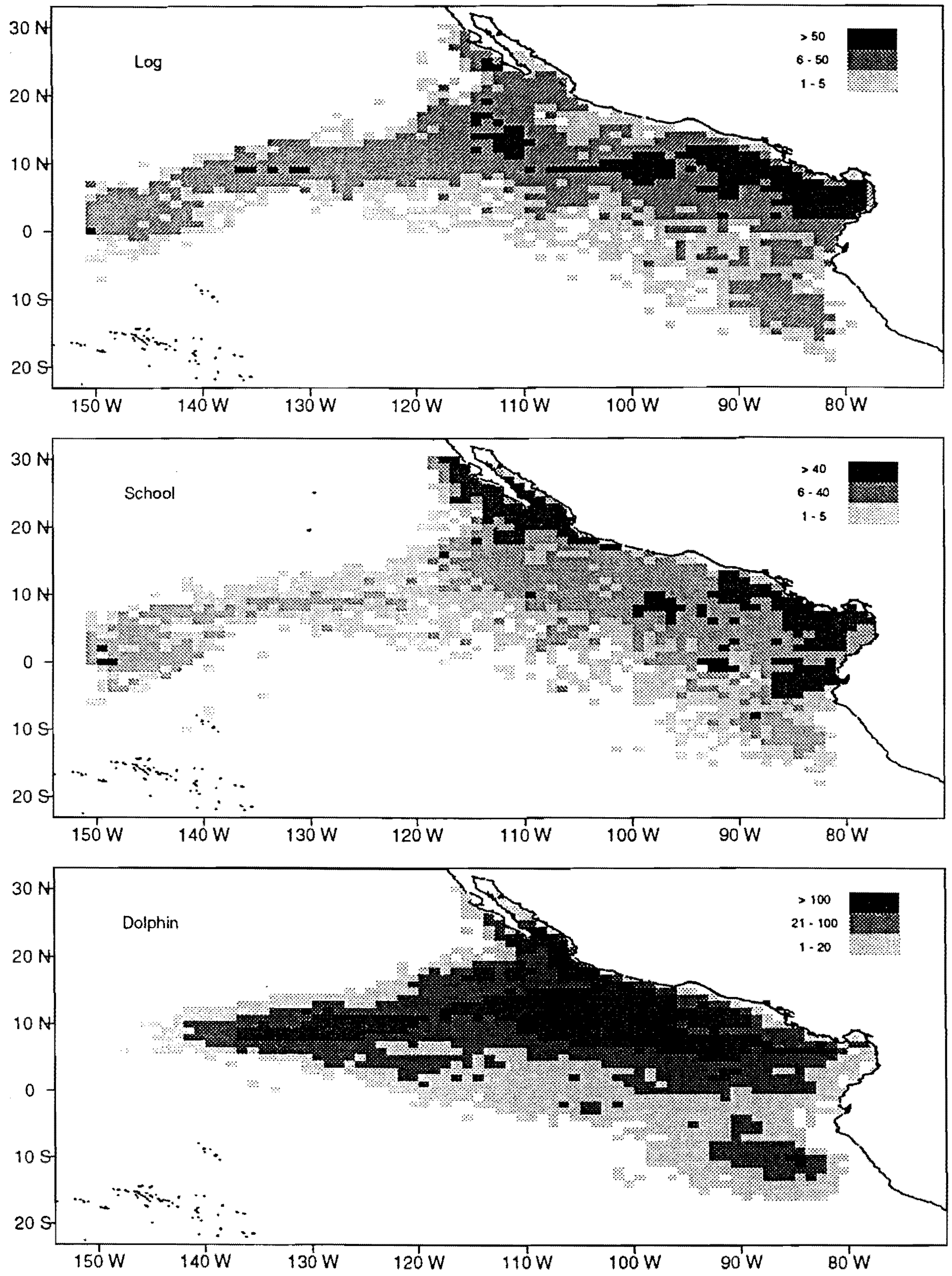


Figure 8. Distribution of log, school and dolphin sets, expressed as number of sets per 1-degree area, for the period 1980-90.

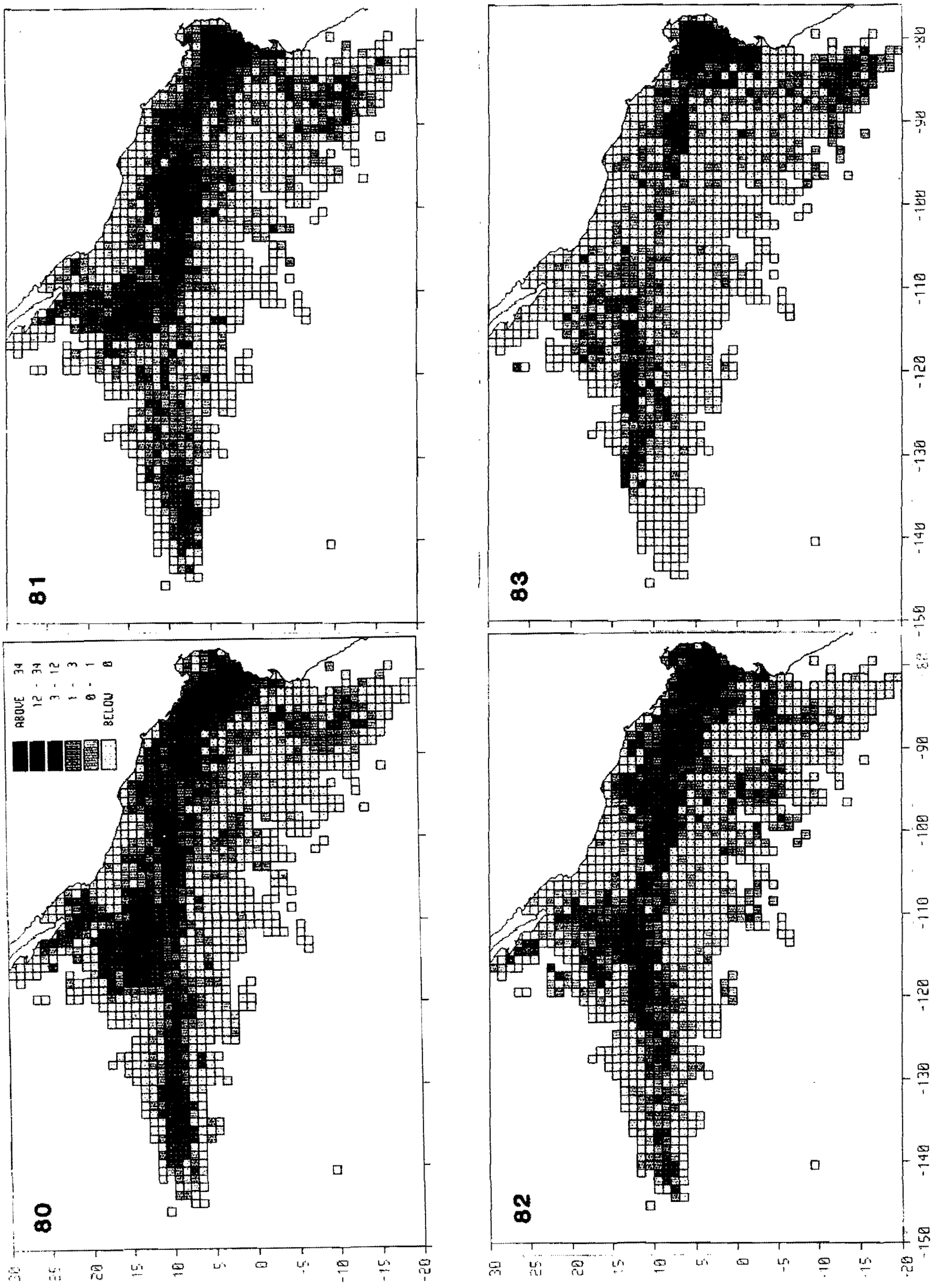


Figure 9. Annual distribution of log sets for 1980-90, expressed as number of sets per 1-degree area.

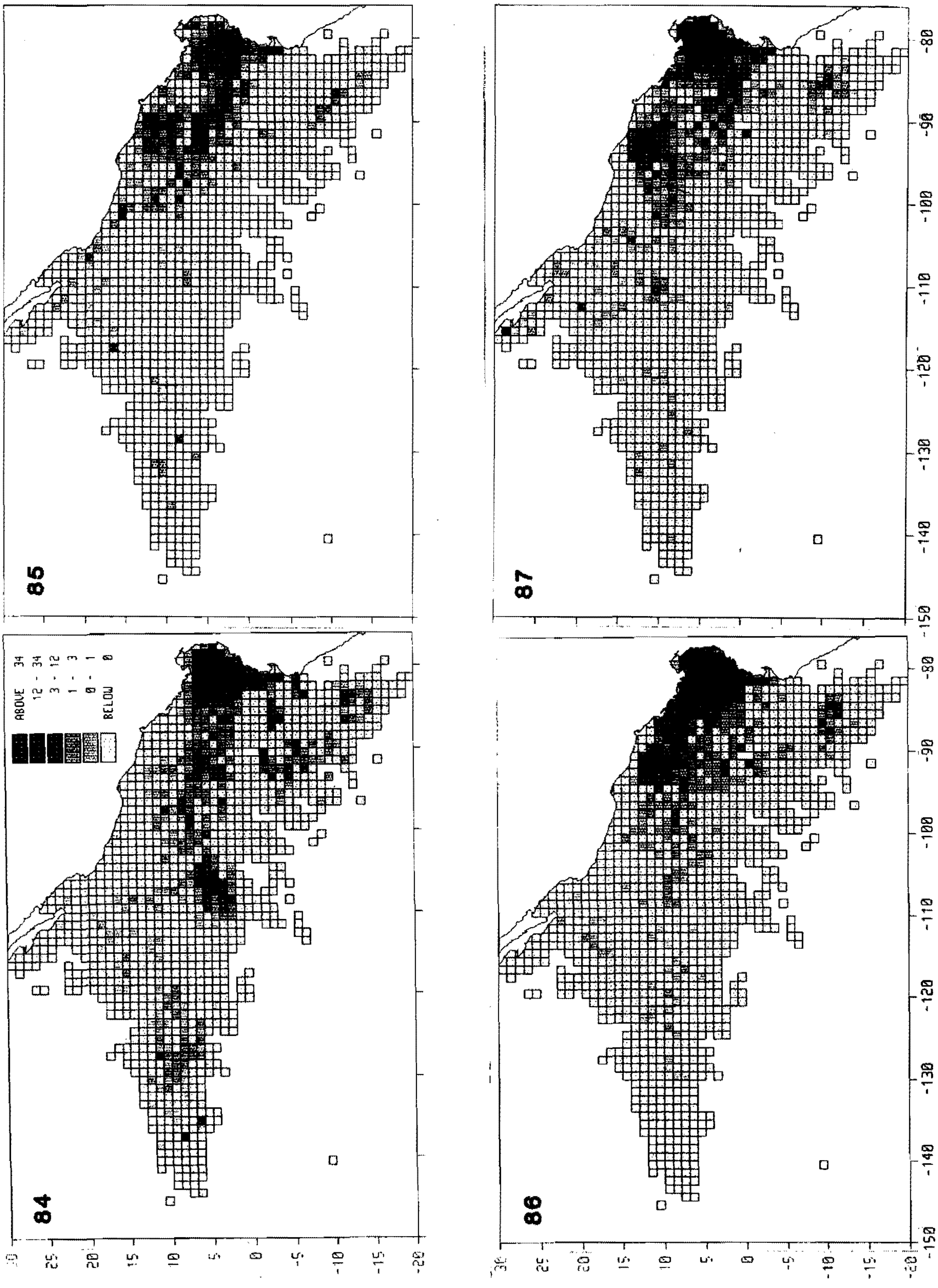
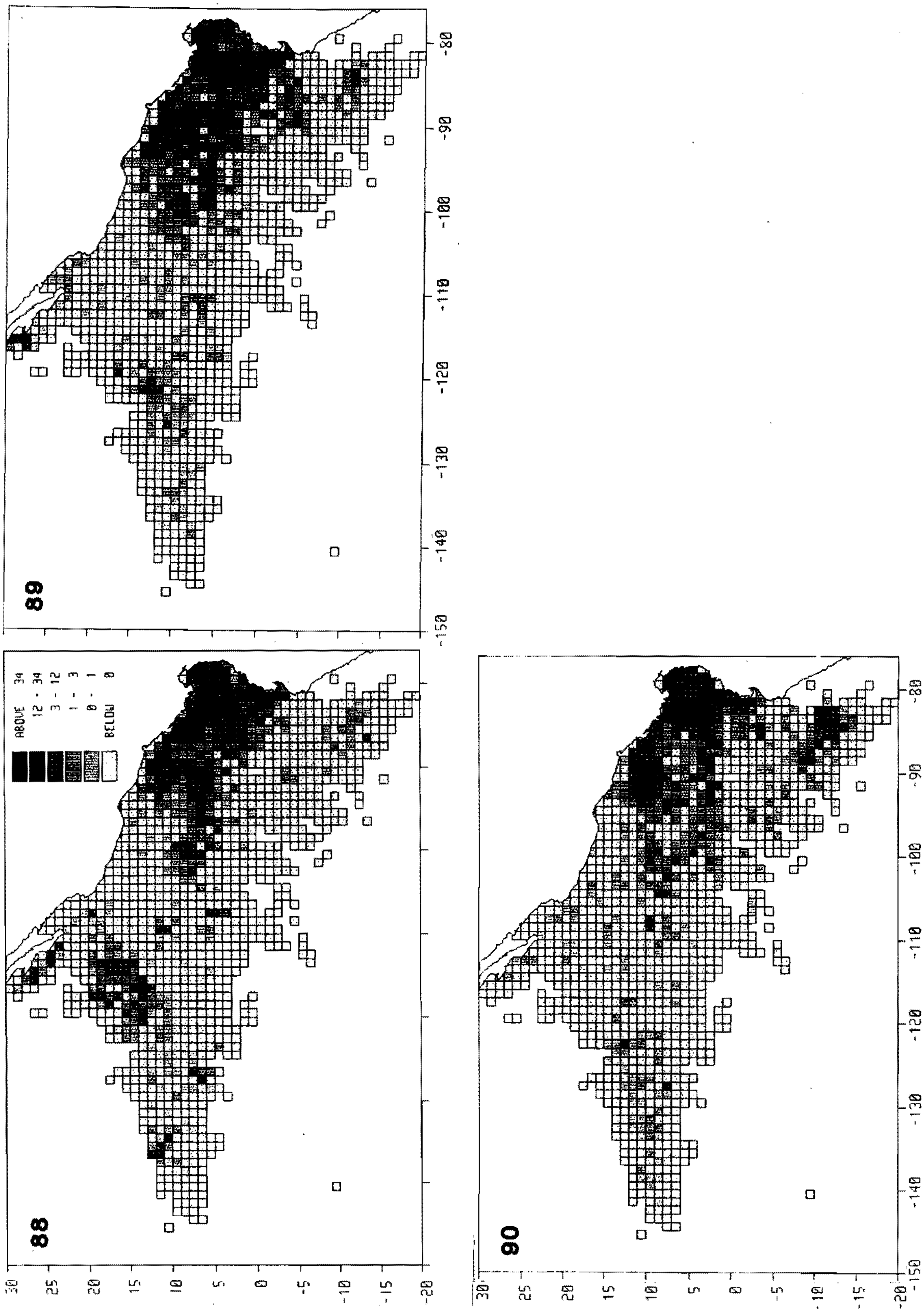


Figure 9. Continued.



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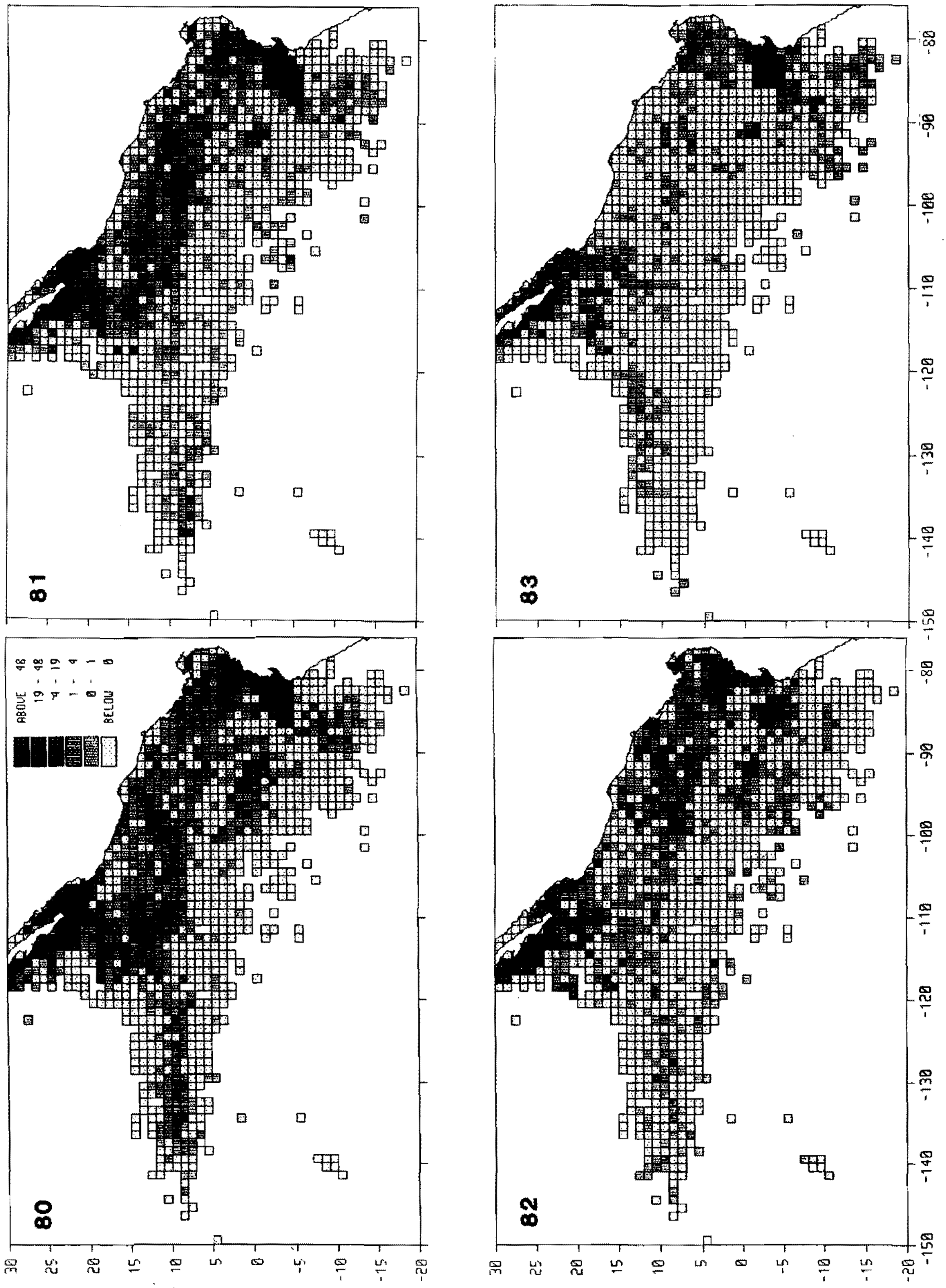


Figure 10. Annual distribution of school sets for 1980-90, expressed as number of sets per 1-degree area.

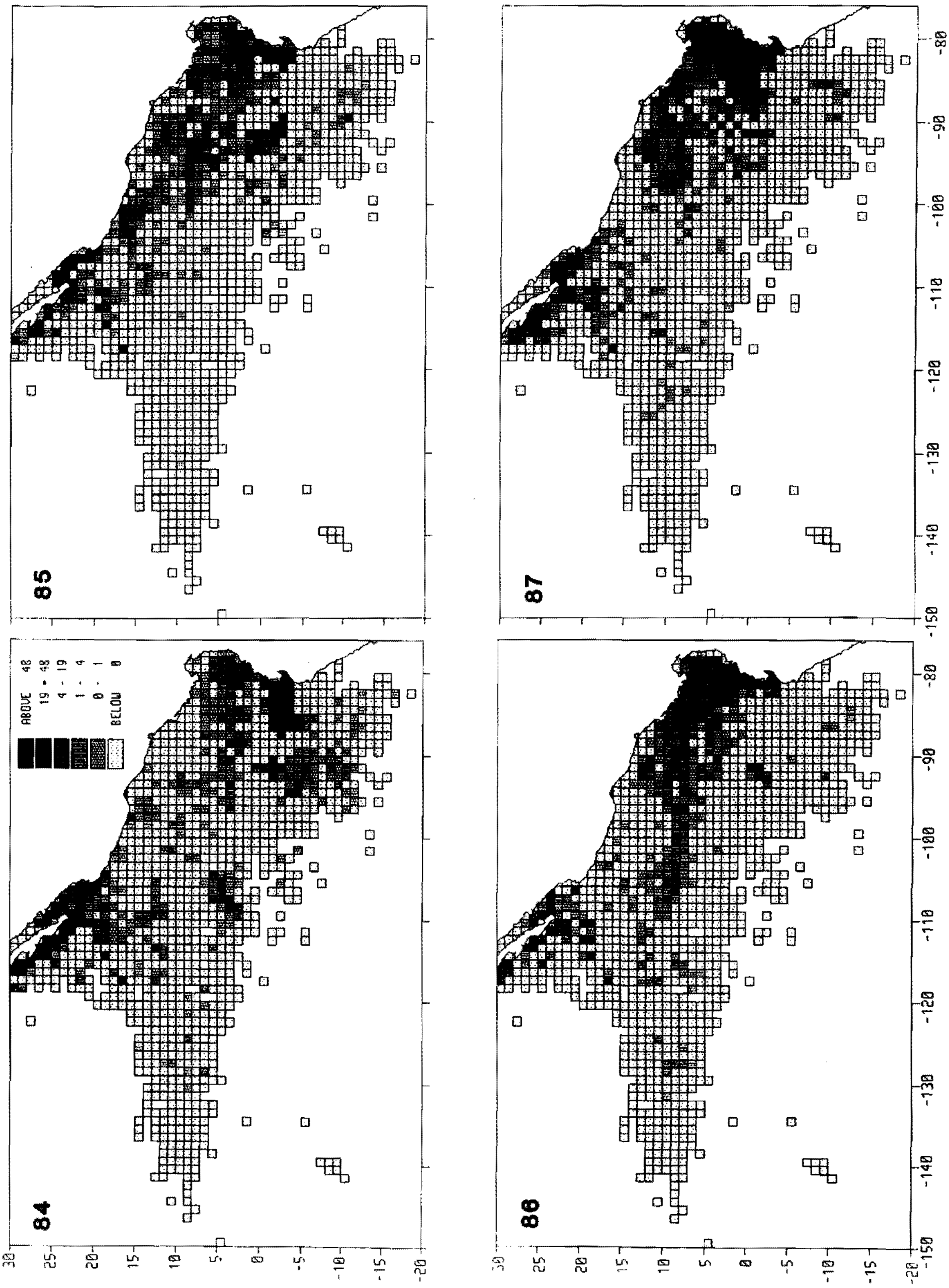
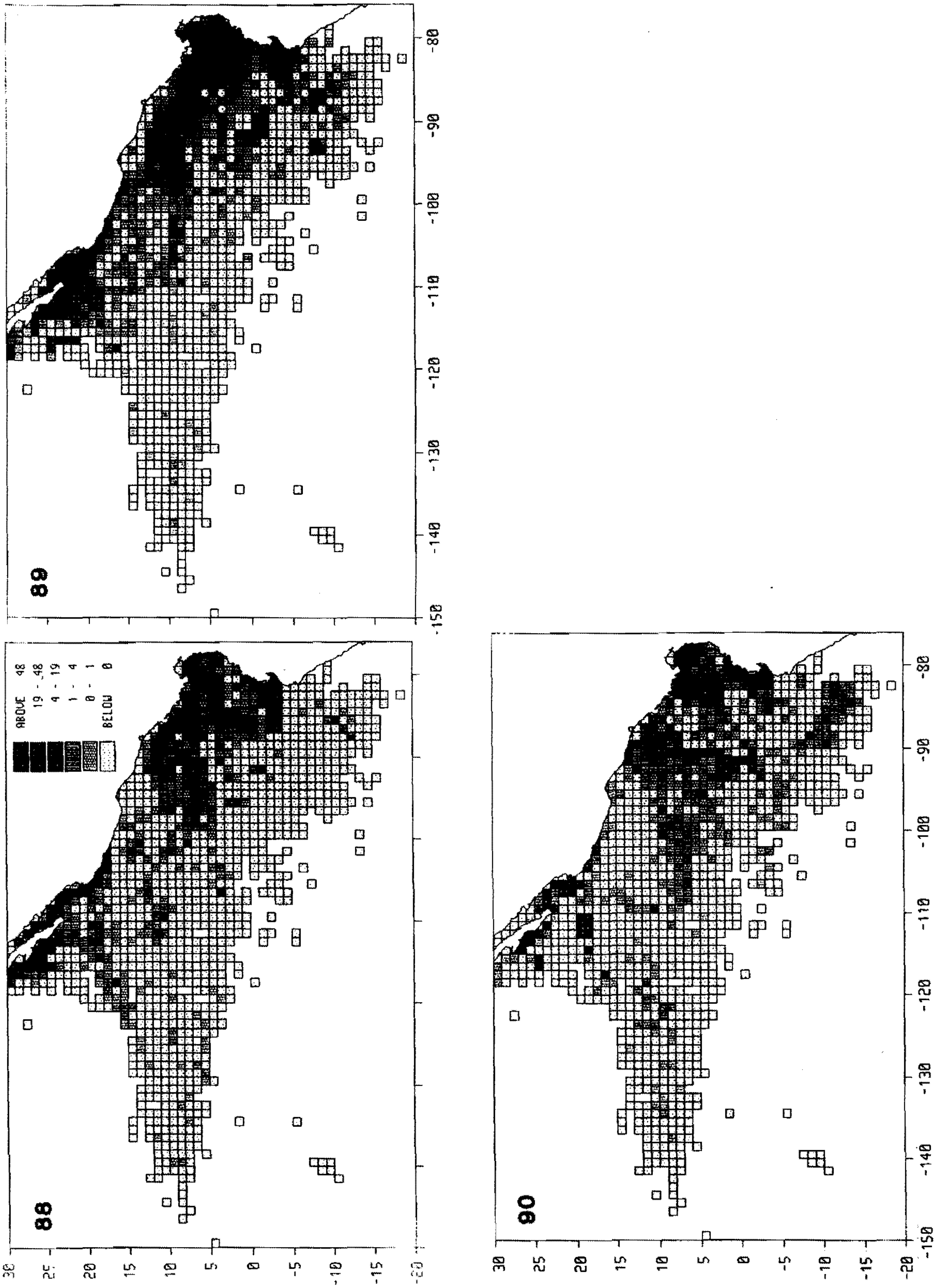


Figure 10. Continued.



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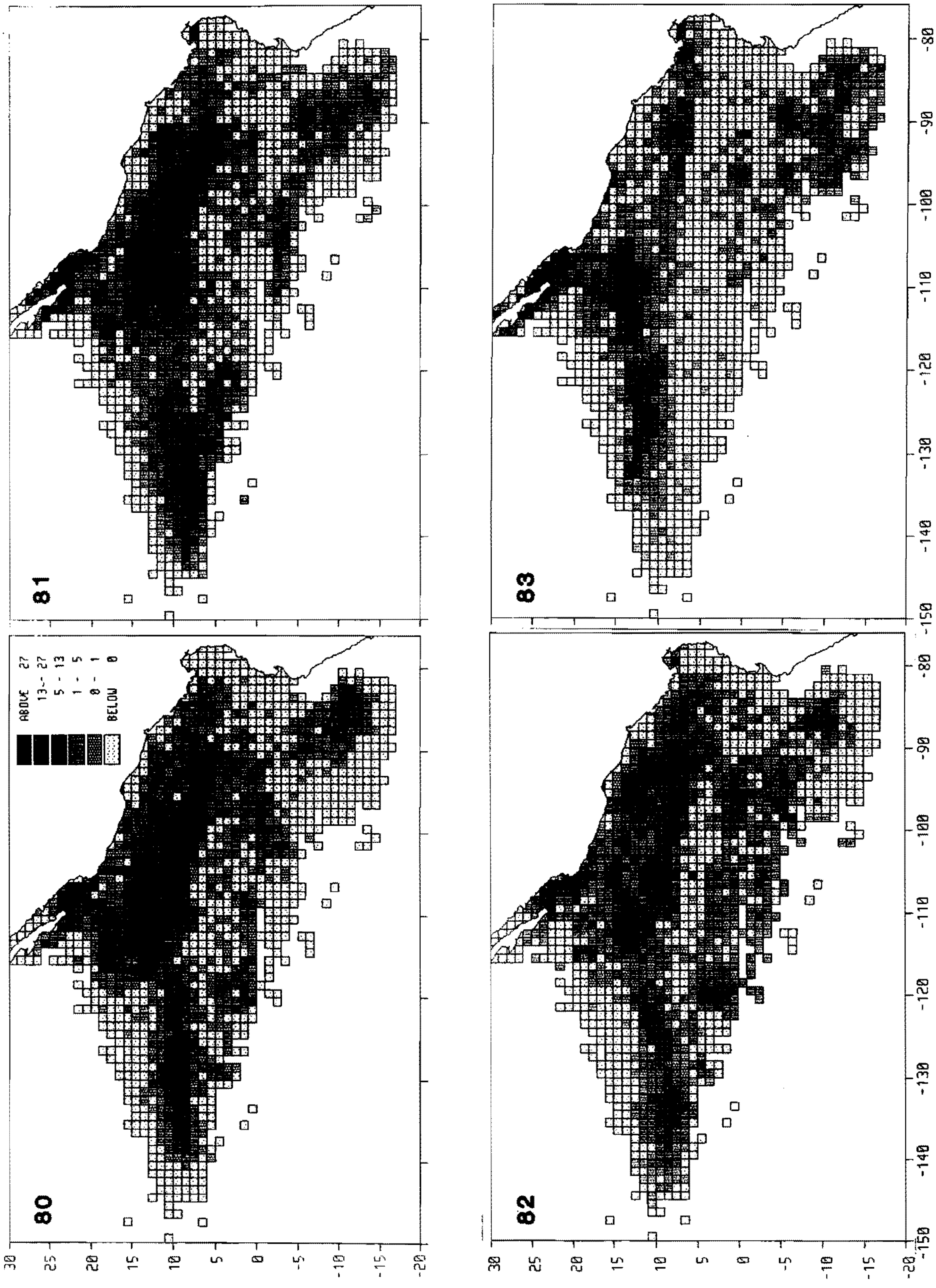
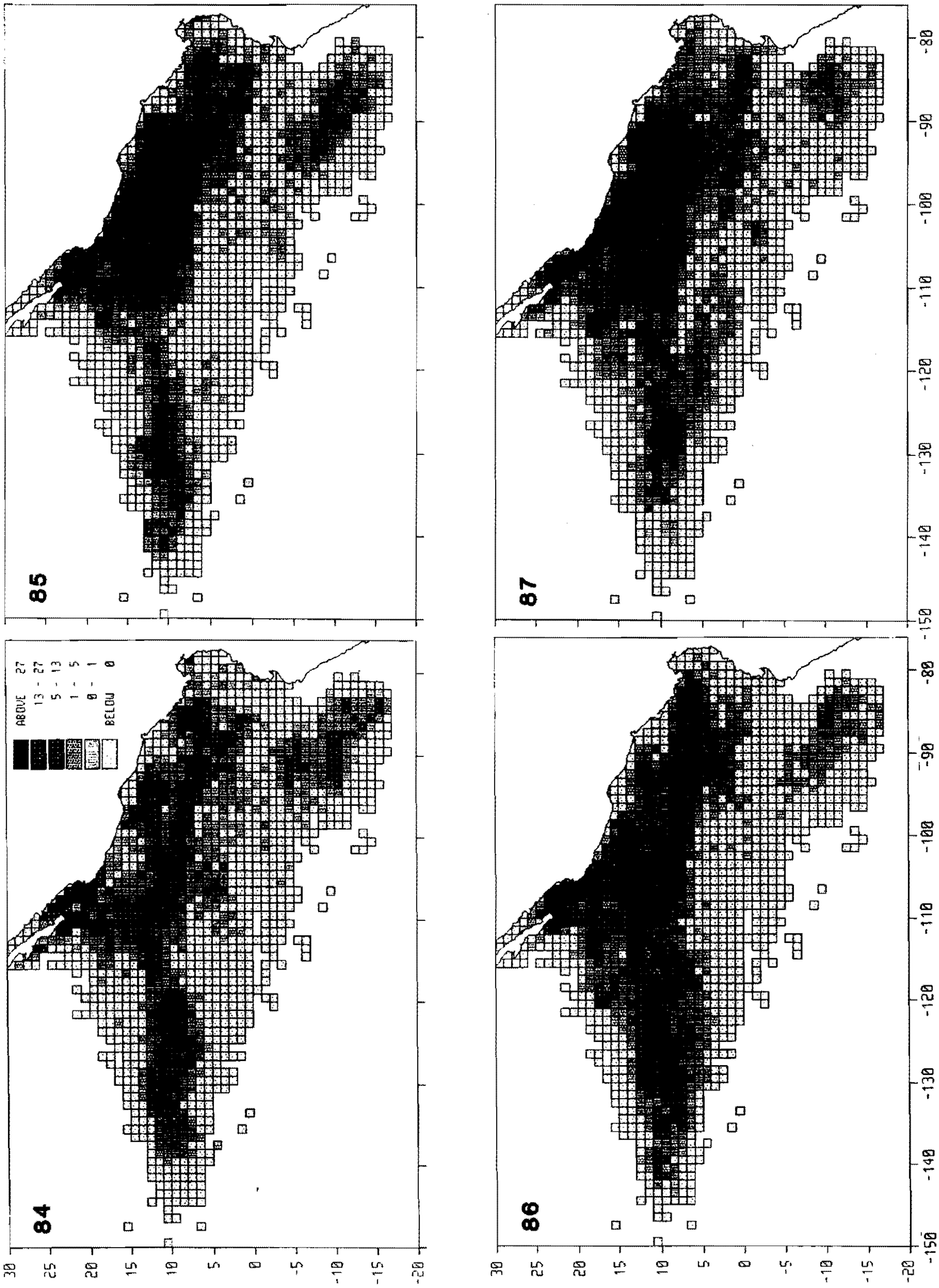


Figure 11. Annual distribution of dolphin sets for 1980-90, expressed as number of sets per 1-degree area.



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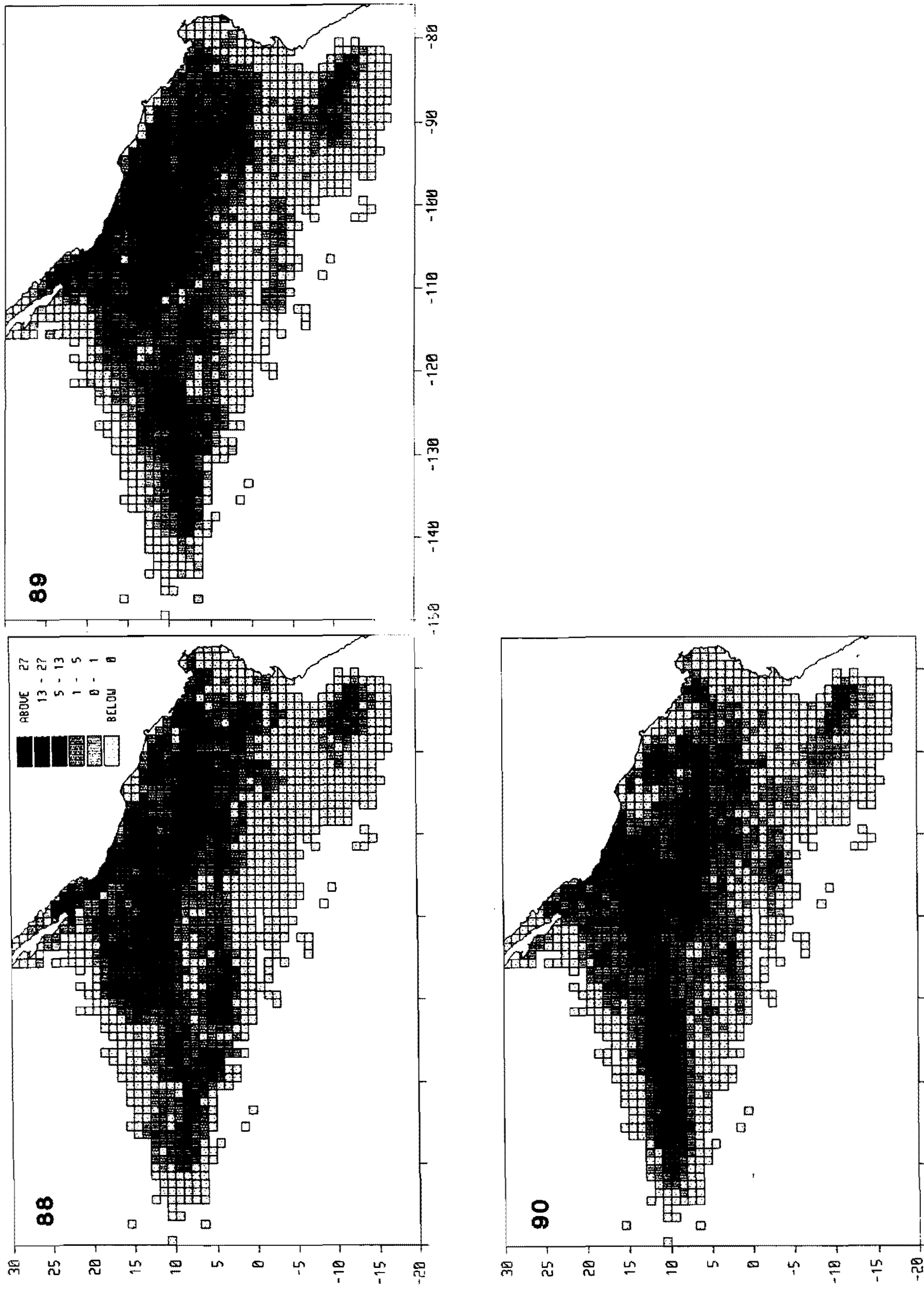


Figure 11. Continued.

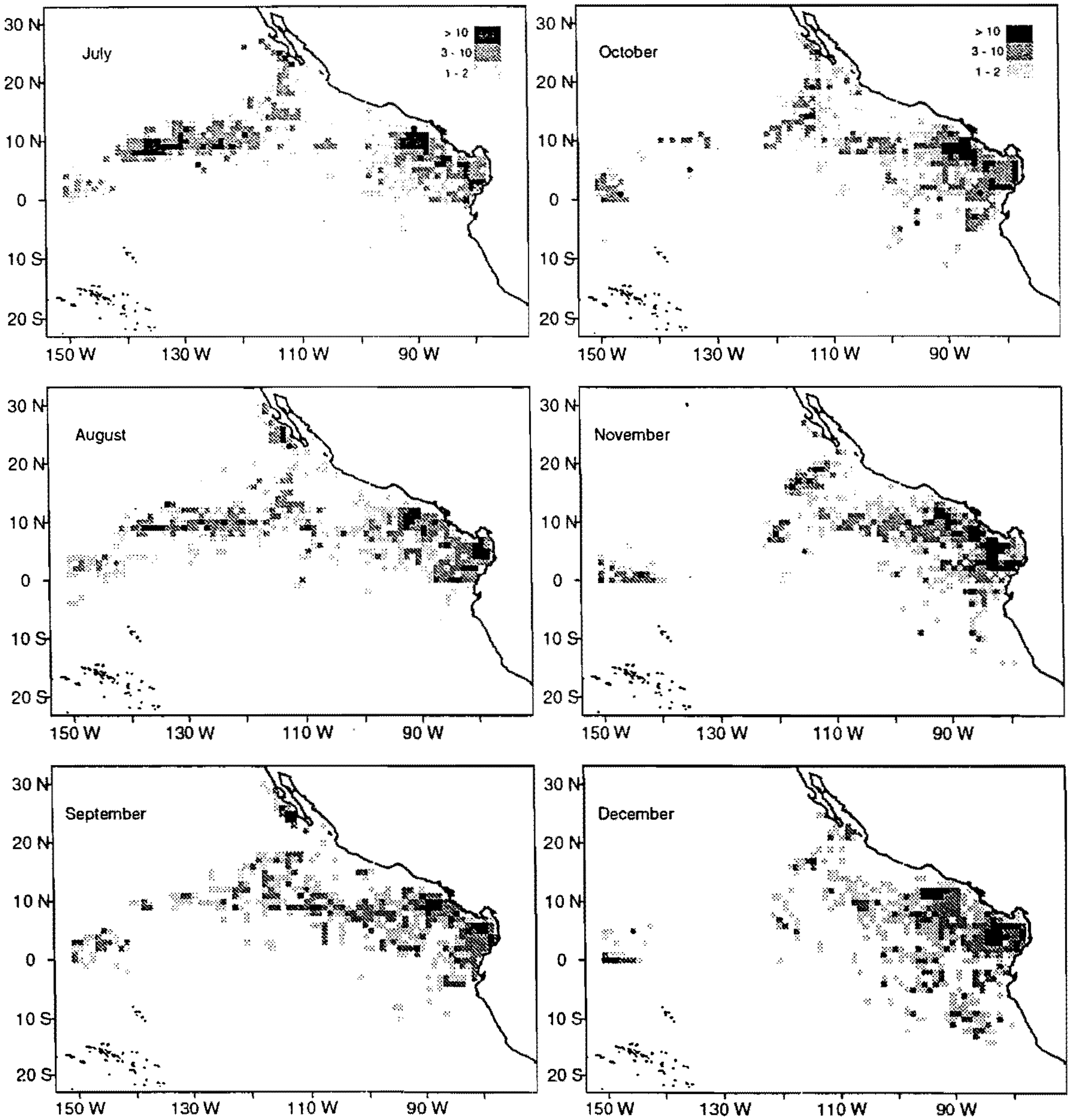


Figure 12. Monthly distribution of log sets for 1980-90, expressed as number of sets per 1-degree area.

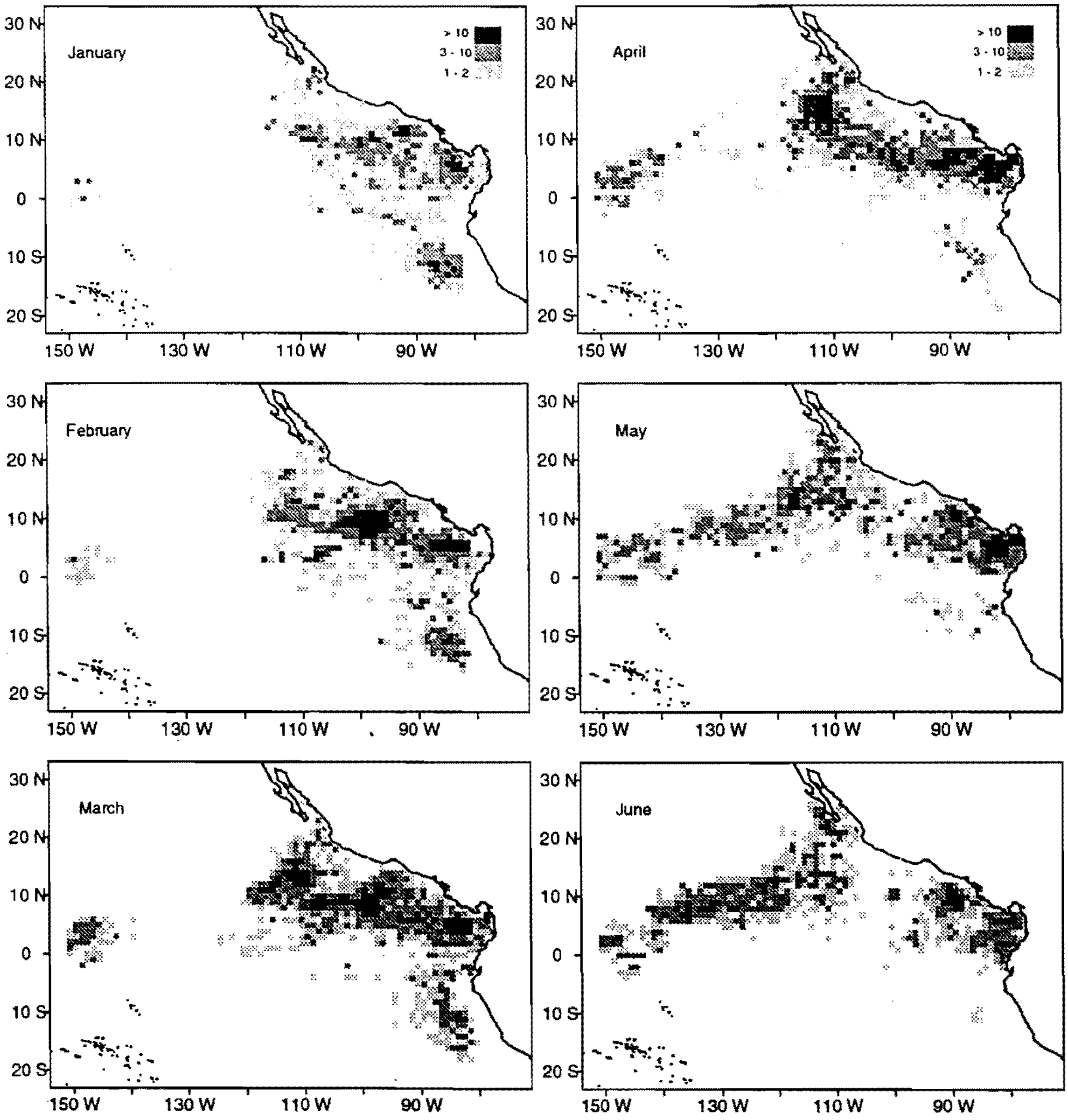


Figure 12. Continued.

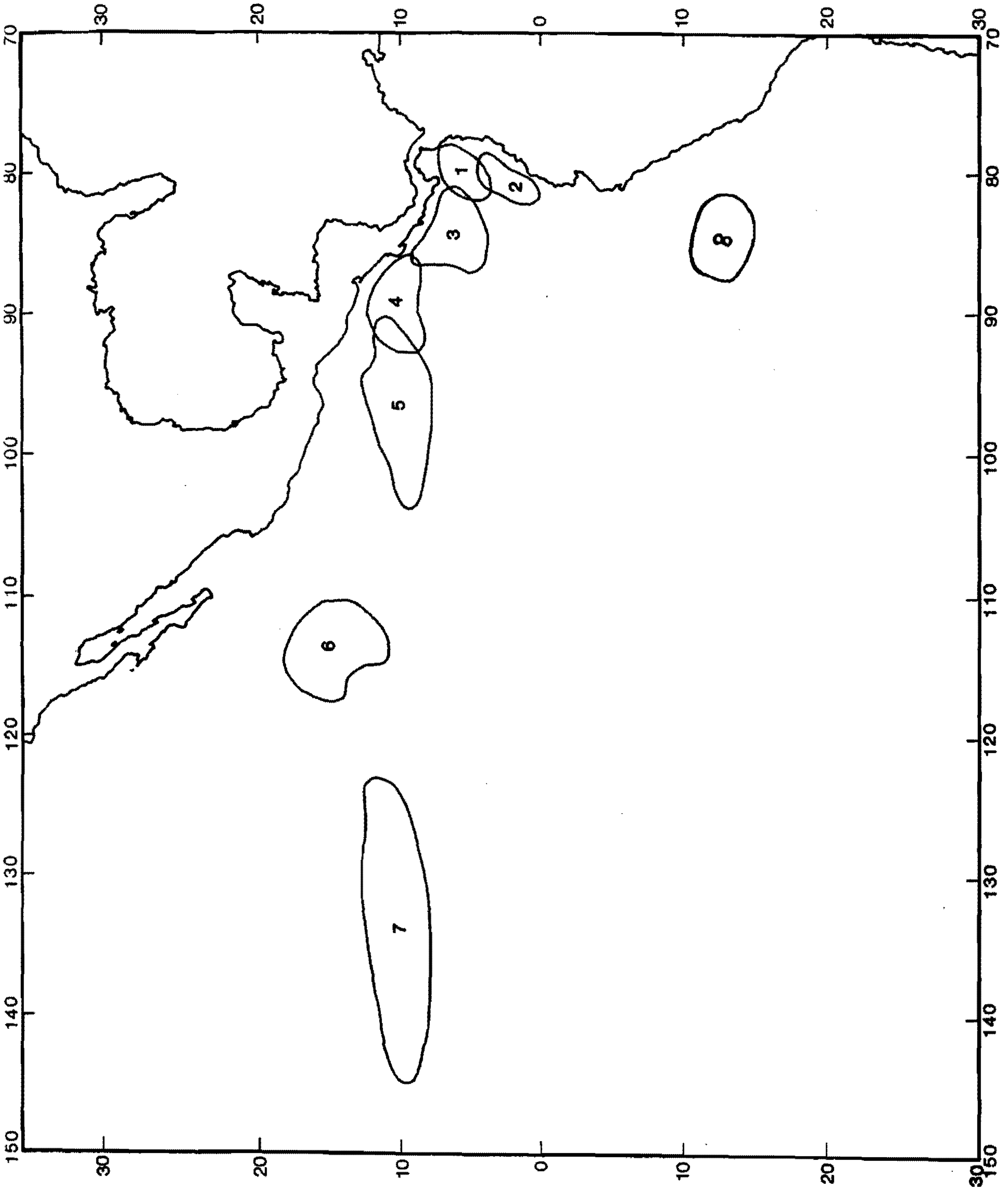


Figure 13. Generalized log fishing areas for the period 1980-90.

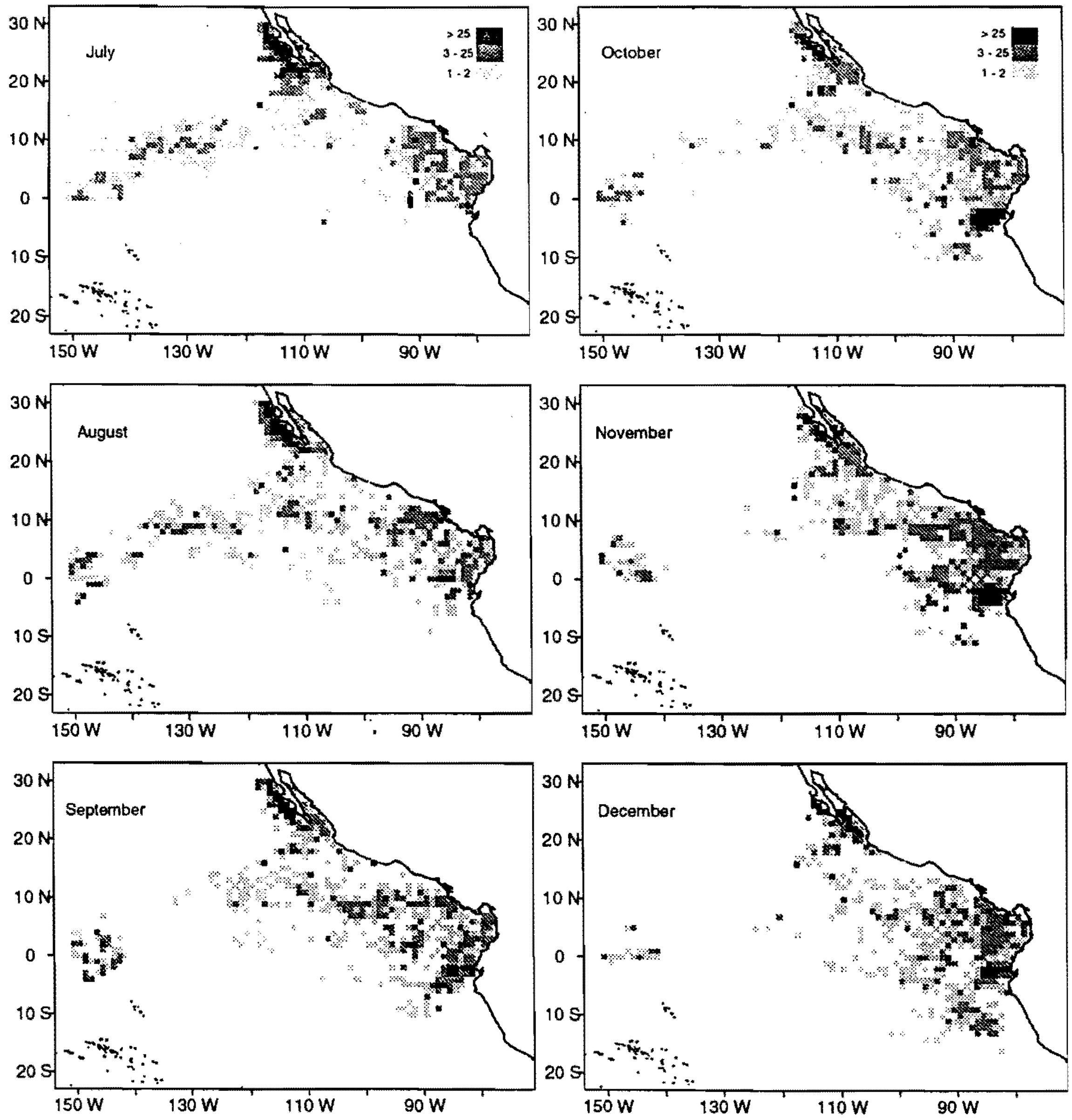
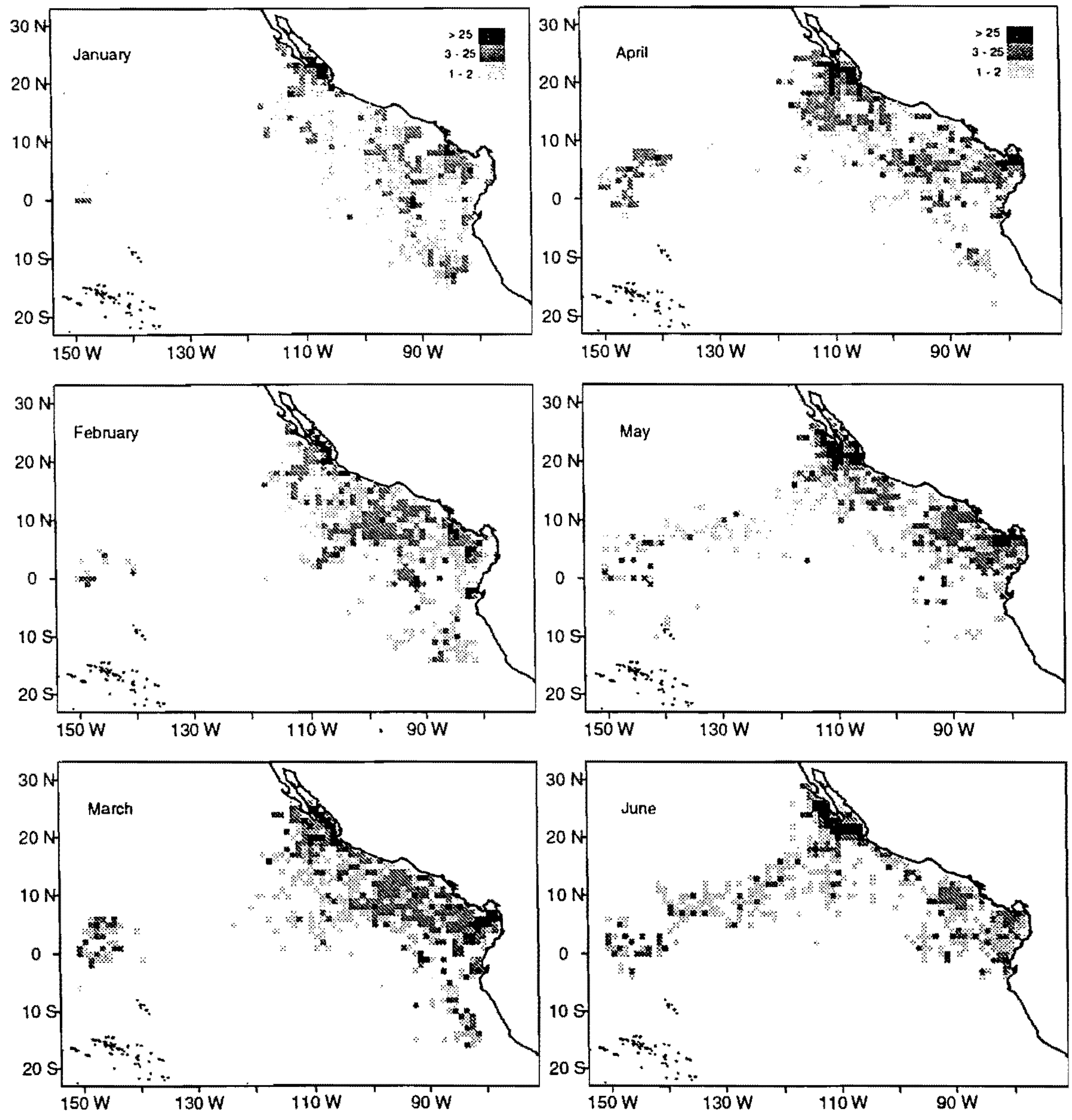


Figure 14. Monthly distribution of school sets for 1980-90, expressed as the number of sets per 1-degree area.



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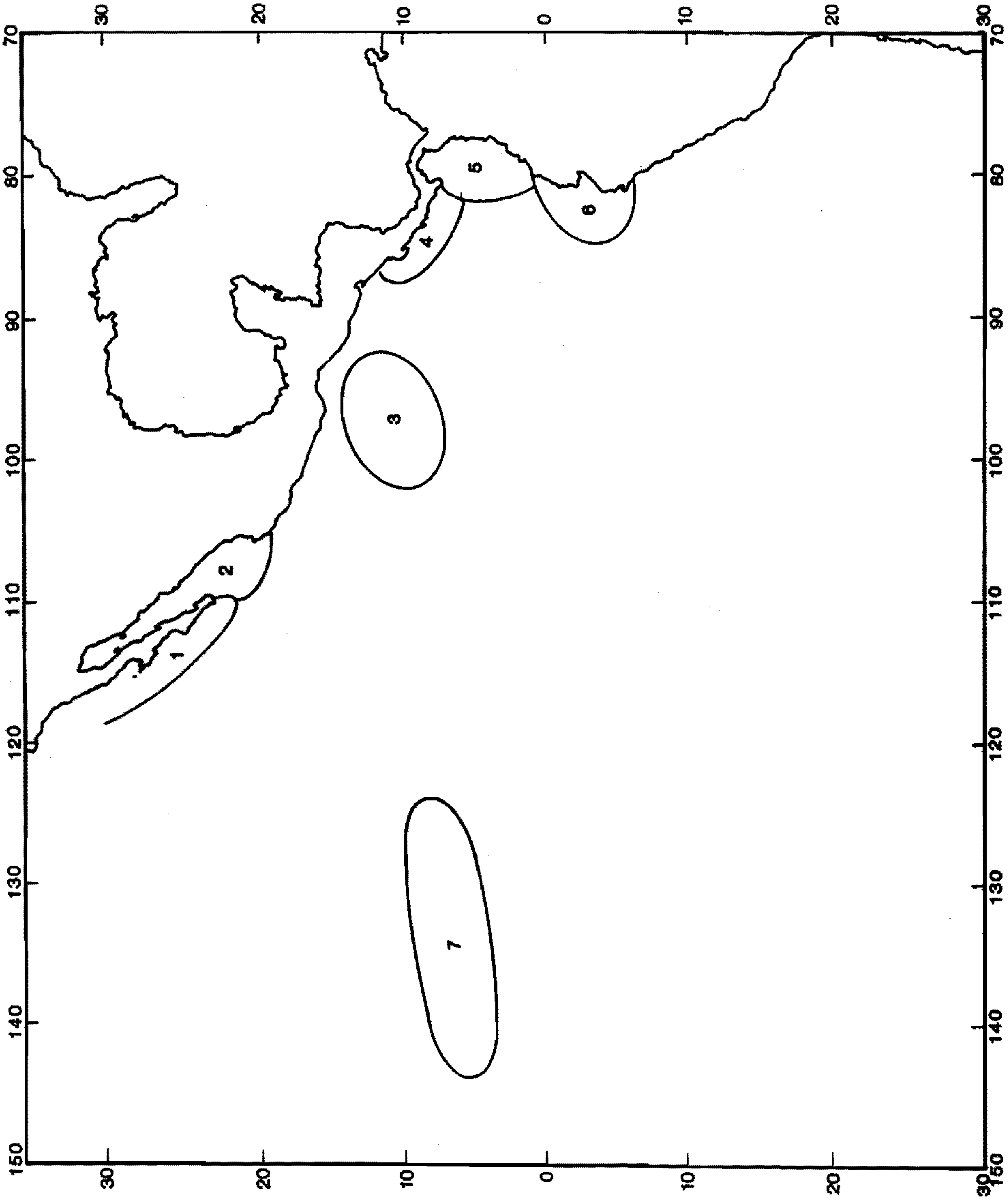


Figure 15. Generalized school fishing areas for the period 1980-90.

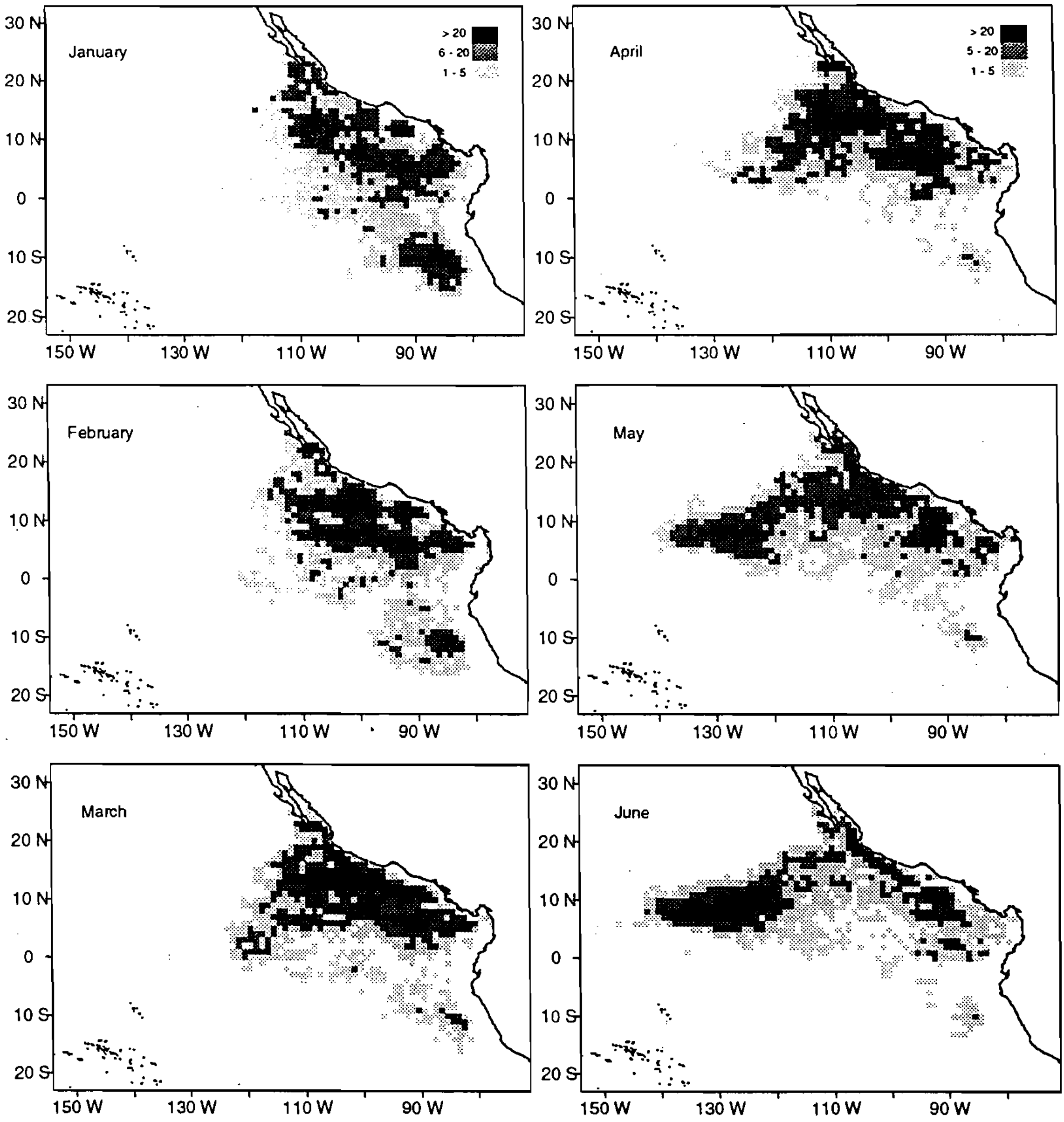
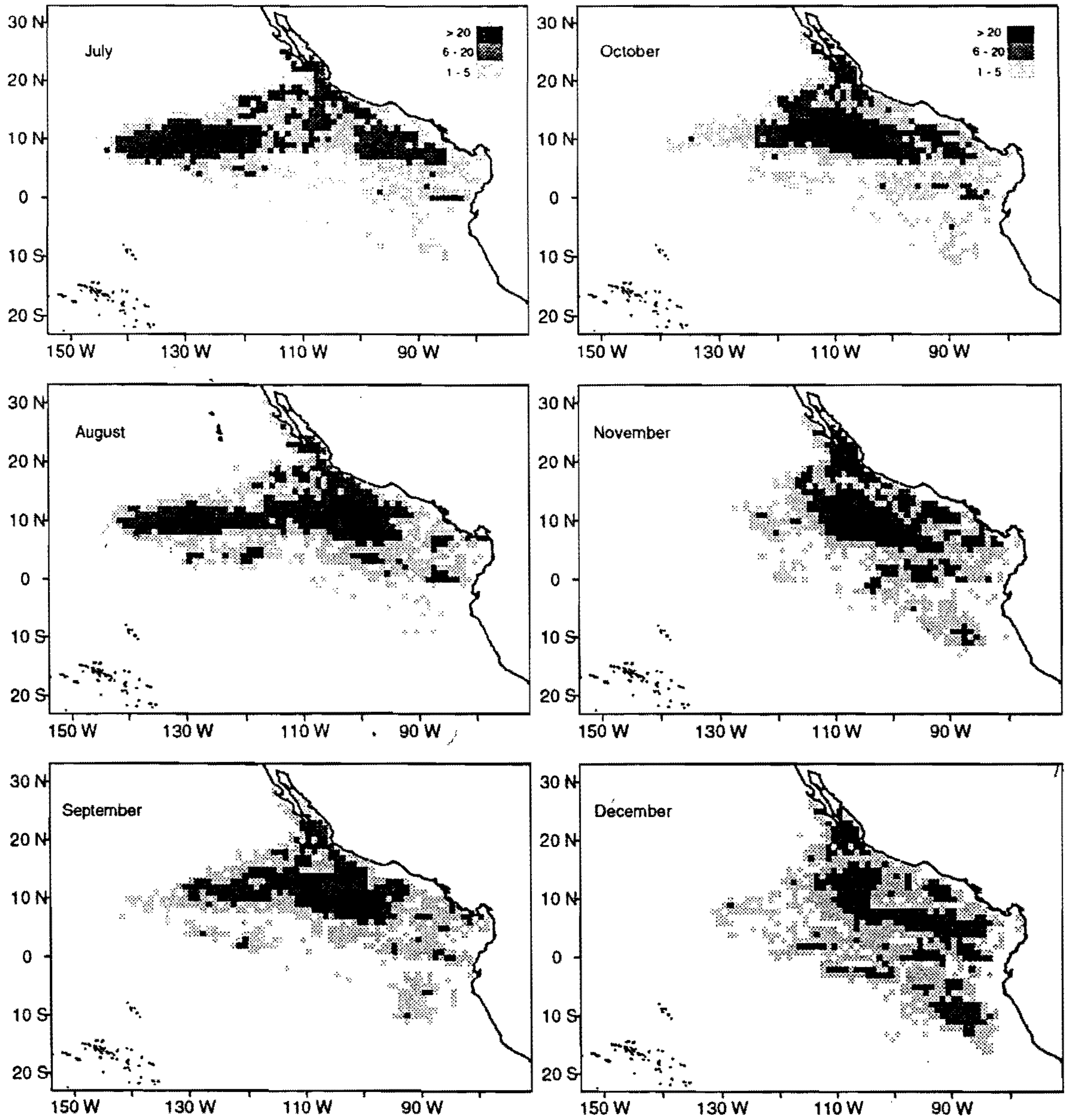


Figure 16. Monthly distribution of dolphin sets for 1980-90, expressed as number of sets per 1-degree area.



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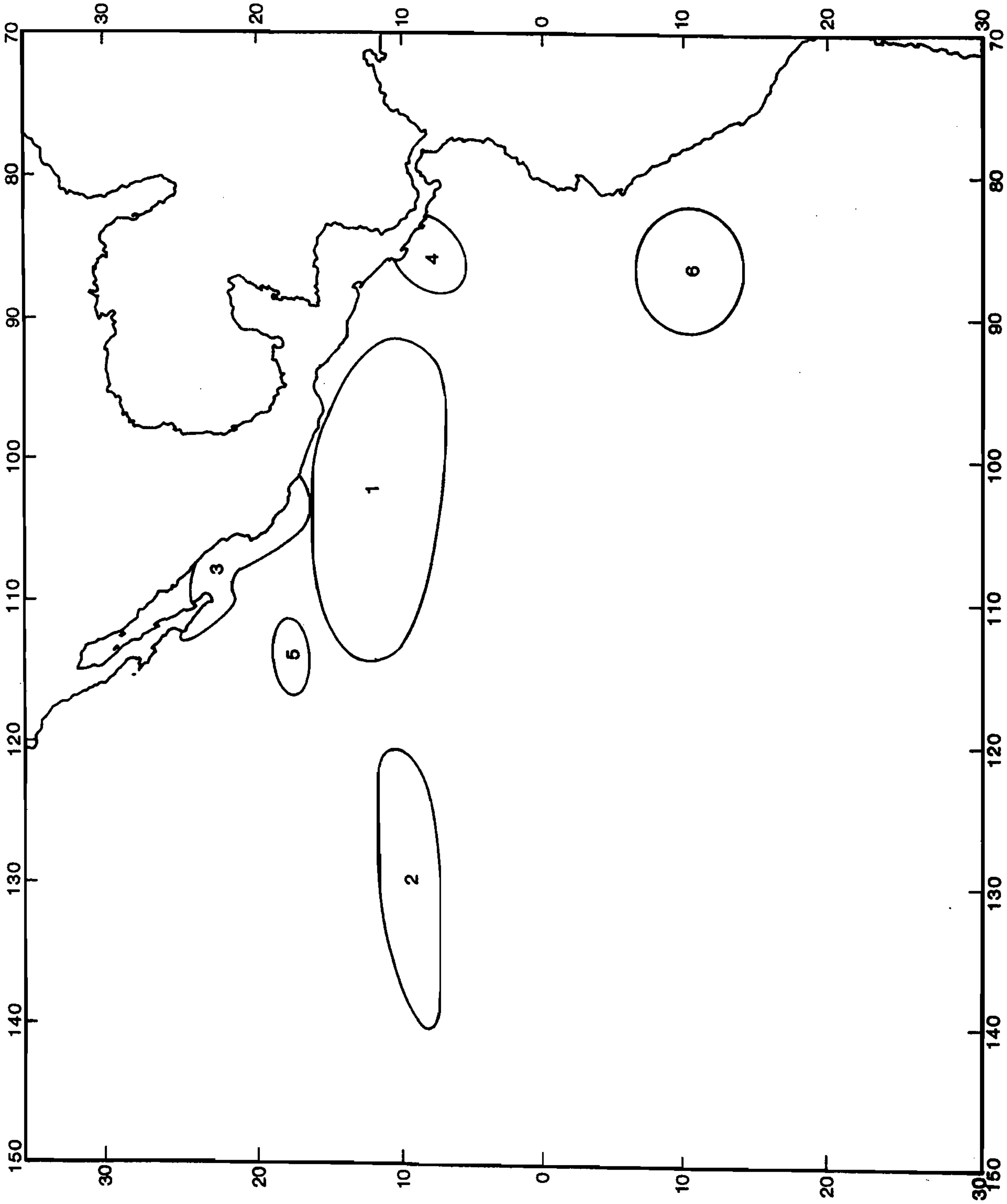


Figure 17. Generalized dolphin fishing areas for the period 1980-90.

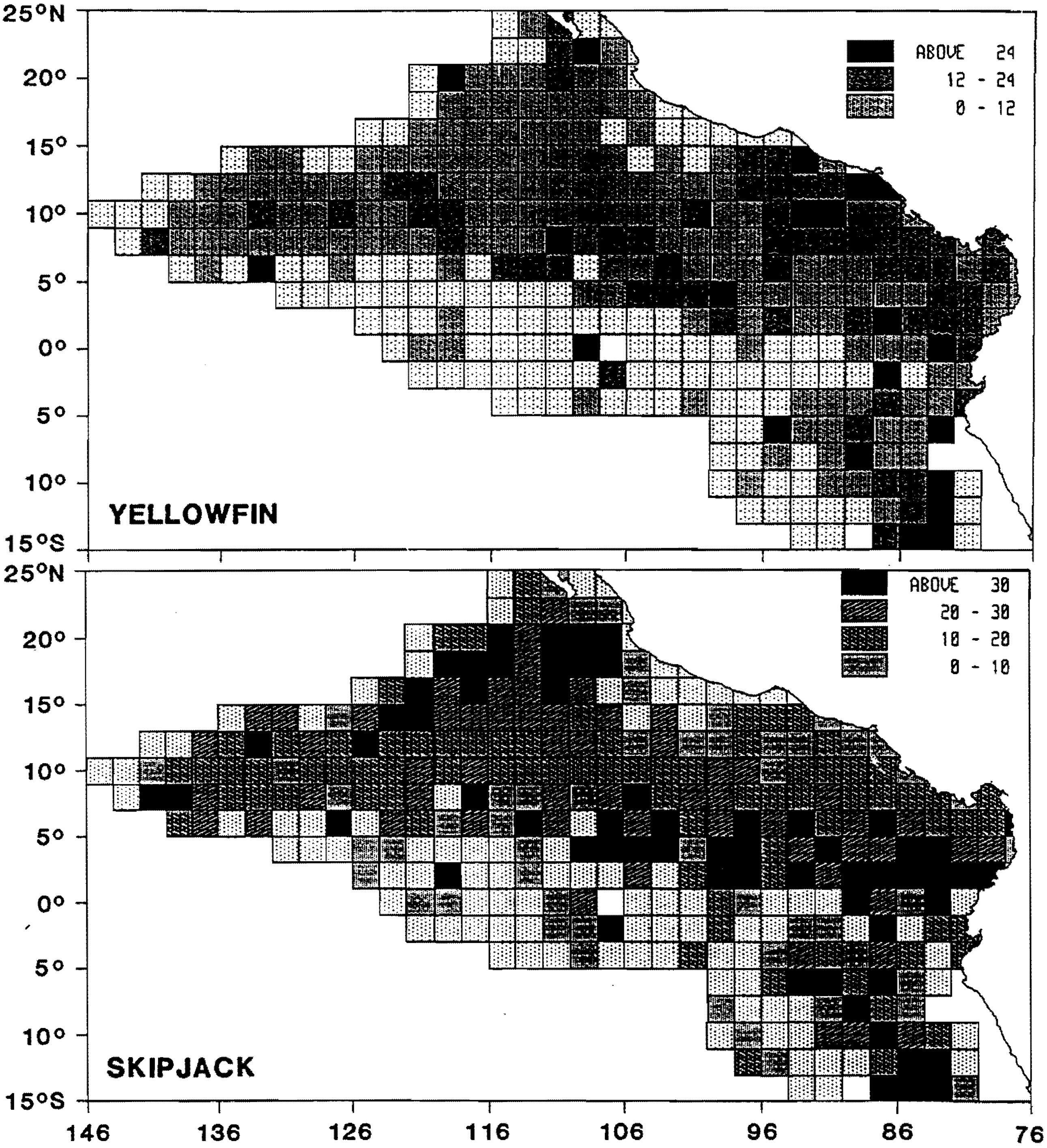


Figure 18. Distribution of average catches of yellowfin and skipjack per successful set in log sets, 1980-90.

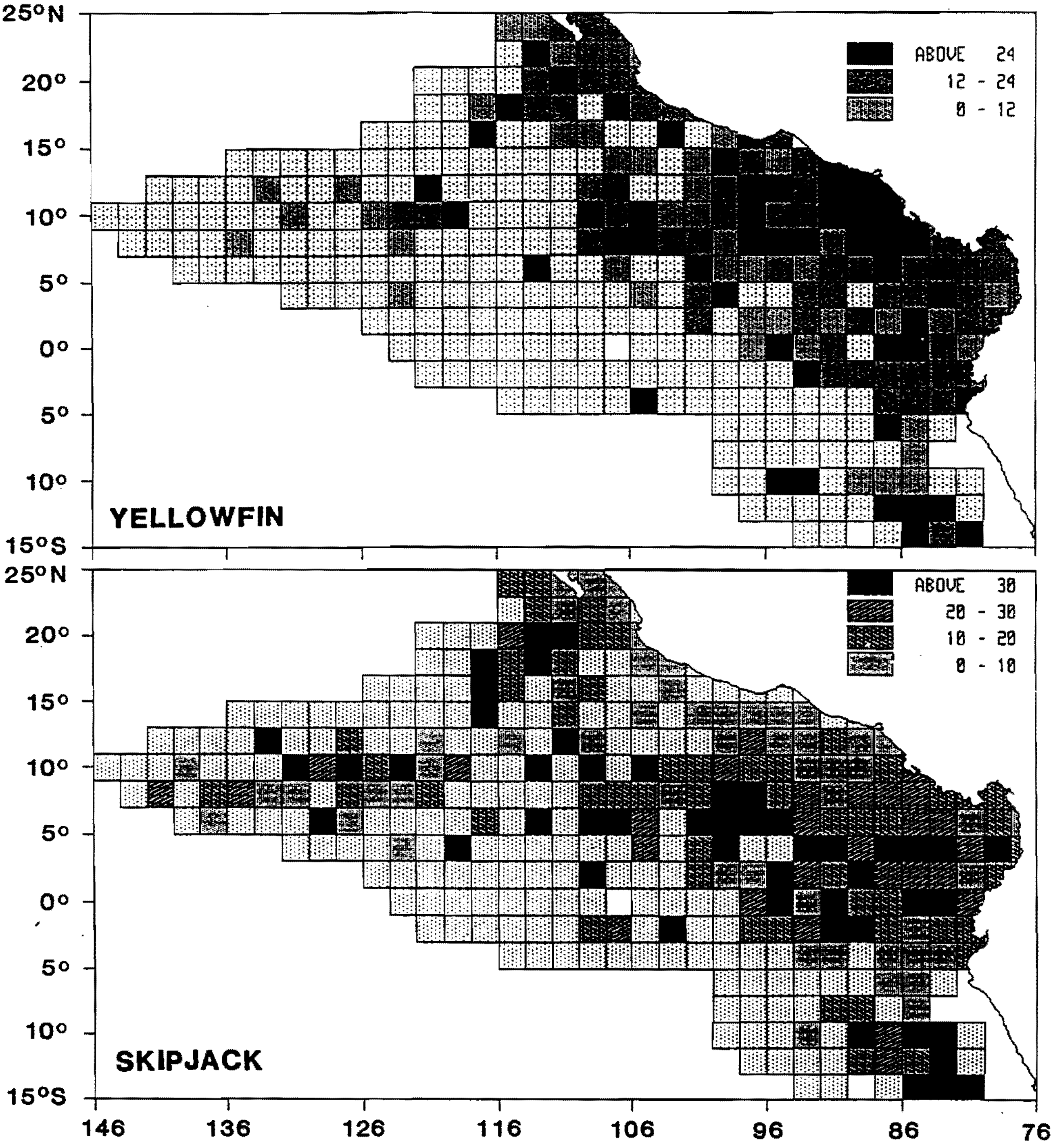


Figure 19. Distribution of average catches of yellowfin and skipjack per successful set in school sets, 1980-90.

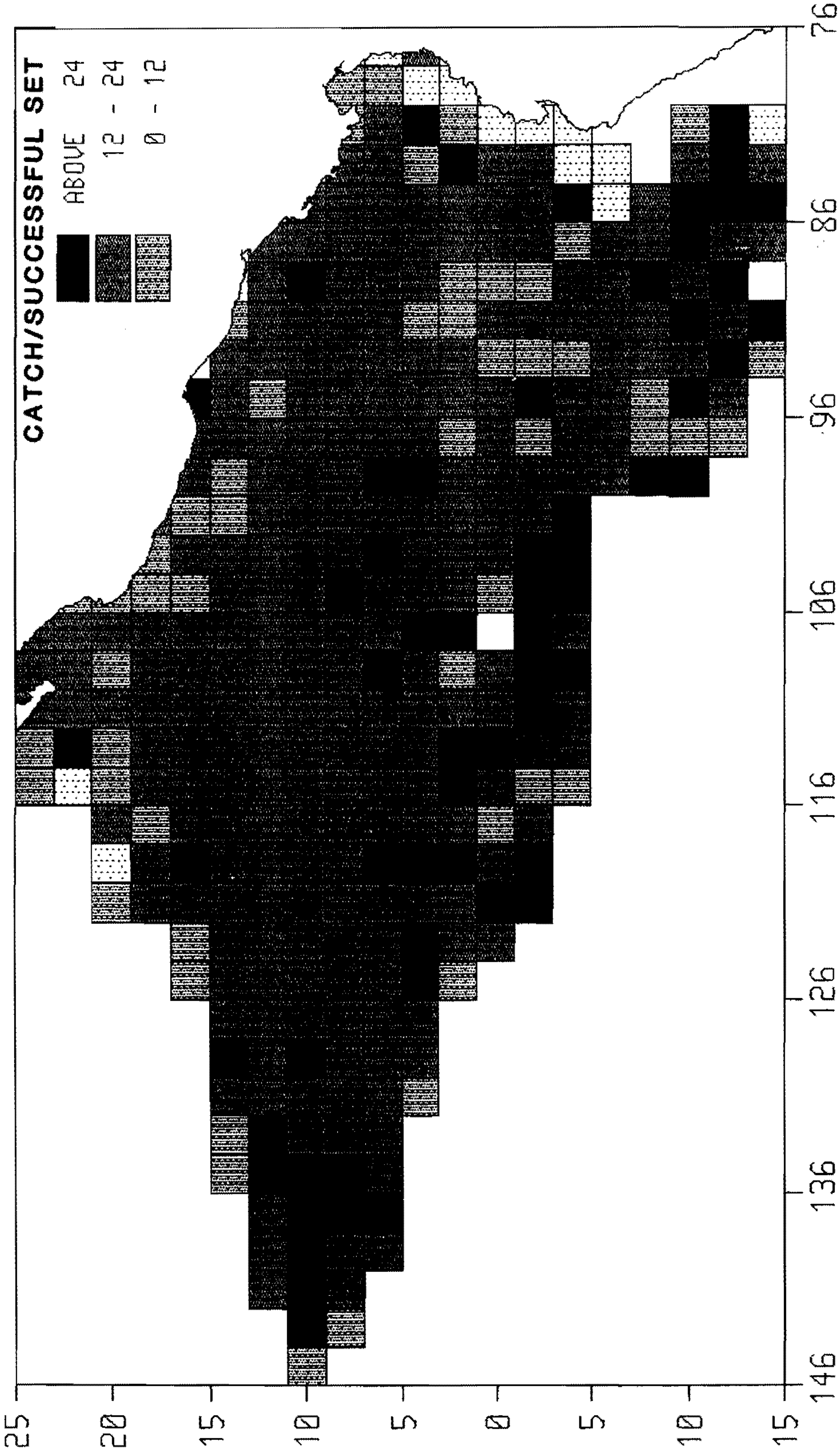


Figure 20. Distribution of average catches of yellowfin per successful set in dolphin sets, 1980-90.

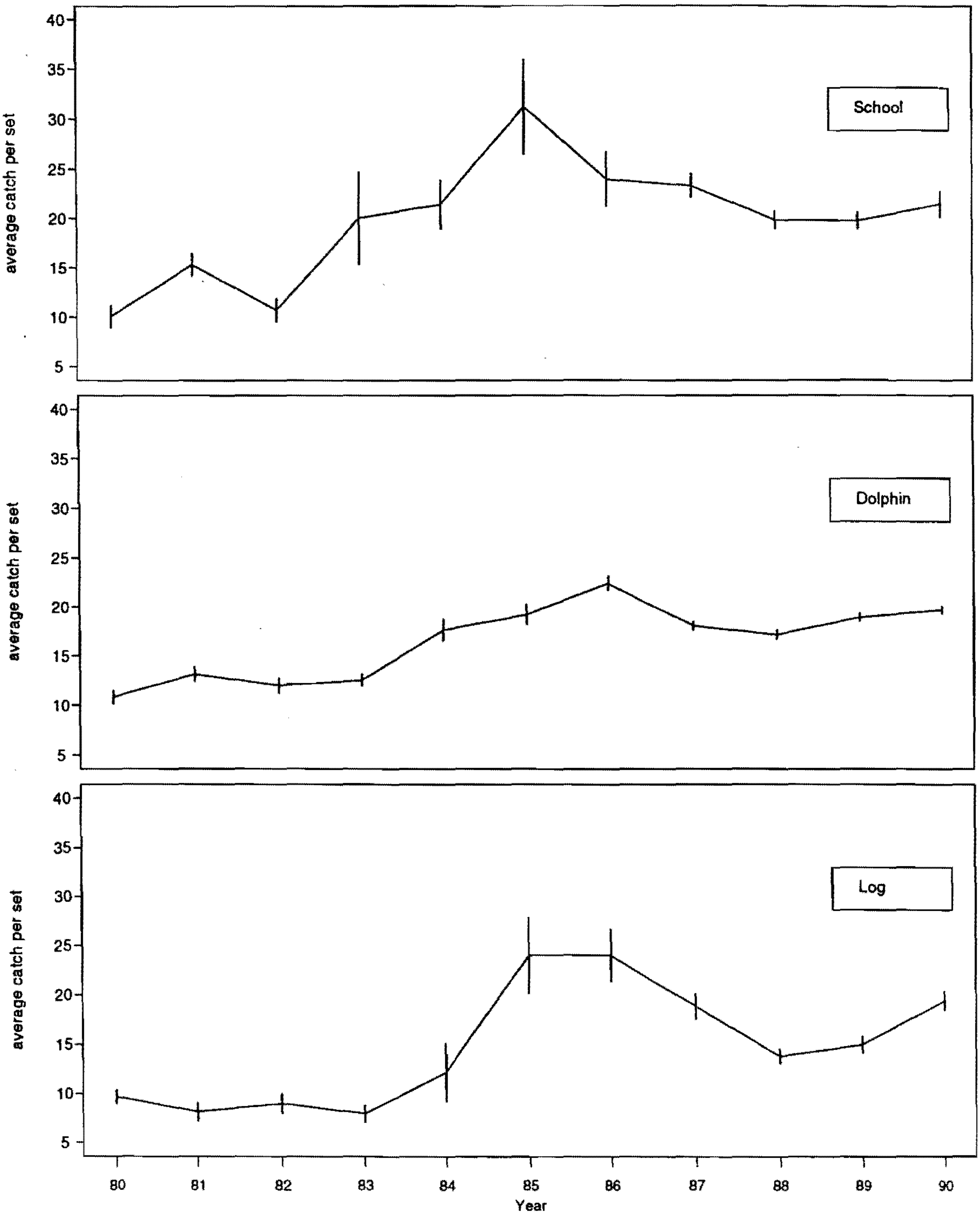


Figure 21. Average yellowfin catch per successful set by mode of purse seining for 1980-90. Vertical bars represent the estimate plus/minus one standard error. Standard errors were estimated using the Delta-t Method estimator for the variance of the quotient of two random variables.

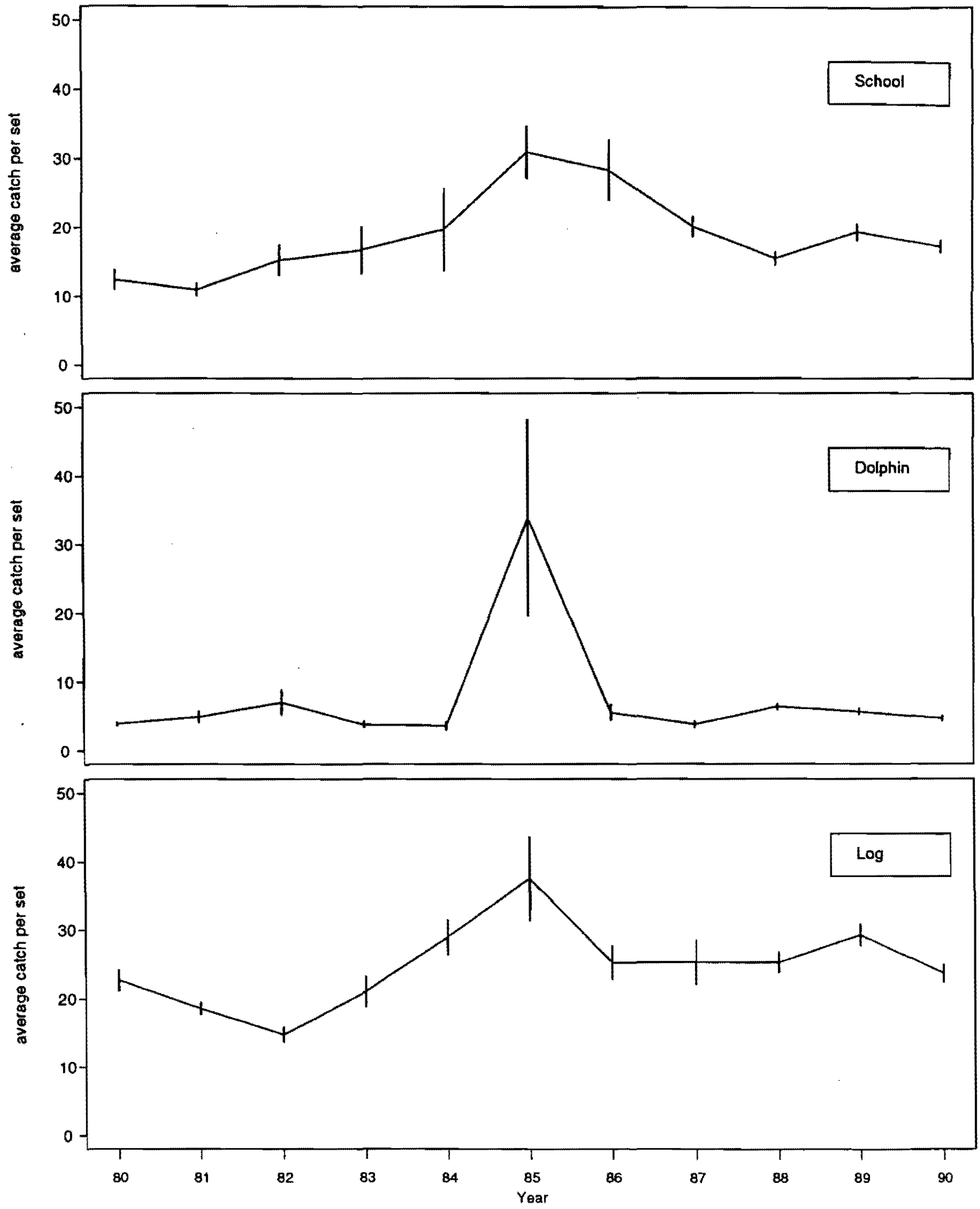


Figure 22. Average skipjack catch per successful set by mode of purse seining for 1980-90. Vertical bars represent the estimate plus/minus one standard error. Standard errors were estimated using the Delta-t Method estimator for the variance of the quotient of two random variables.

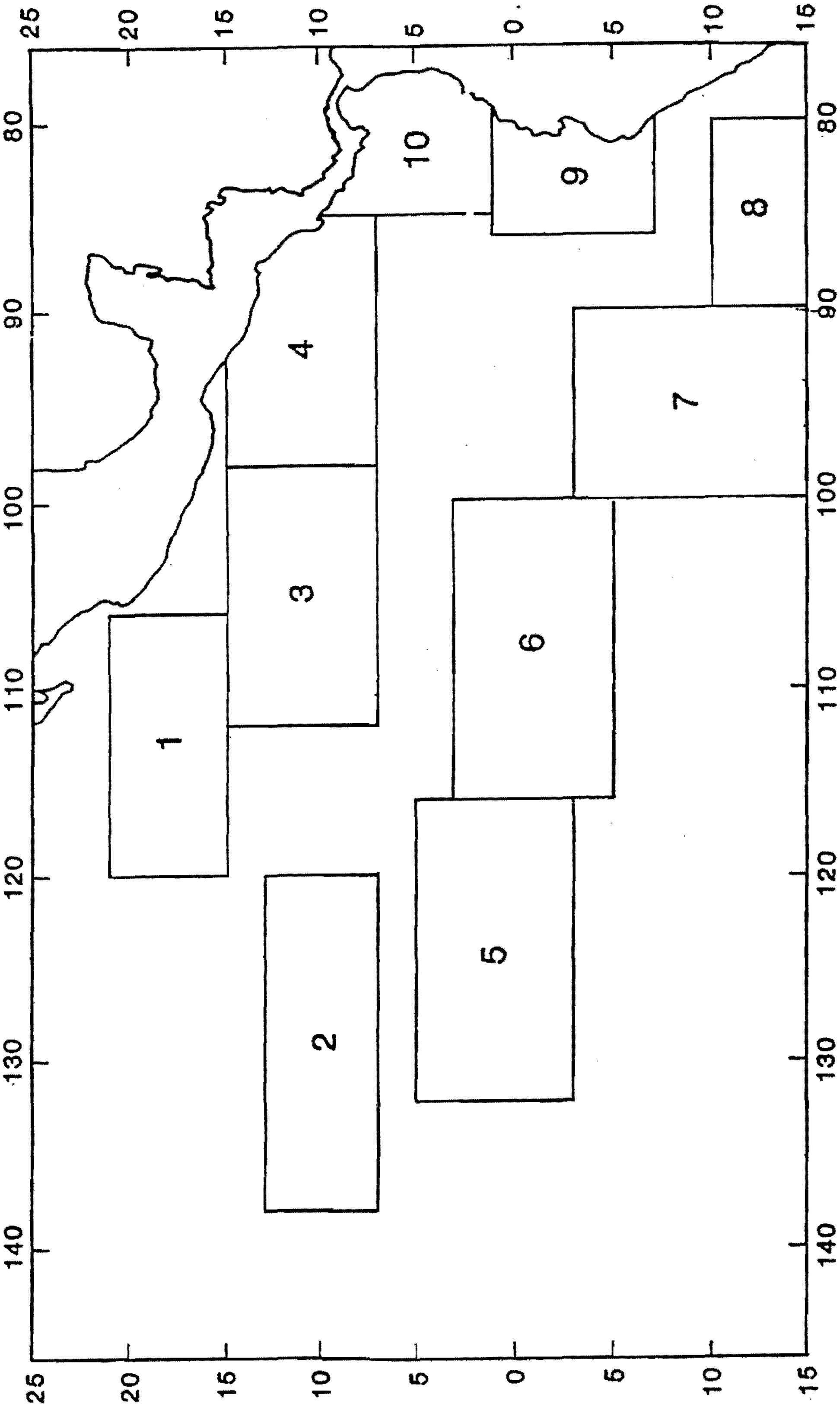


Figure 23. Areas selected for monthly analysis of catch and number of sets.

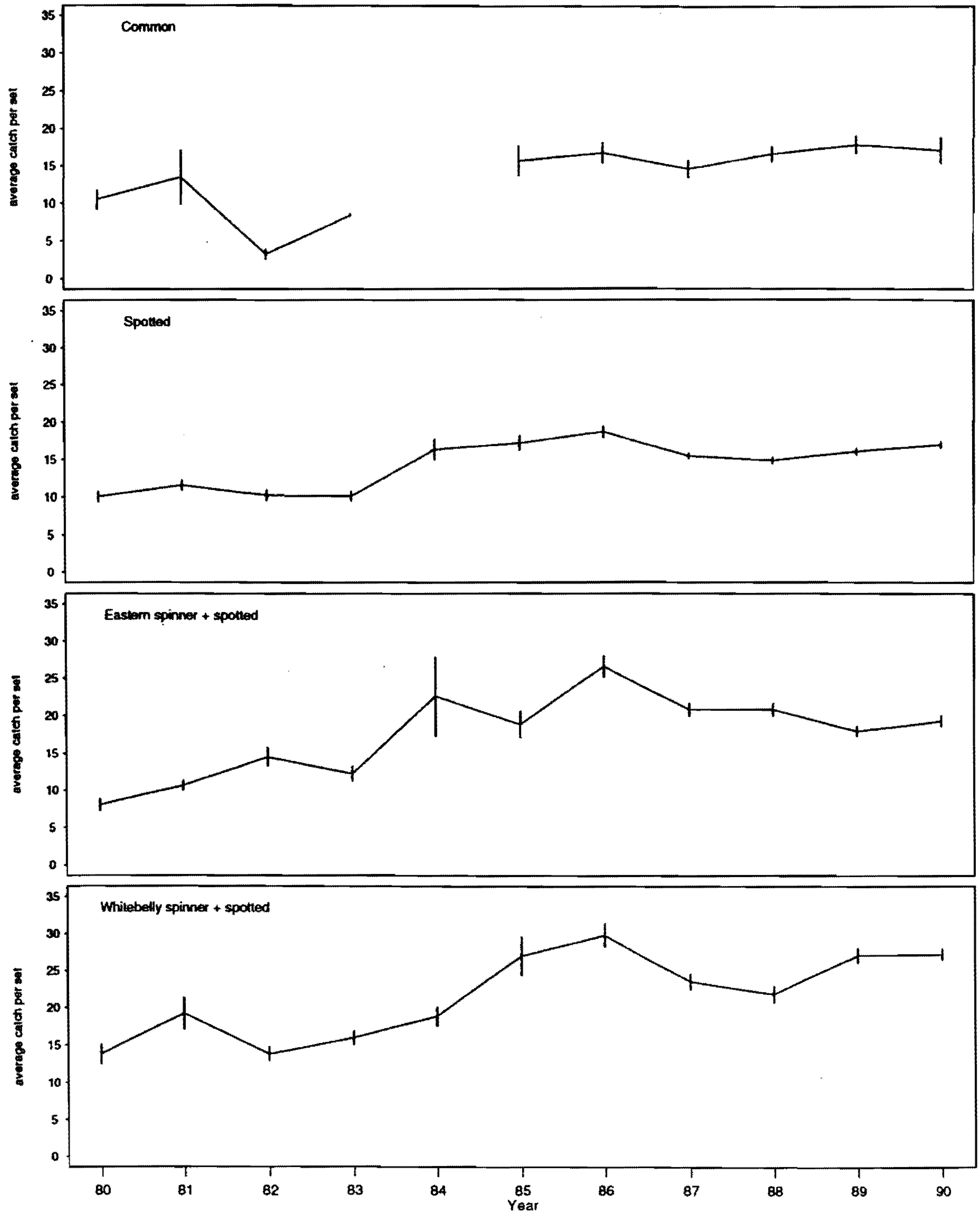


Figure 24. Average yellowfin catch per successful set by dolphin herd type, 1980-90. Vertical bars represent the estimate plus/minus one standard error. Standard errors were estimated using the Delta-t Method estimator for the variance of the quotient of two random variables.

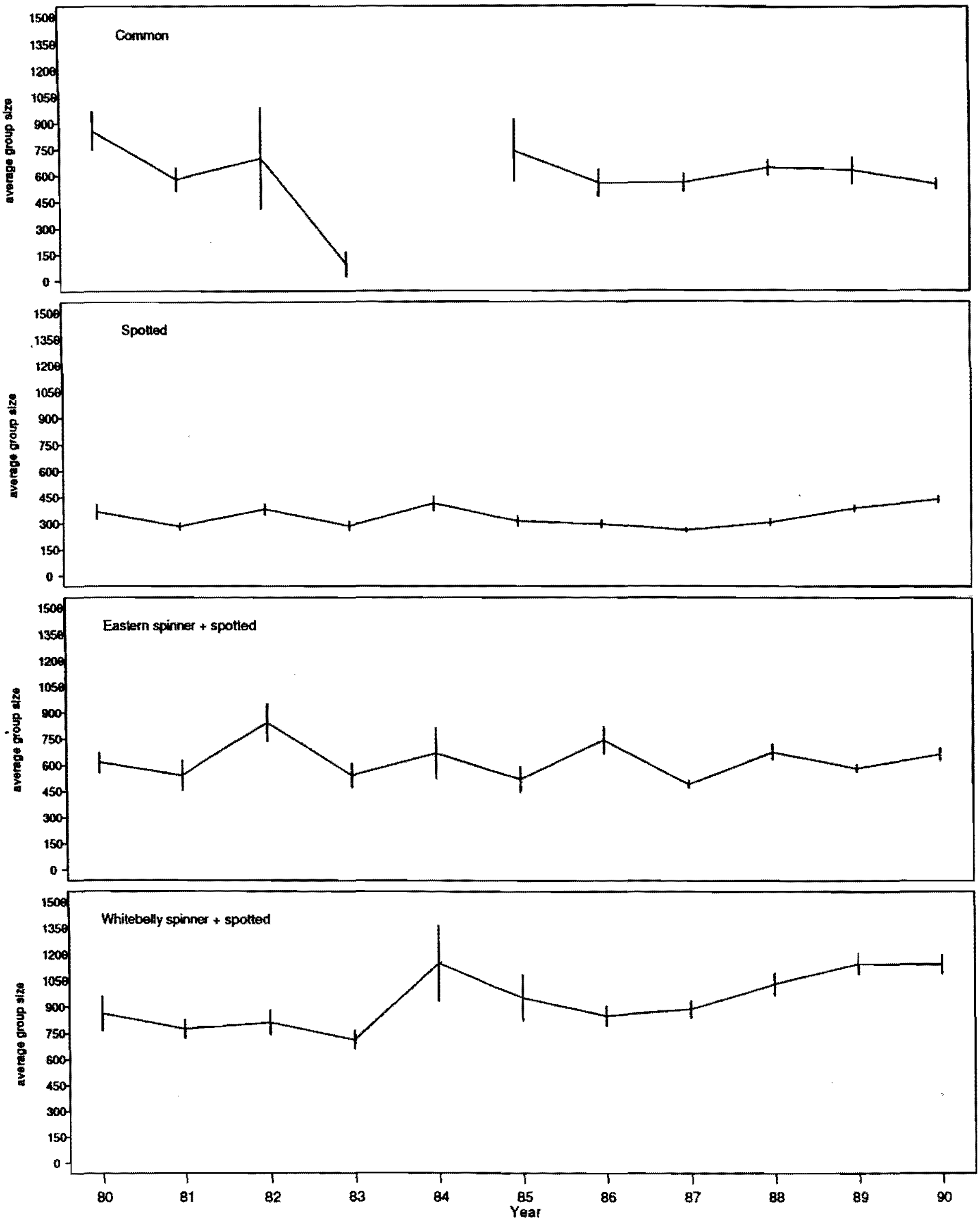


Figure 25. Average dolphin herd size by dolphin herd type, 1980-90. Vertical bars represent the estimate plus/minus one standard error. Standard errors were estimated using the Delta-t Method estimator for the variance of the quotient of two random variables.

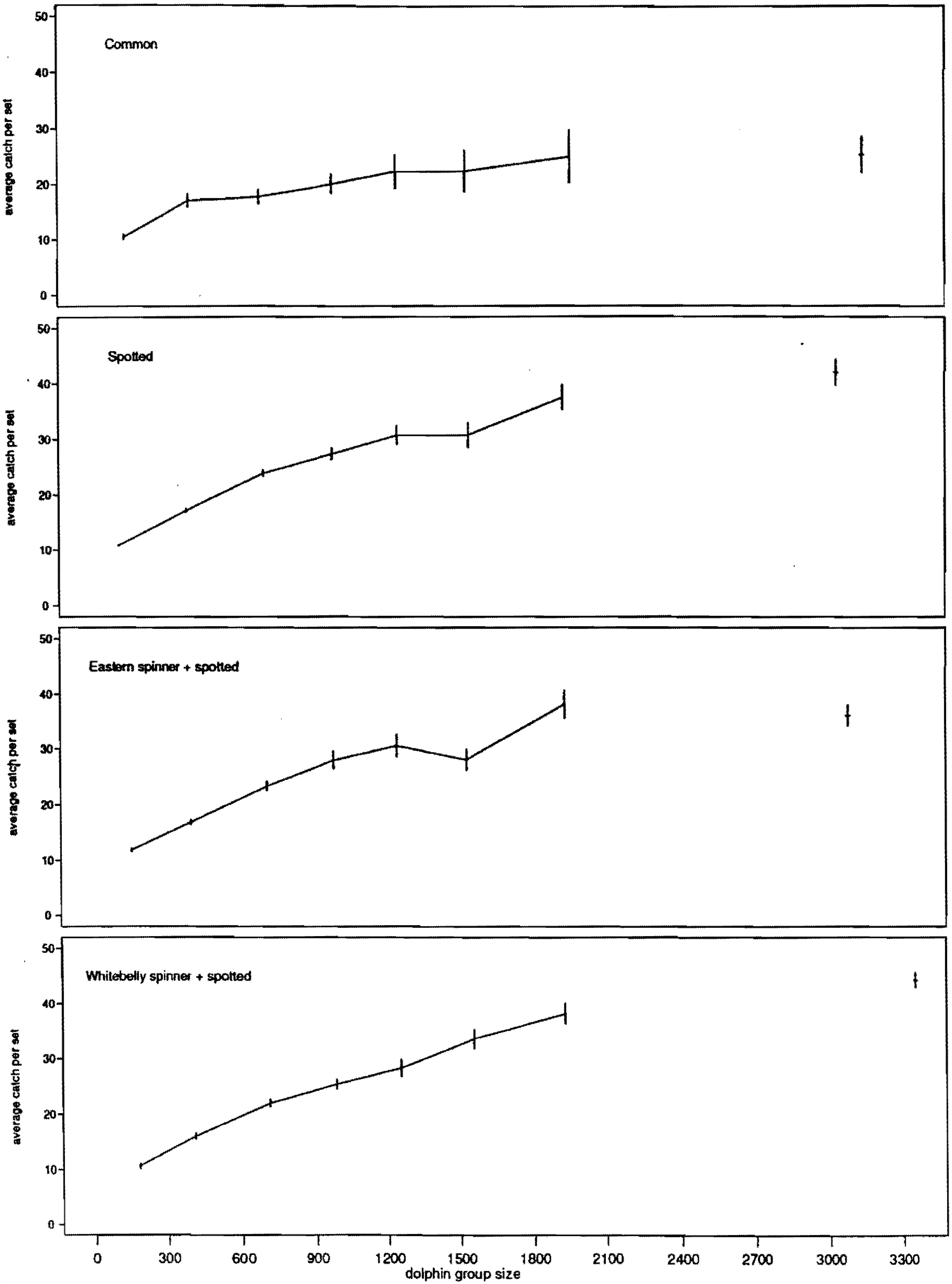


Figure 26. Average yellowfin catch per successful set *versus* dolphin herd size by herd type, 1980-90. Vertical bars represent the estimate plus/minus one standard error. Standard errors were estimated using the Delta-t Method estimator for the variance of the quotient of two random variables.

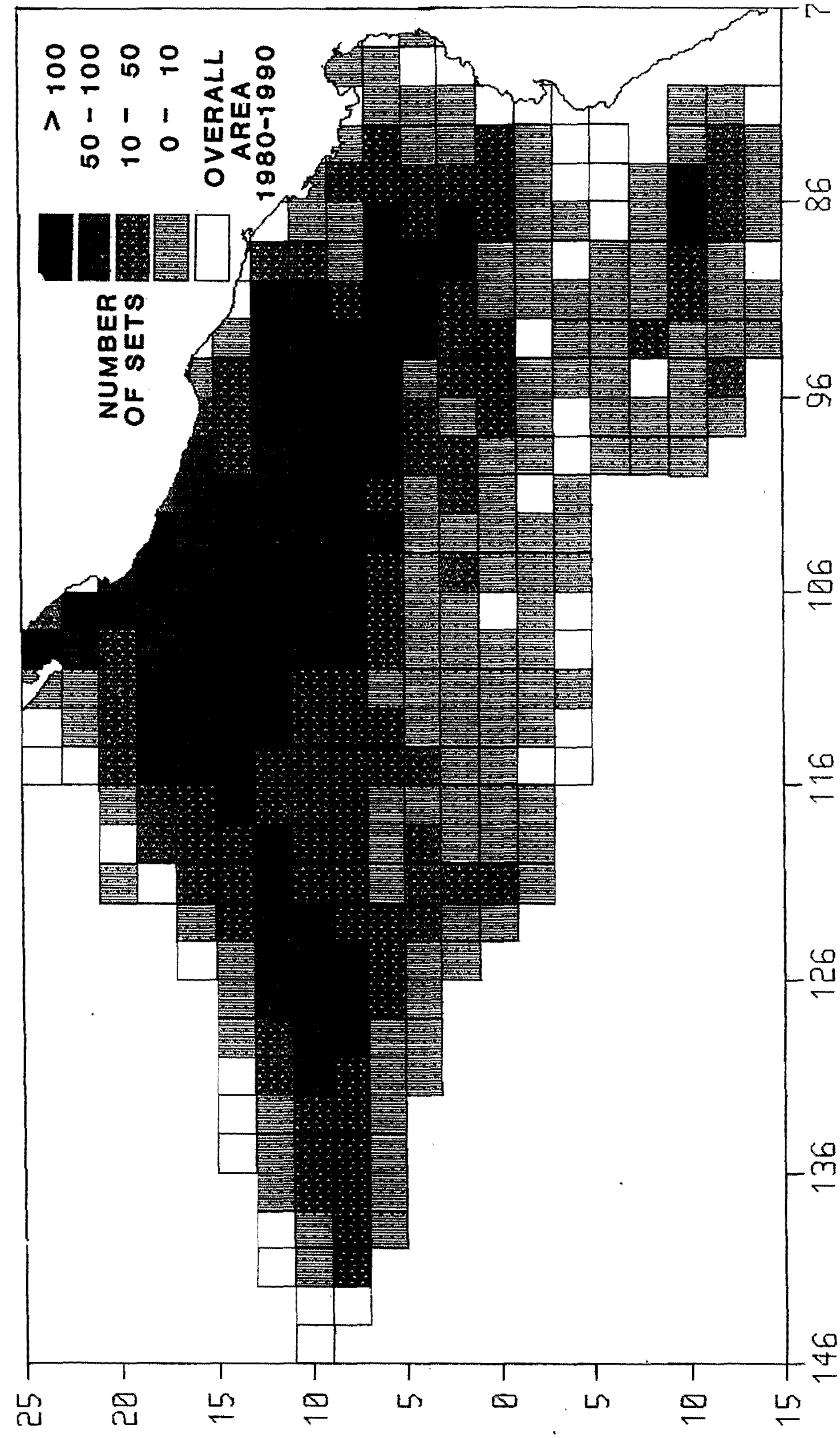


Figure 27. Distribution of sets involving pure herds of spotted dolphins for 1980-90, expressed as the number of sets per 2-degree area.

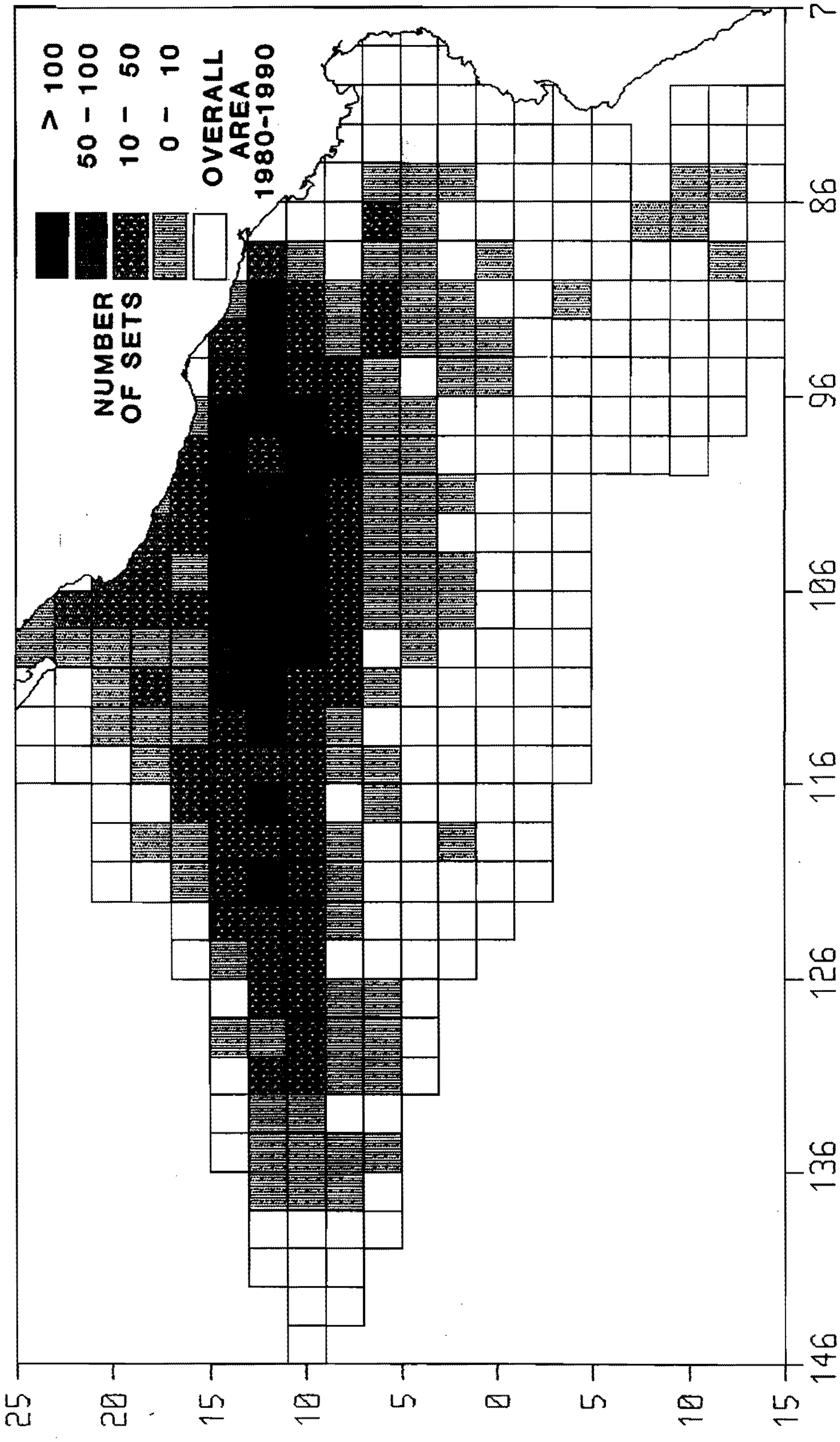


Figure 28. Distribution of sets involving mixed herds of spotted and eastern spinner dolphins for 1980-90, expressed as the number of sets per 2-degree area.

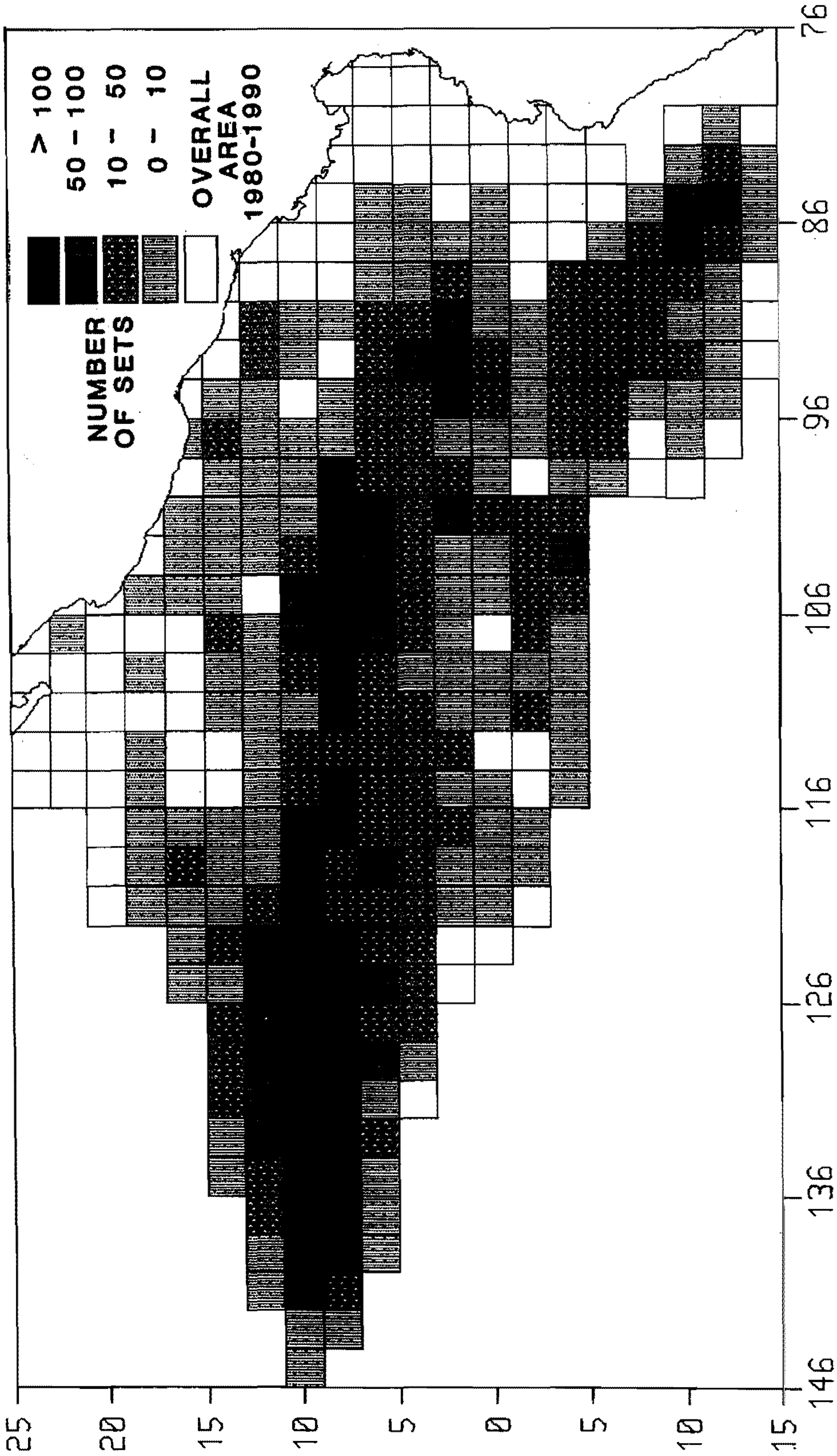


Figure 29. Distribution of sets involving mixed herds of spotted and whitebelly spinner dolphins for 1980-90, expressed as the number of sets per 2-degree area.

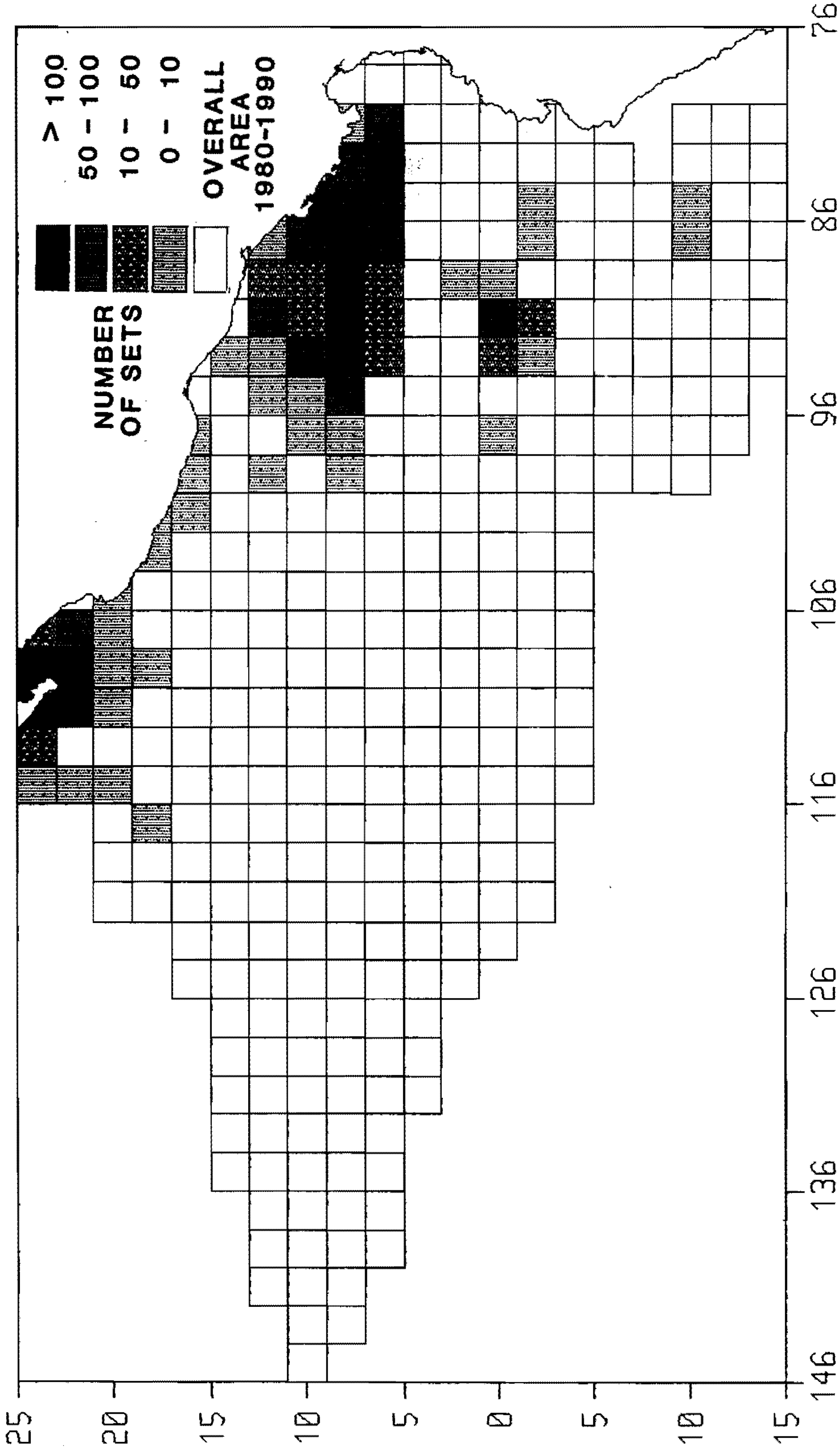


Figure 30. Distribution of sets involving pure schools of common dolphins for 1980-90, expressed as the number of sets per 2-degree area.

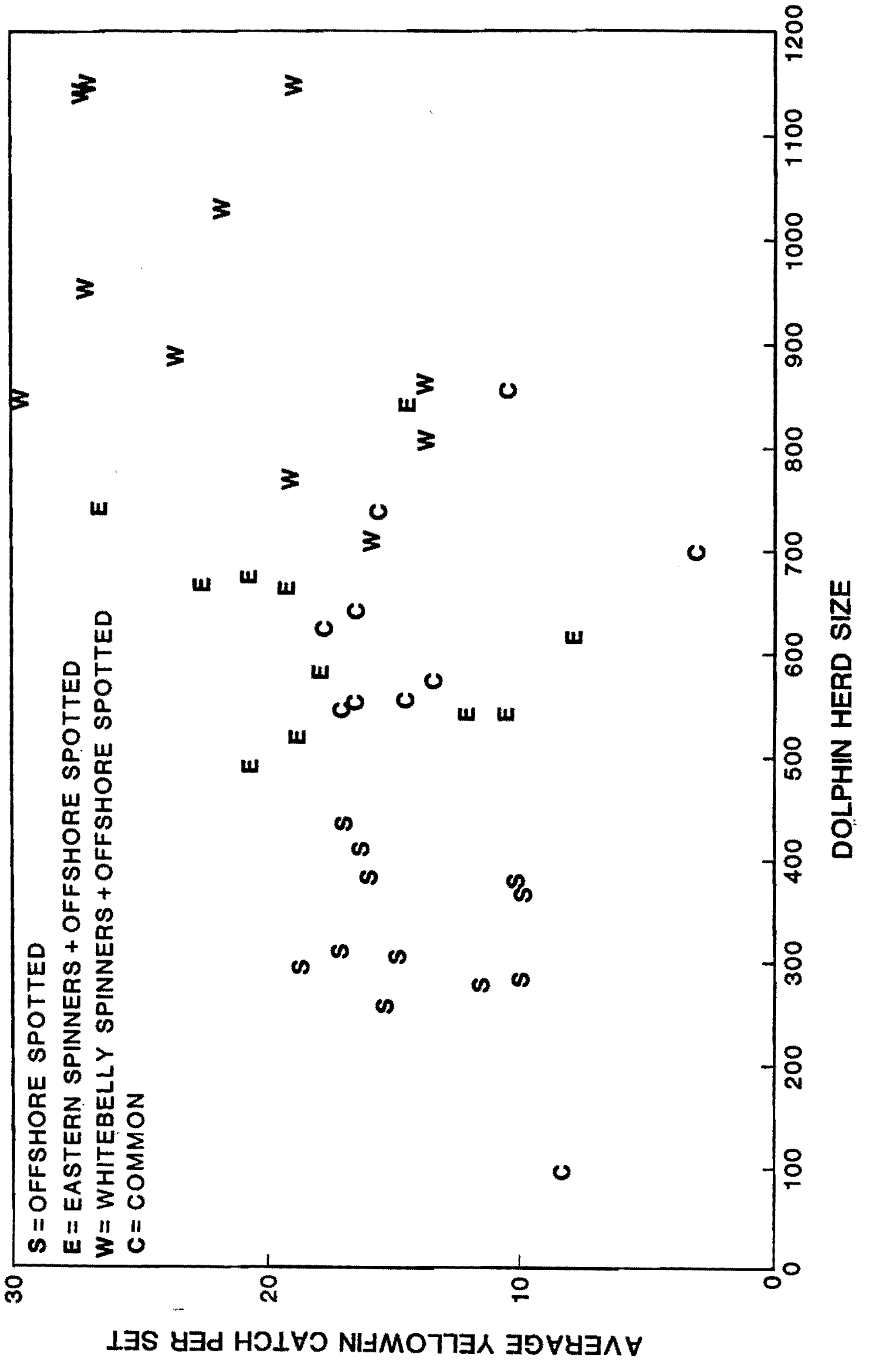


Figure 31. Yellowfin catch per successful sets *versus* dolphin herd size, 1980-90. Points represent yearly averages.

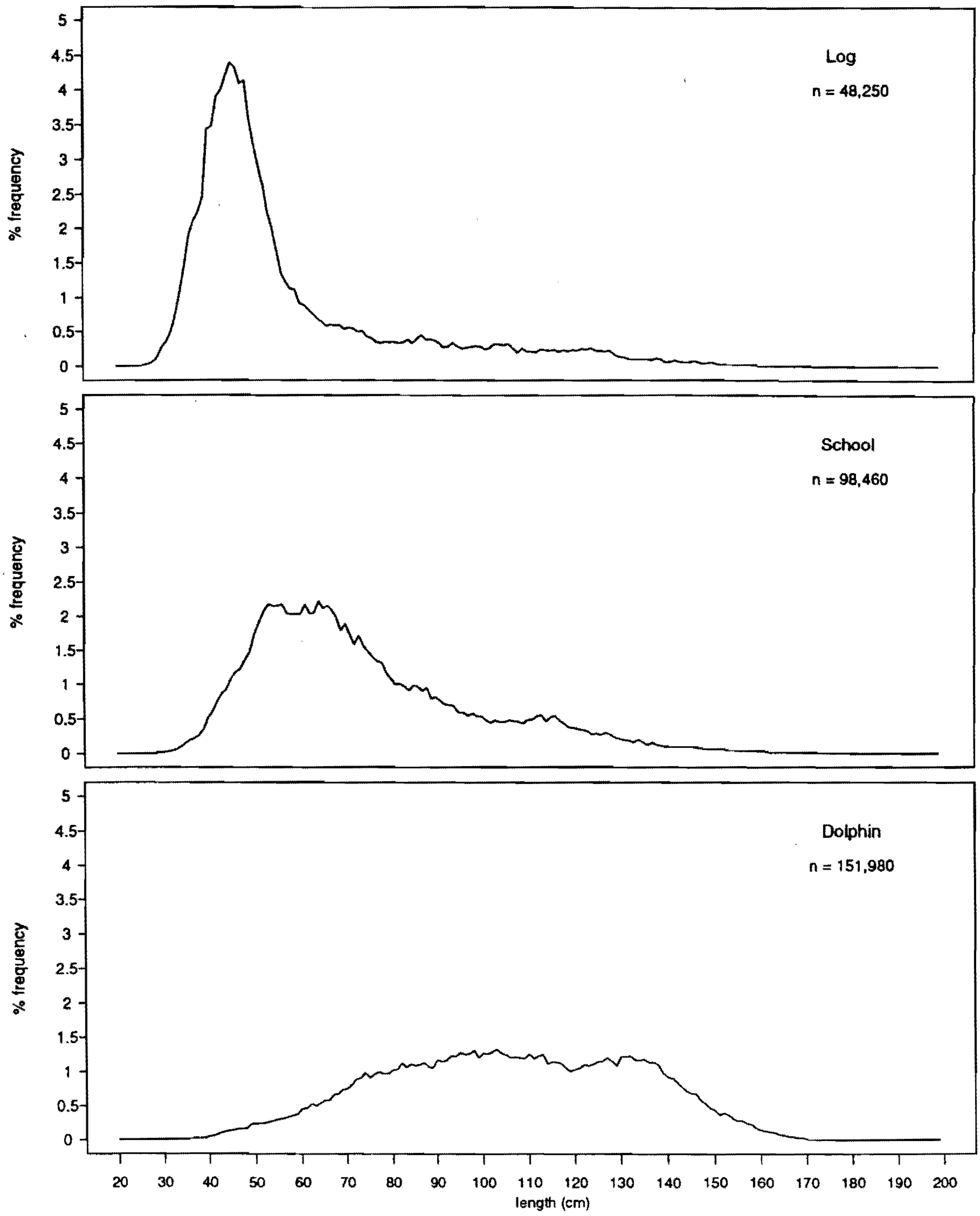


Figure 32. Yellowfin length-frequency distribution, in percentage of numbers, by mode of purse seining for 1980-90. Data for this figure kindly provided by Pat Tomlinson, IATTC.

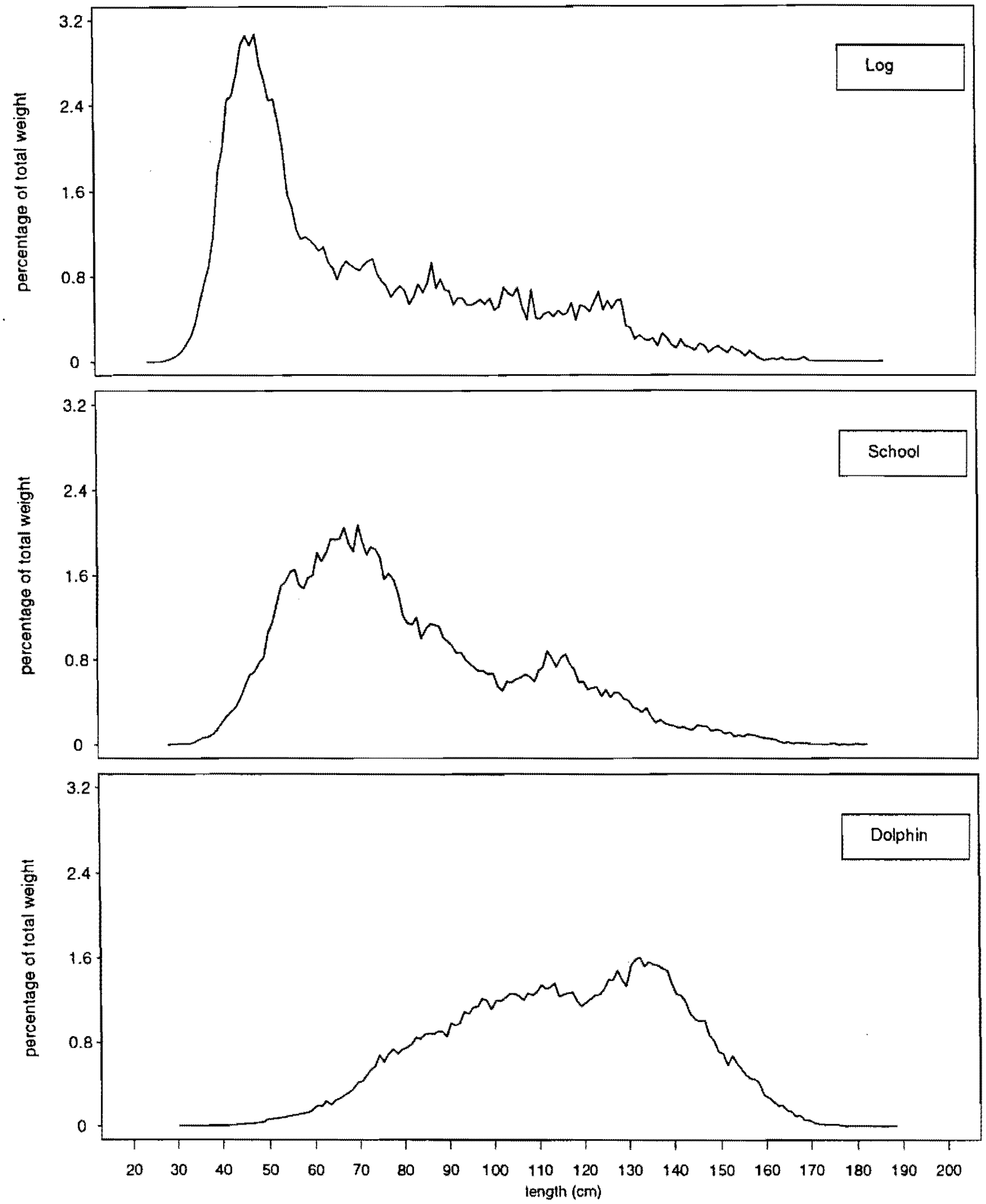


Figure 33. Yellowfin length-frequency distribution, in percentage of total weight, by mode of purse seining, 1980-90. Data for this figure kindly provided by Pat Tomlinson, IATTC.

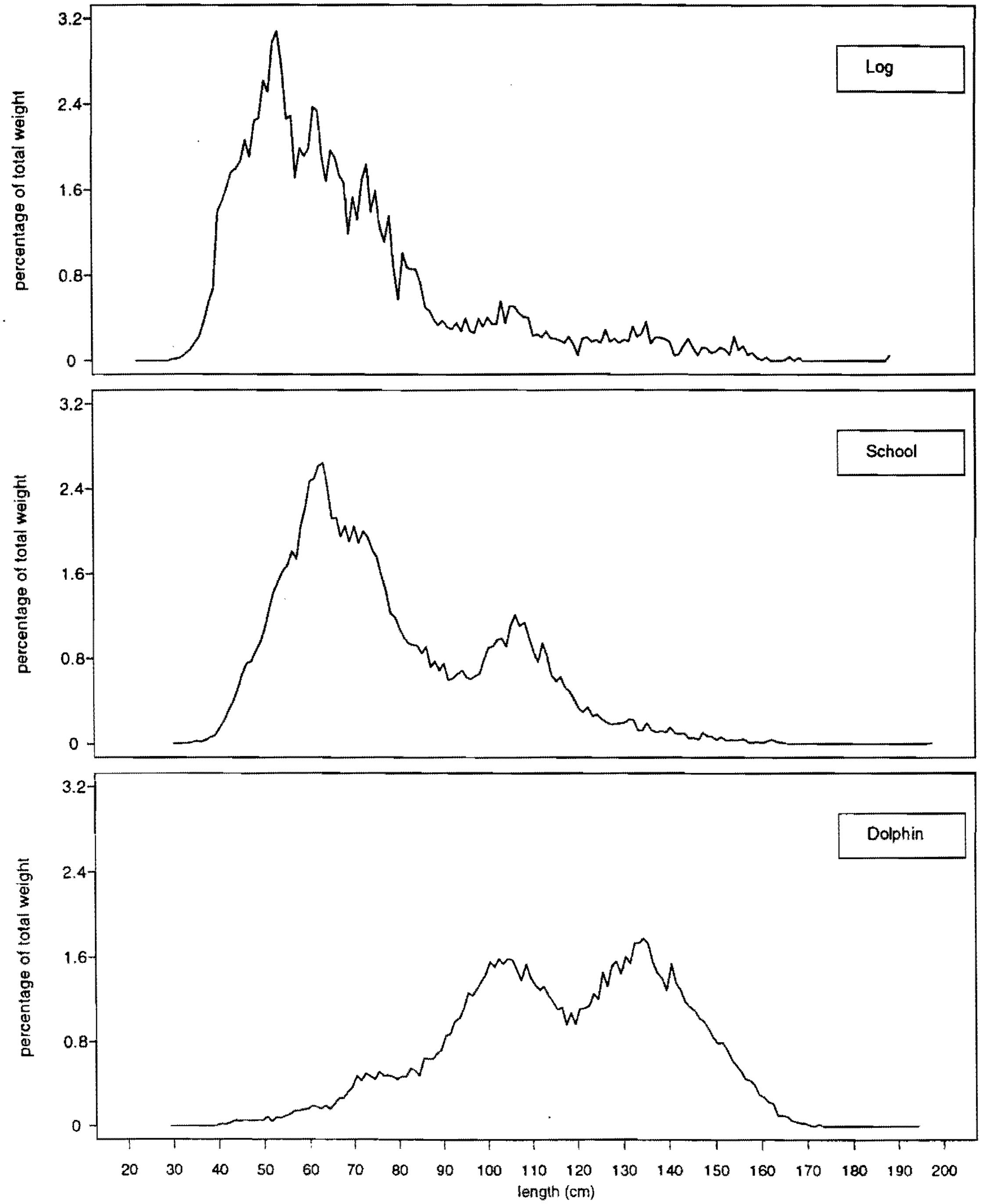


Figure 34. Yellowfin length-frequency distribution, in percentage of total weight, by mode of purse seining, 1969-79. Data for this figure kindly provided by Pat Tomlinson, IATTC.

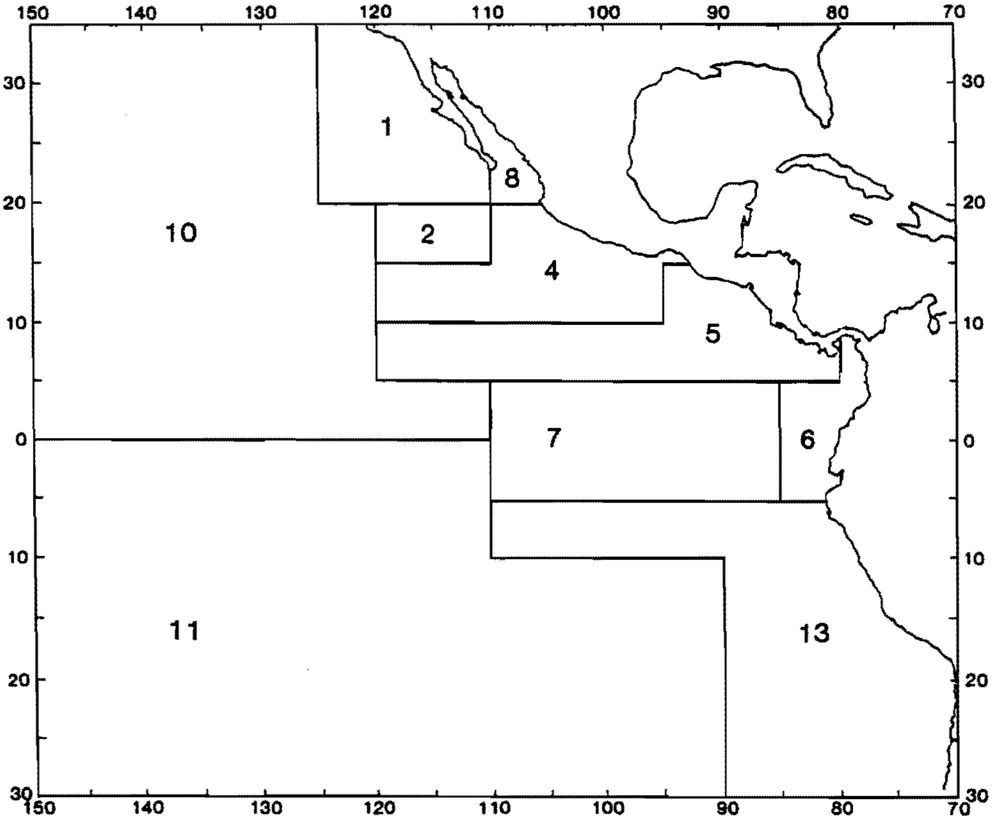


Figure 35. Areas used for sampling lengths of tunas in the EPO, from Anonymous (Figure 14, 1994).

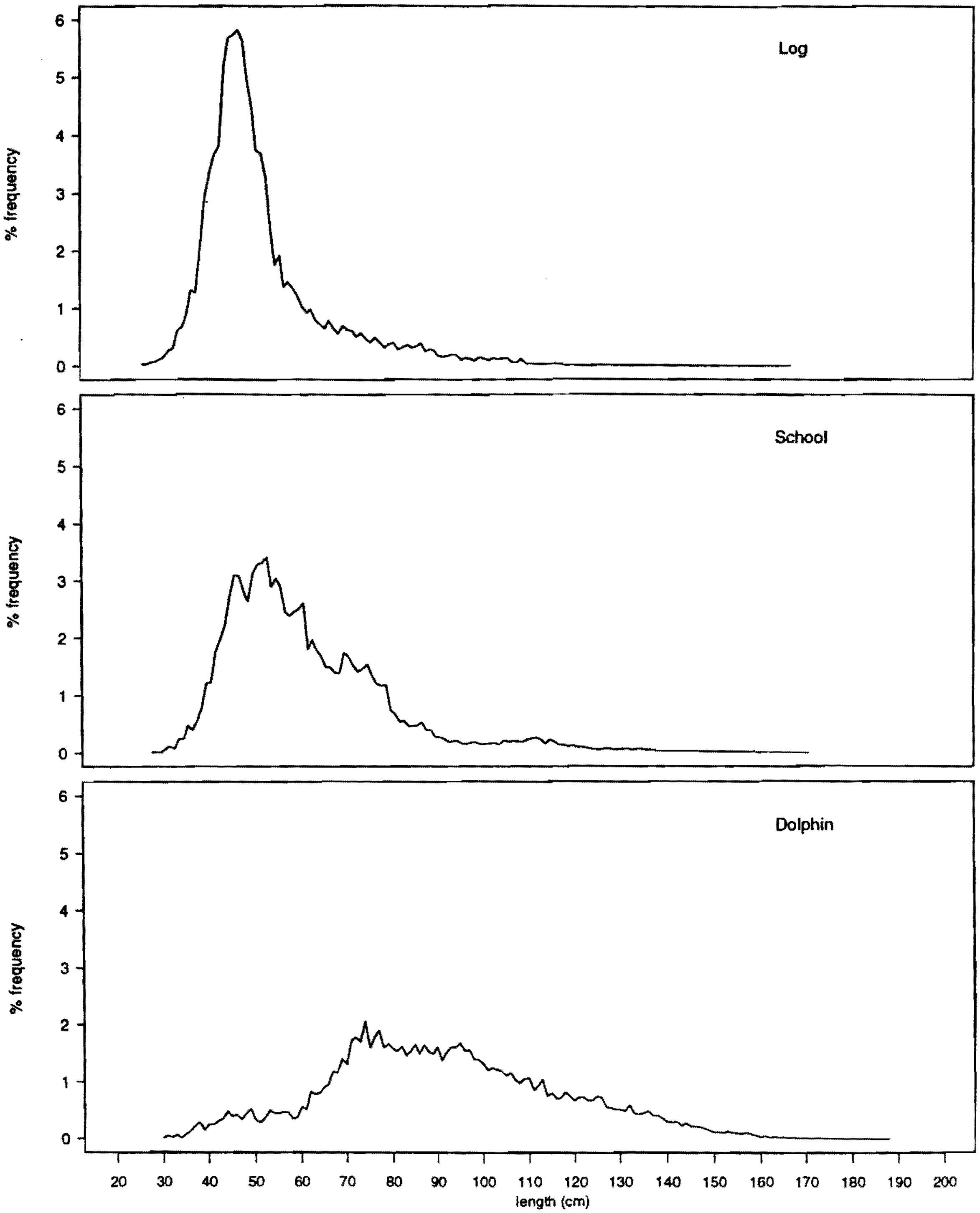


Figure 36. Yellowfin length-frequency distribution, in percentage of numbers, in Area A1 by mode of purse seining, 1980-90. Data for this figure kindly provided by Pat Tomlinson, IATTC.

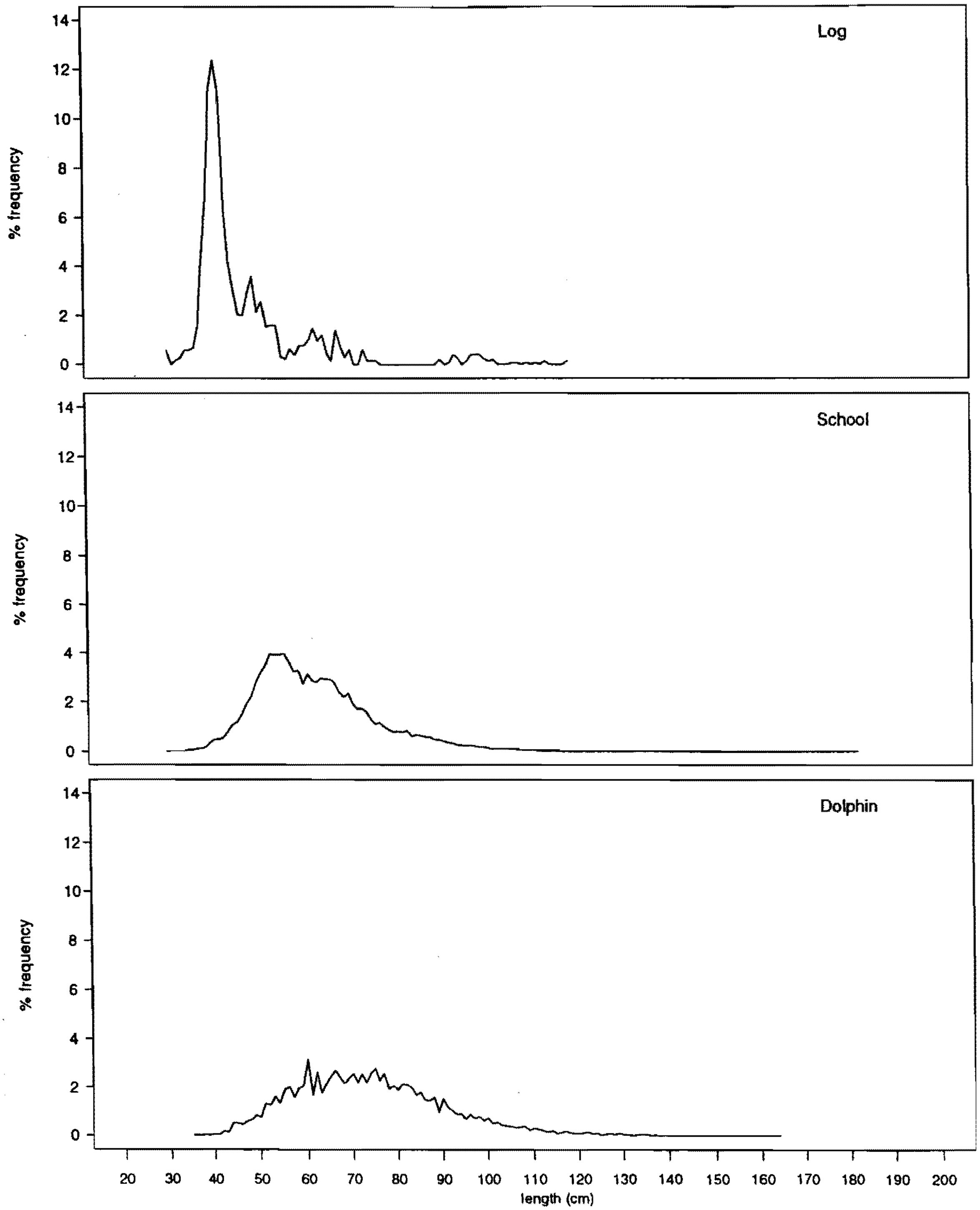


Figure 37. Yellowfin length-frequency distribution, in percentage of numbers, in Area A2 by mode of purse seining, 1980-90. Data for this figure kindly provided by Pat Tomlinson, IATTC.

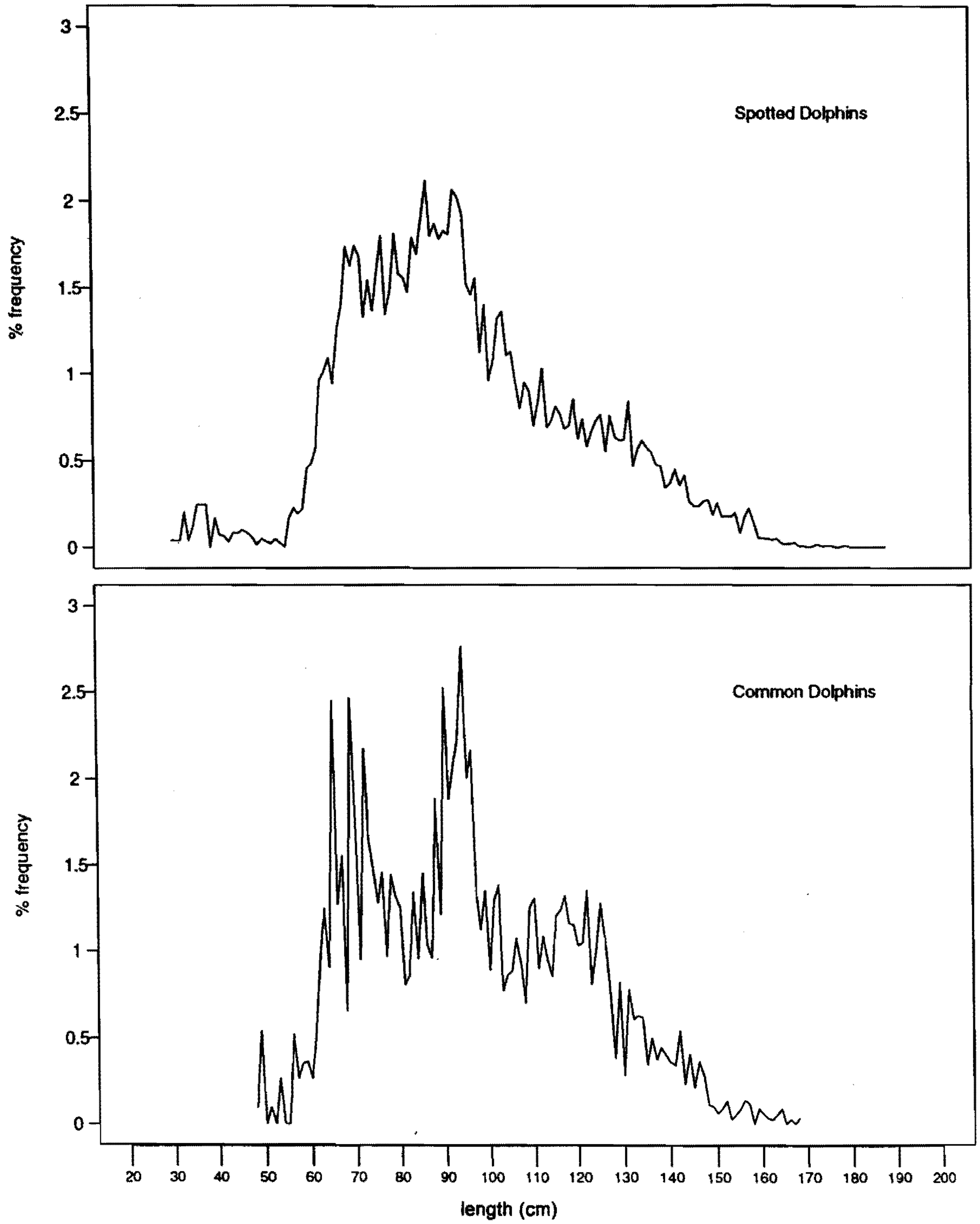


Figure 38. Yellowfin length-frequency distribution, in percentage of numbers, in Area A1 in purse-seine sets on spotted and "common" dolphins, 1980-90. Data for this figure kindly provided by Pat Tomlinson, IATTC.

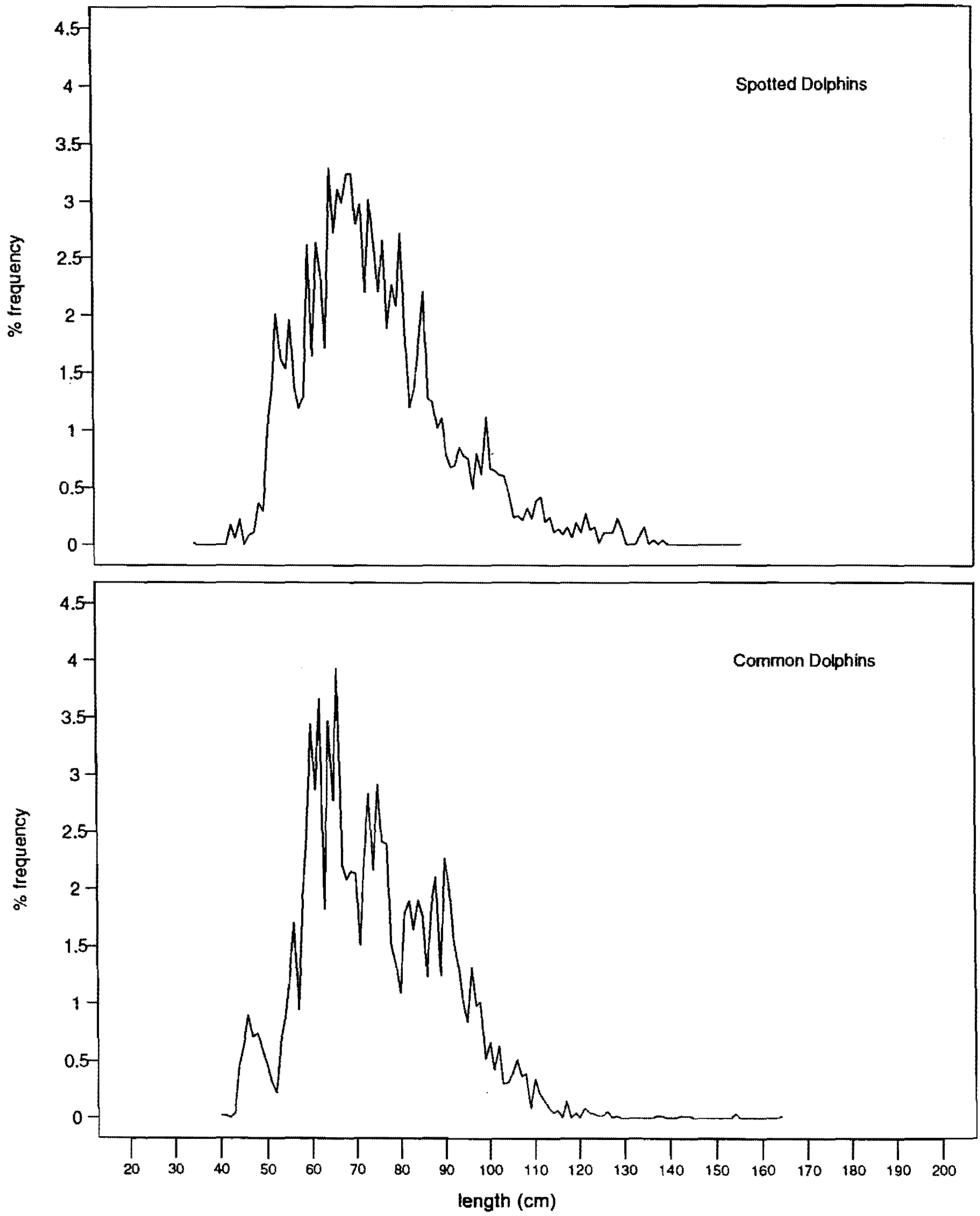


Figure 39. Yellowfin length-frequency distribution, in percentage of numbers, in Area A2 in purse-seine sets on spotted and "common" dolphins, 1980-90. Data for this figure kindly provided by Pat Tomlinson, IATTC.

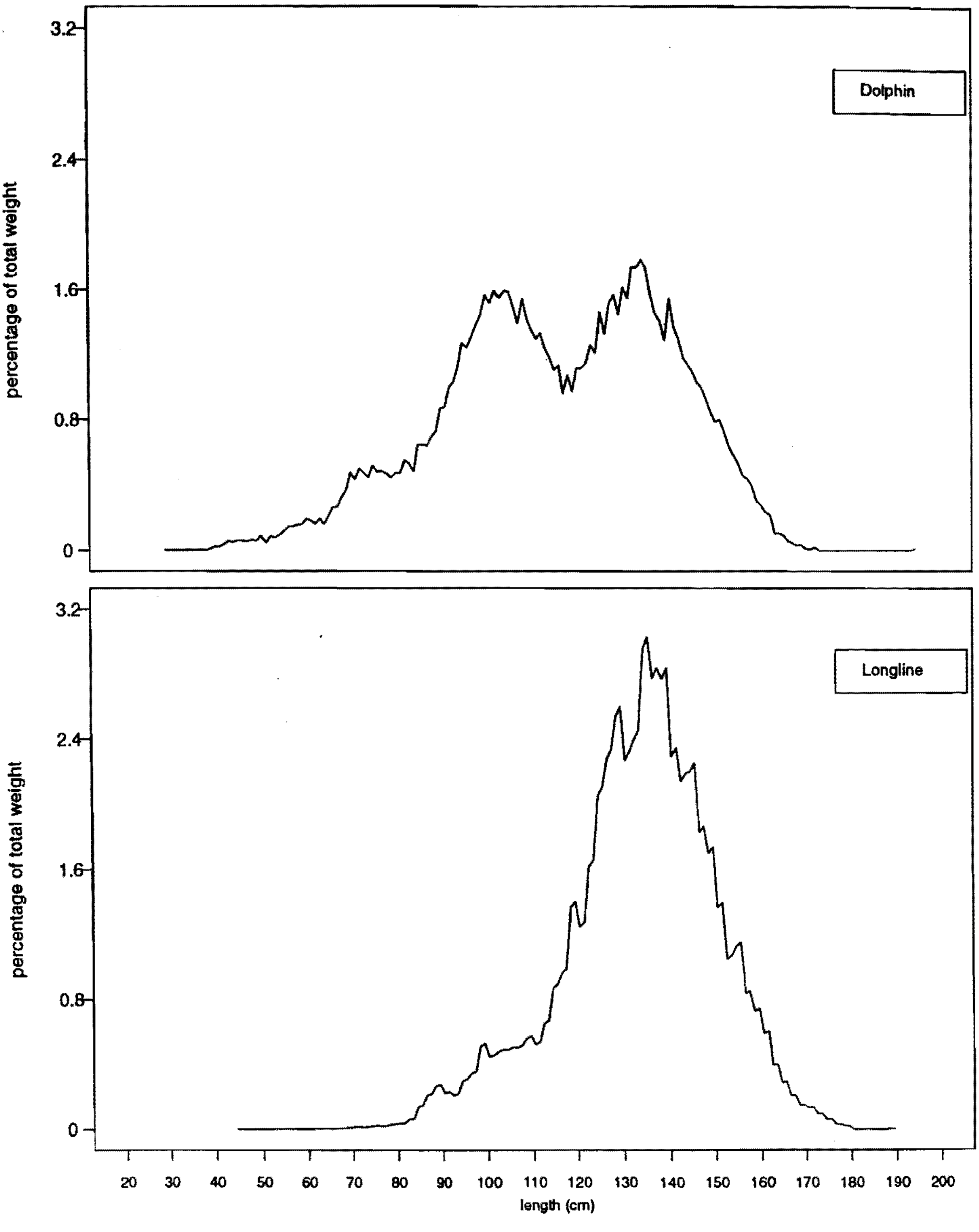


Figure 40. Yellowfin length-frequency distribution, in percentage of total weight for purse-seine sets on dolphins and longlines, 1969-79. Data for this figure kindly provided by Pat Tomlinson, IATTC.

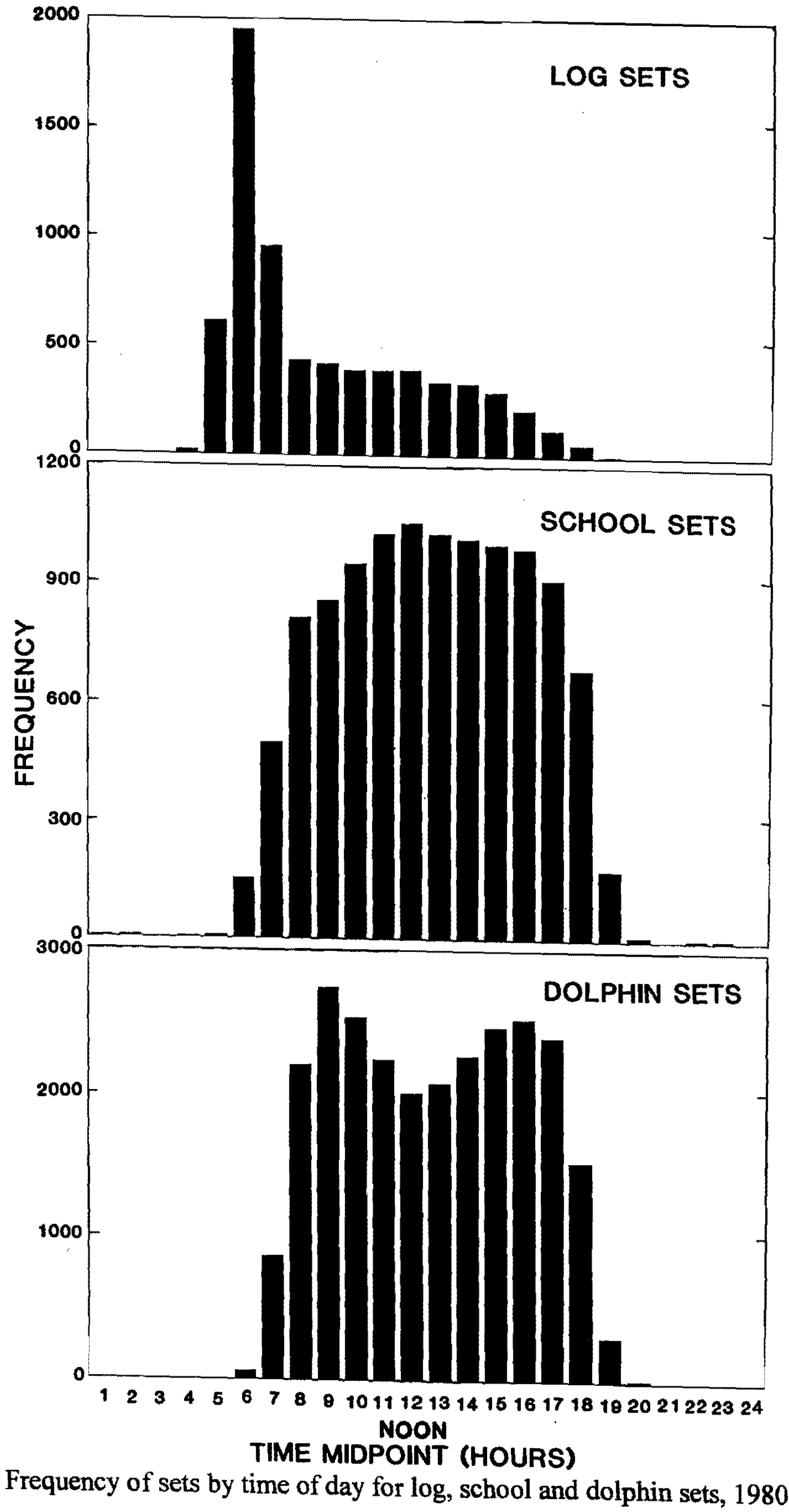


Figure 41. Frequency of sets by time of day for log, school and dolphin sets, 1980-90.

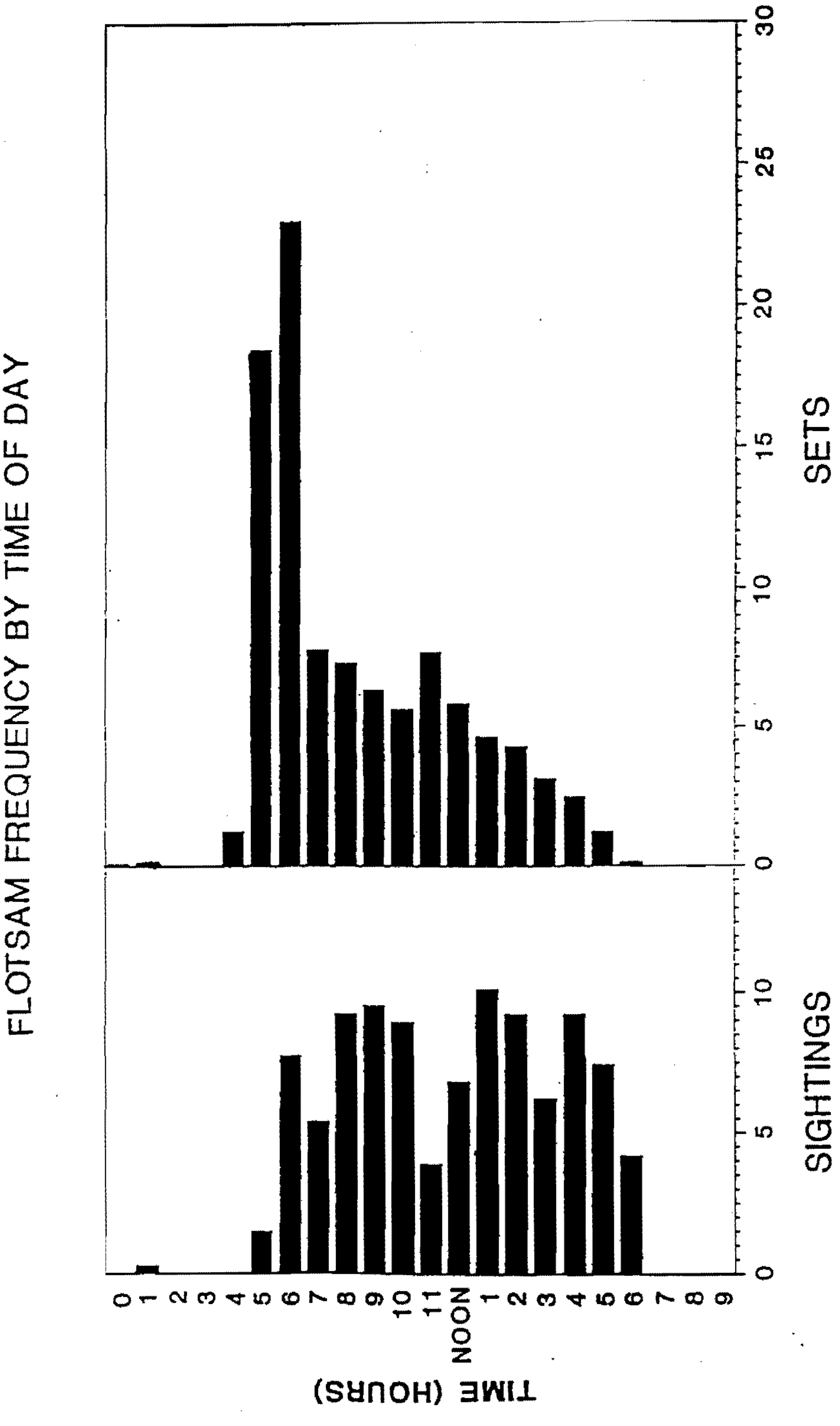


Figure 42. Frequency of log sets and sightings of floating objects by time of day, 1987-90. A sighting is an observation of a floating object that did not lead to a set.

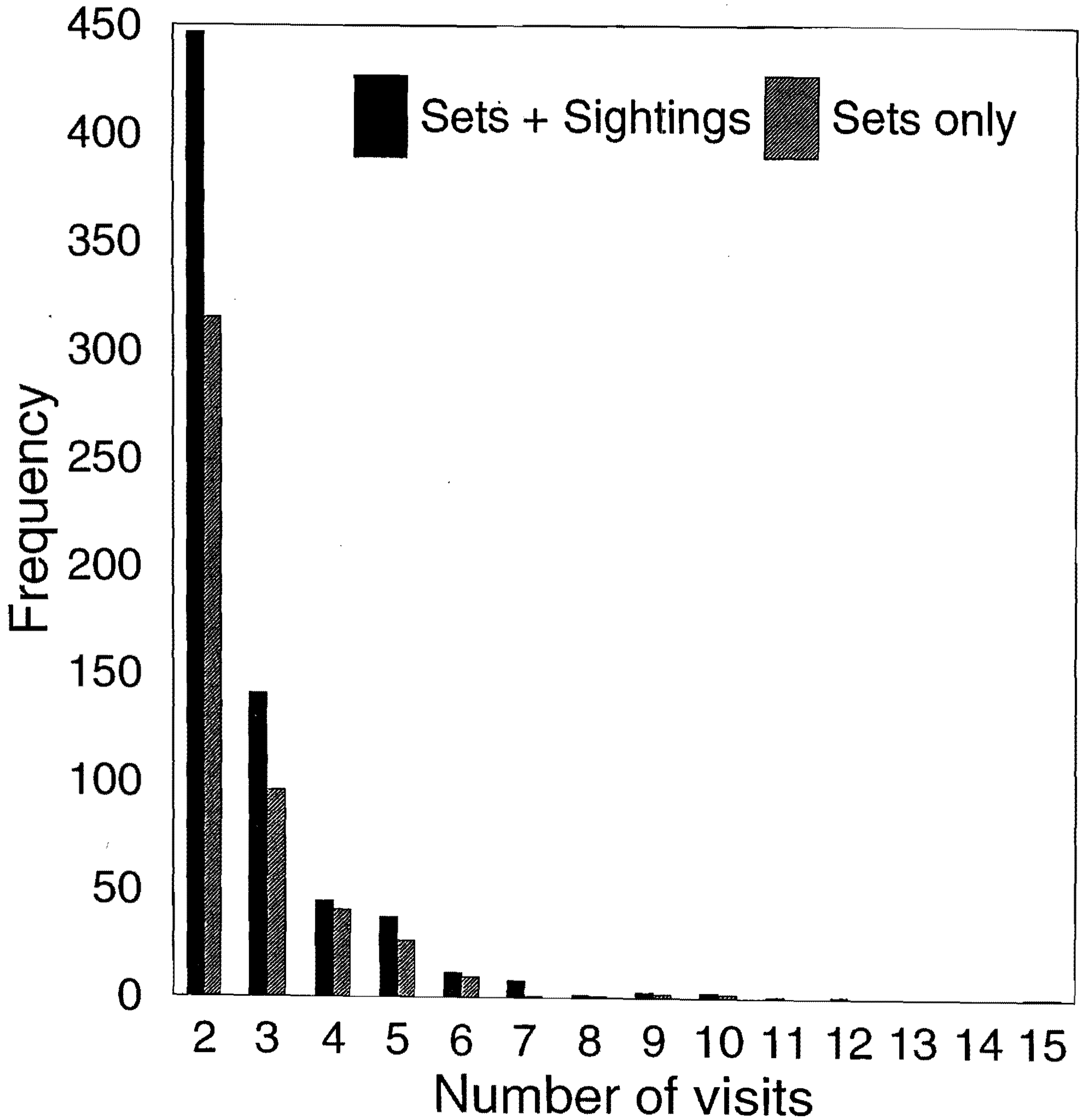


Figure 43. Frequency distribution of all observations (sets and sightings) and of sets for all objects with multiple visits. Total number of sets and sighting is 702.

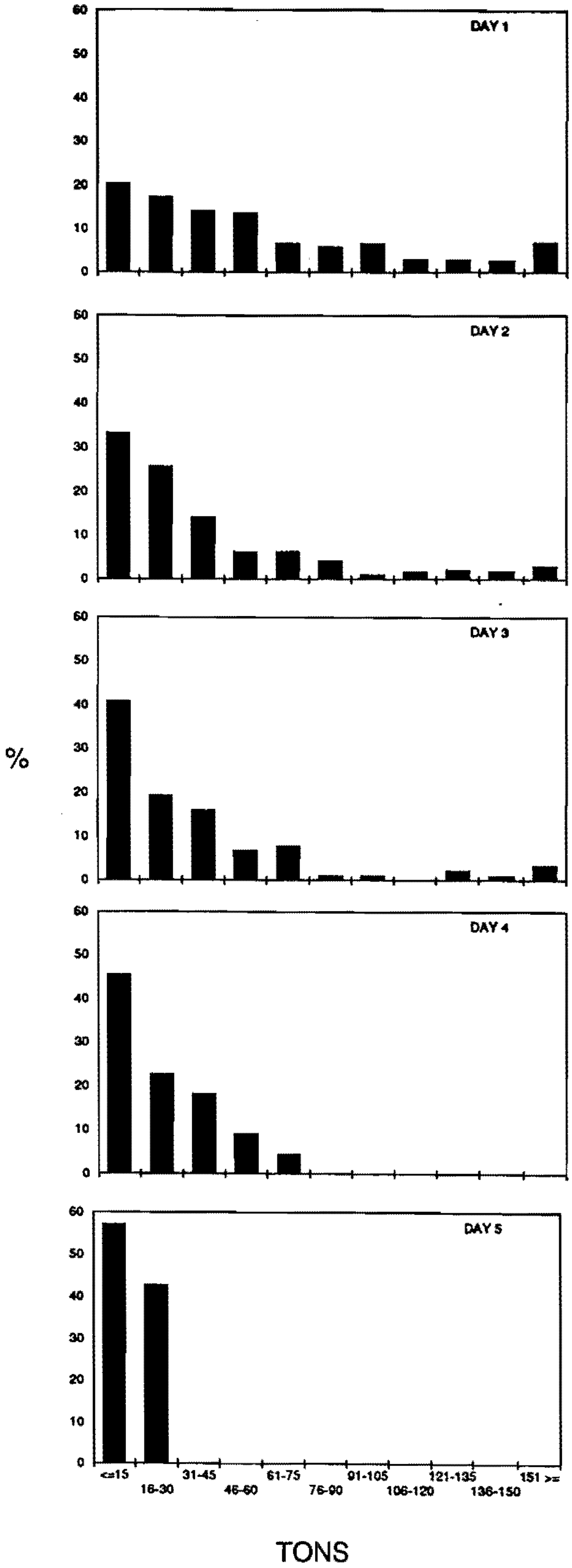


Figure 44. Frequency distribution of catches of all tunas by day in consecutive sequences of sets.

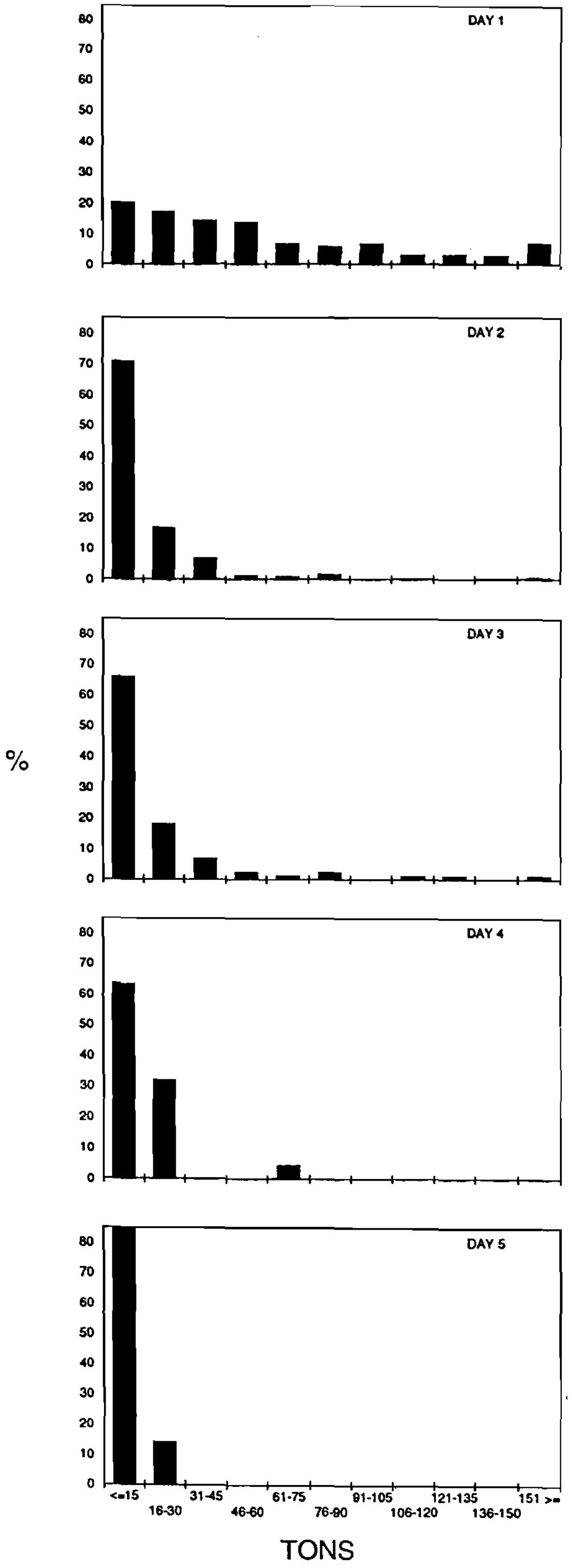


Figure 45. Frequency distribution of catches of yellowfin tunas by day in consecutive sequences of sets.

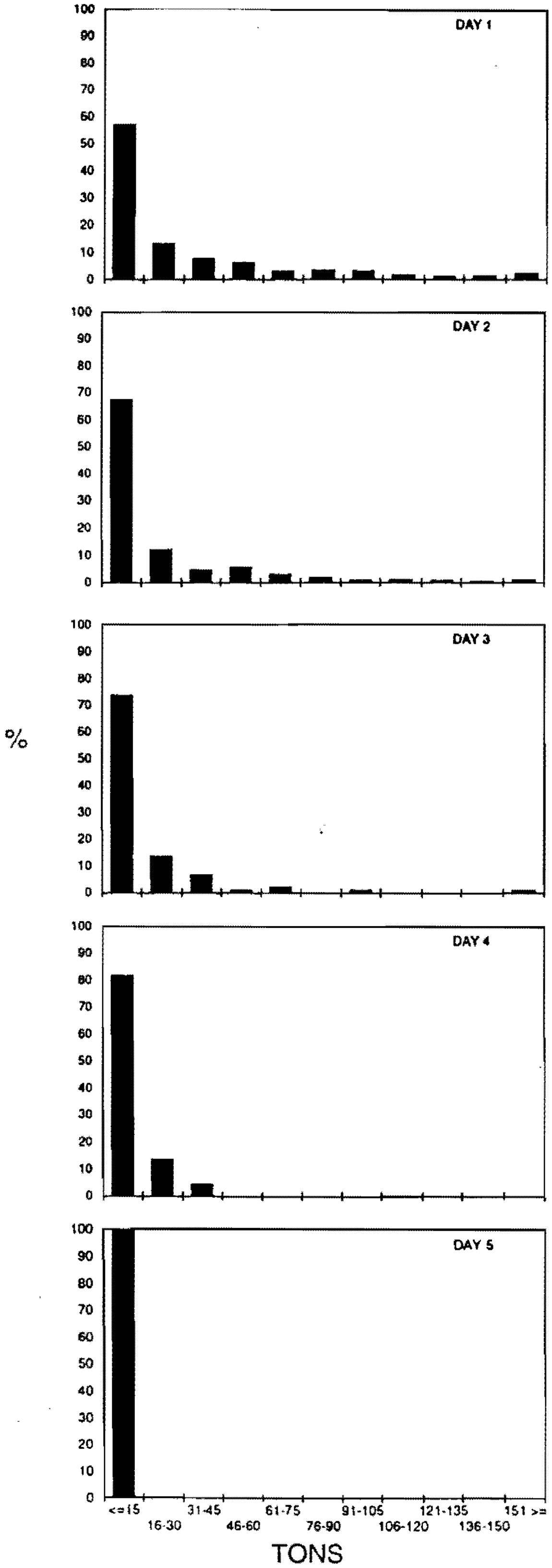


Figure 46. Frequency distribution of catches of skipjack tunas by day in consecutive sequences of sets.

Table 3. French purse-seine catch composition* (in %) before and after correction (1984-1990).

		LOG CATCH		FREE CATCH		TOTAL CATCH	
		BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
	YF	23.4	23.6	78.1	77.9	54.1	54.1
1984	SJ	74.6	74.1	20.5	20.6	44.2	44.0
	BE	2.0	2.3	0.8	0.8	1.3	1.5
	YF	20.8	22.5	86.3	86.1	46.3	47.2
1985	SJ	75. 7	73.6	11.5	11.6	50.7	49.5
	BE	3.4	3.9	0.4	0.5	2.3	2.6
	YF	13.5	16.9	74.6	75.4	39.5	41.8
1986	SJ	81.4	77.1	22.5	21.5	56.3	53.4
	BE	5.1	6.1	2.5	2.6	4.0	4.6
	YF	24.1	28.5	57.3	58.2	38.7	41.5
1987	SJ	72.0	65.9	41.2	39.8	58.5	54.5
	BE	3.9	5.6	0.8	1.3	2.5	3.7
	YF	16.5	20.9	77.4	77.7	50.8	52.9
1988	SJ	79.7	74.4	21.2	20.6	46.7	44.1
	BE	3.8	4.7	1.1	1.3	2.3	2.8
	YF	21.5	34.1	50.0	57.6	34.9	45.1
1989	SJ	75.8	59.8	49.1	40.3	63.2	50.6
	BE	2.8	6.1	0.9	2.1	1.9	4.2
	YF	17.0	30.2	81.4	78.8	53.0	57.4
1990	SJ	78.6	62.6	16.0	16.7	43.6	36.9
	BE	4.4	7.2	2.5	4.4	3.4	5.6
Ave.	YF	19.5	25.0	72.3	73.2	45.2	48.5
(1984-	SJ	76.8	69.8	25.9	24.4	52.0	47.7
1990)	BE	3.7	5.2	1.3	1.9	2.5	3.6

*Albacore is not listed as it is quite uncommon, but it is taken into account in the calculation of the species composition.

Table 4. Skipjack size distribution from French purse seiners, 1984-90 (% of total number of skipjack).

SIZE RANGE (FL)	LOG SCHOOLS	FREE SCHOOLS
SJ < 50 cm	45.2	35.0
50 cm < SJ < 60 cm	42.9	50.2
SJ > 70 cm	0.6	1.4
Size class with the highest size frequency	50-52 cm	50-52 cm

Table 5. Yellowfin size distribution from French purse seiners, 1984-90 (% of total number of yellowfin).

SIZE RANGE (FL)	LOG SCHOOLS	FREE SCHOOLS
YF < 40 cm	2.6	0.0
40 cm < YF < 70 cm	78.6	28.6
10 cm < YF < 100 cm	9.8	13.8
120 cm < YF < 150 cm	3.7	39.7
YF > 150 cm	0.1	3.4
Size class with the highest size frequency	46-50 cm	50-54 cm & 126-130 cm

Table 6. Bigeye size. distribution from French purse seiners, 1984-89. (% of total number of bigeye).

SIZE RANGE (FL)	LOG SCHOOLS	FREE SCHOOLS
BE < 40 cm	2.9	0
40 cm < BE< 80 cm	86.9	54.3
80 cm < BE< 130 cm	9.9	35.5
BE> 130 cm	0.3	10.2
Size class with the highest size frequency	58-62 cm	50-54 cm

Table 7. The development of artificial log use in the EEC purse-seine fishery in the western Indian Ocean (1989-1991).

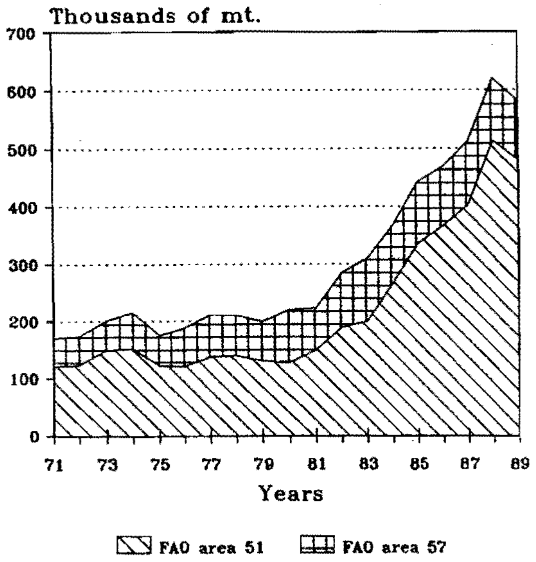
	FRANCE & associated				**SPAIN & associated**			
	NATURAL LOG		**ARTIFICIAL LOG**		**NATURAL LOG**		**ARTIFICIAL LOG**	
	CATCH mt.	**%**	**CATCH mt.**	**%**	**CATCH mt.**	**%**	**CATCH mt.**	**%**
1989	44,441	52.2	269	0.3	63,870	51.5	141	0.1
1990	34,112	43.2	543	0.7	55,717	46.2	7,678	6.4
1991*	41,222	53.7	2 210	2.9	35,730	36.4	14,174	14.4

*Data are incomplete (1½ months of data are still missing).

Table 8. The occurrence of natural and artificial log schools by time-area strata, Spanish logbooks, 1991, western Indian Ocean.

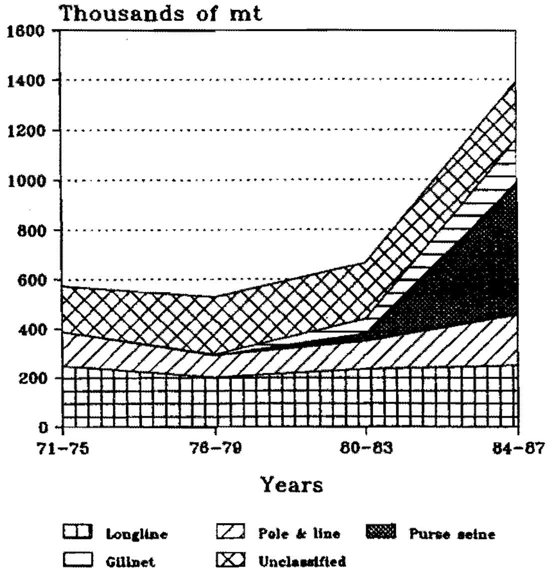
Type of Schools Fished in Each Time-Area Strata	**Number of 5°x5°/Month Time Area Strata Concerned**	
	Number	**% of Total**
Unassociated schools only	42	27.6
Unassociated schools + artificial log schools	14	9.2
Unassociated schools + natural log schools	33	21.7
Unassociated schools + natural log schools + artificial log schools	52	34.2
Natural log schools only	5	3.3
Artificial log schools only	6	3.9
TOTAL	**152**	**100.0**

FIGURE 1: INDIAN OCEAN TUNA CATCH IN FAO AREAS 51 AND 57 FROM 1971 TO 1989 (80 E is the limit between the 2 areas)



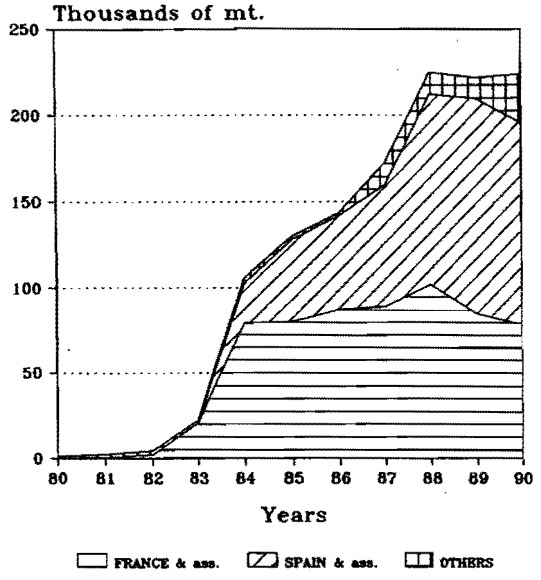
Source: FAO

FIGURE 2: WESTERN INDIAN OCEAN TUNA CATCH BY GEAR (1971 - 87)



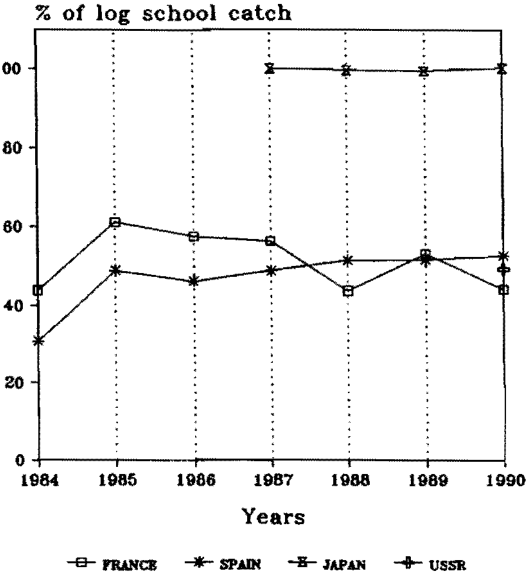
Source: FAO

FIGURE 3 : PURSE SEINER TOTAL CATCH BY COUNTRY IN FAO AREA 51 (1980 - 90)



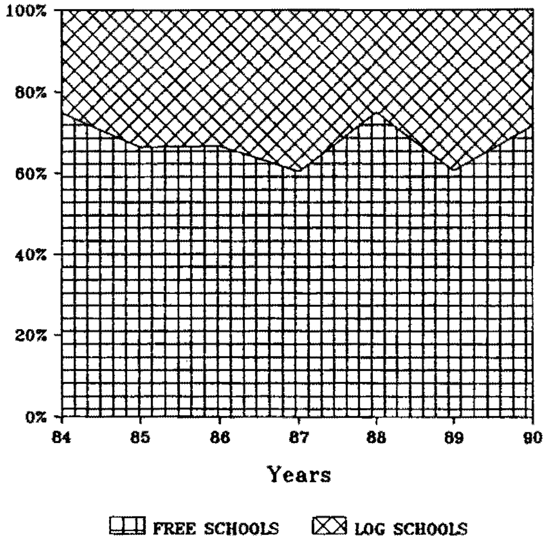
Source: ORSTOM, SFA

FIGURE 4 : PERCENTAGE OF LOG SCHOOL CATCH BY COUNTRY (1984 - 90)



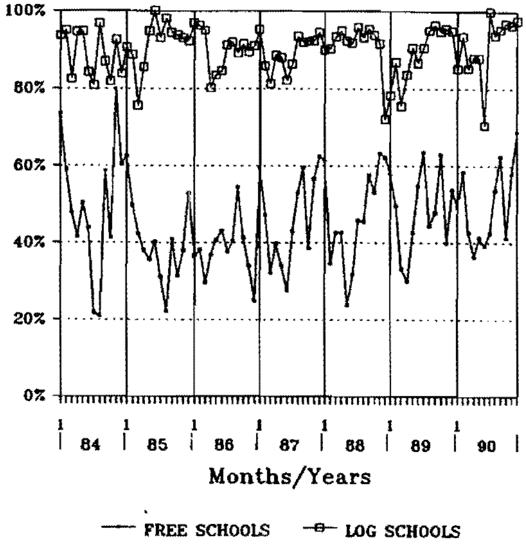
No data for USSR before 1990

FIGURE 5 : YEARLY DISTRIBUTION OF PURSE SEINE SETS ON LOG AND FREE SCHOOLS (1984 - 90)



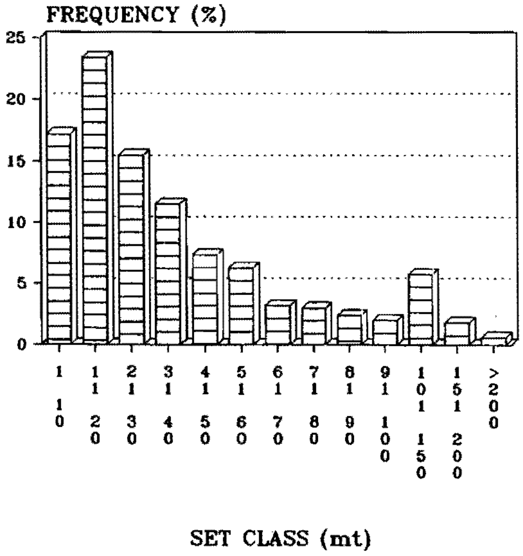
French purse seiners,
Western Indian Ocean

FIGURE 6 : FISHING SUCCESS ON LOG AND FREE SCHOOL SETS (1984 - 90)



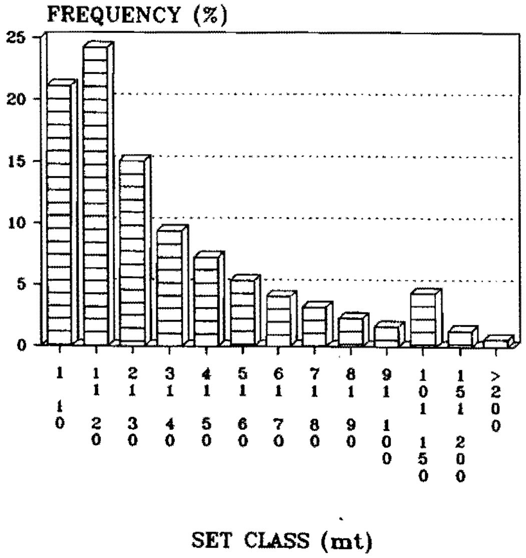
French purse seiners,
Western Indian Ocean

FIGURE 7 : SET SIZE DISTRIBUTION (IN MT) FOR LOG SCHOOLS
French fleet (1984 - 89)



0794 positive sets
(not including 757 nil sets)

FIGURE 8 : SET SIZE DISTRIBUTION (IN MT) FOR FREE SCHOOLS
French fleet (1984 - 89)



5720 positive sets
(not including 9241 nil sets)

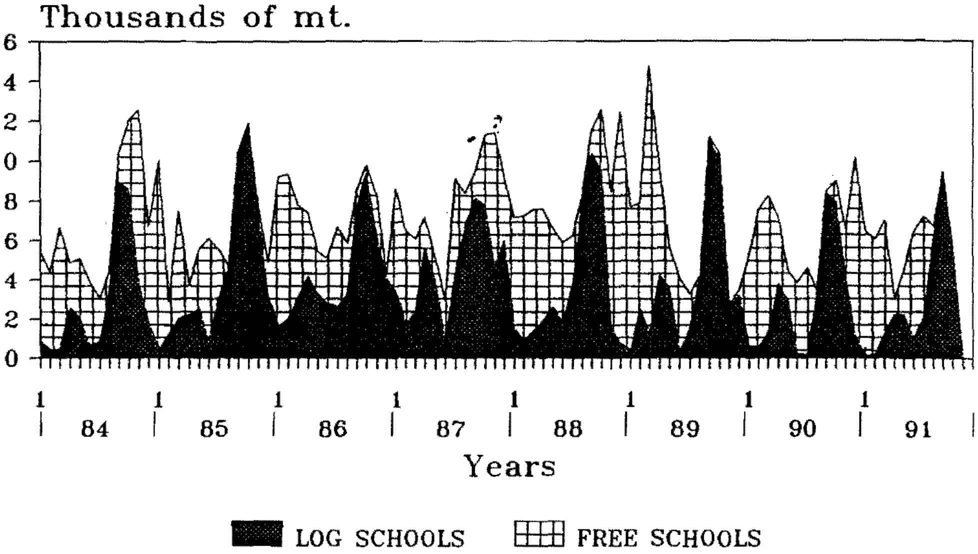
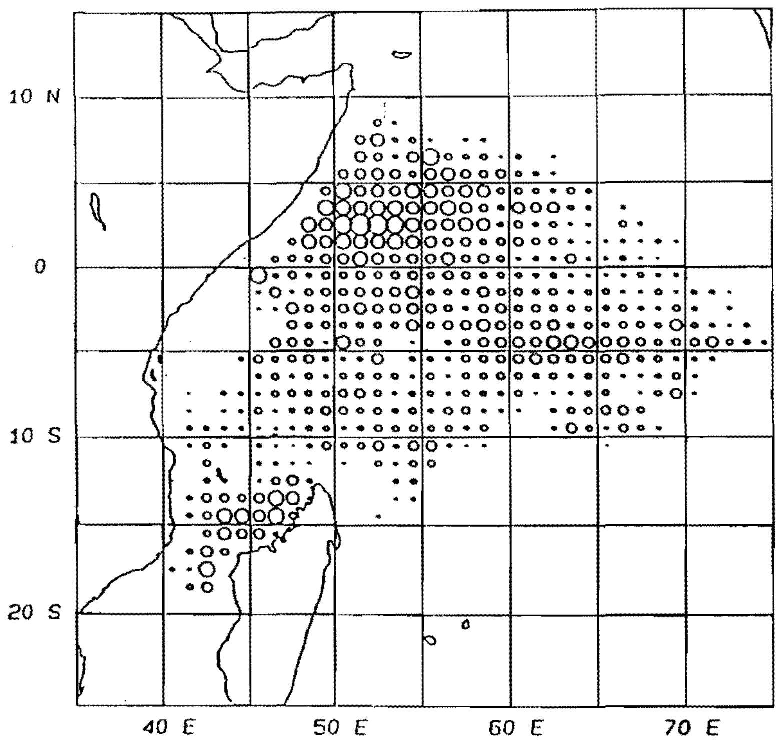
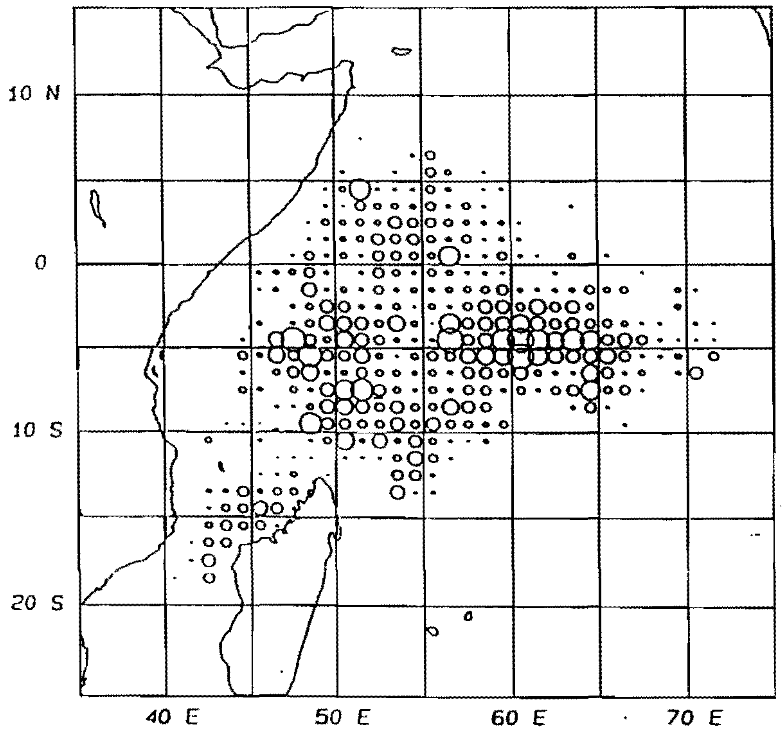


Figure 9. Monthly catch distribution on log and free schools in the Western Indian Ocean for the French fleet (1984-1991). Data for 1991 are uncorrected and incomplete.



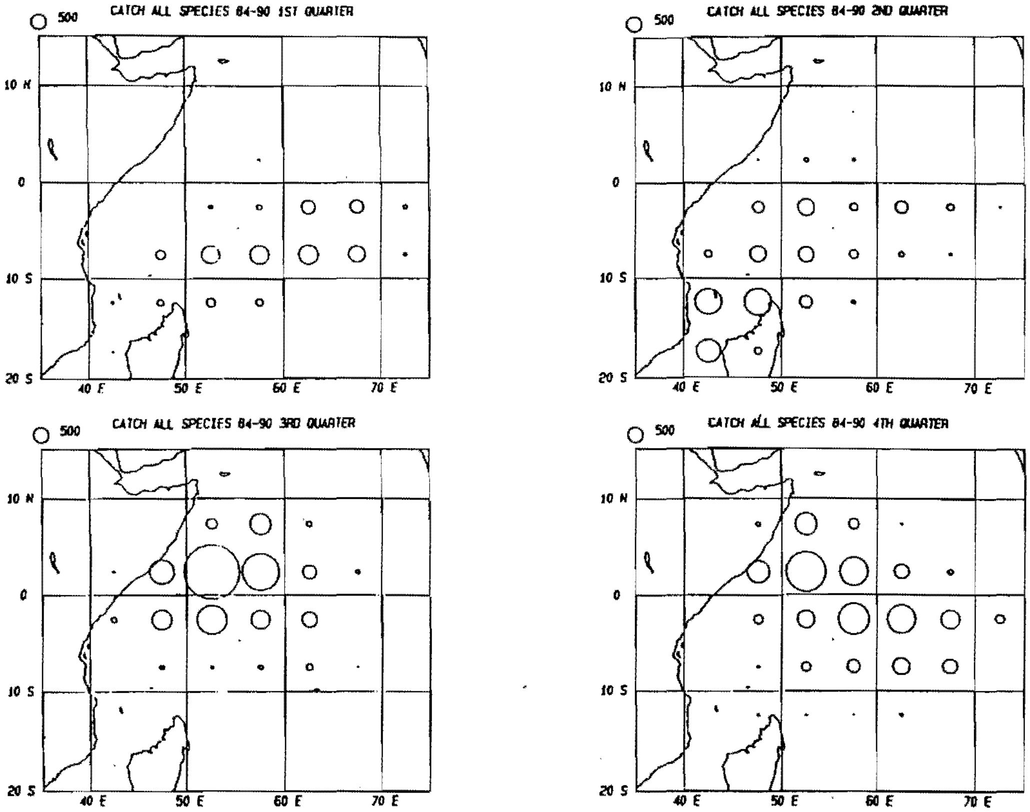
A. LOG SCHOOL CATCH



B. FREE SCHOOL CATCH

Figure 10. Average catch per 1-degree square per type of school. in the Western Indian Ocean for the French fleet (1984-1989).

LOG



FREE

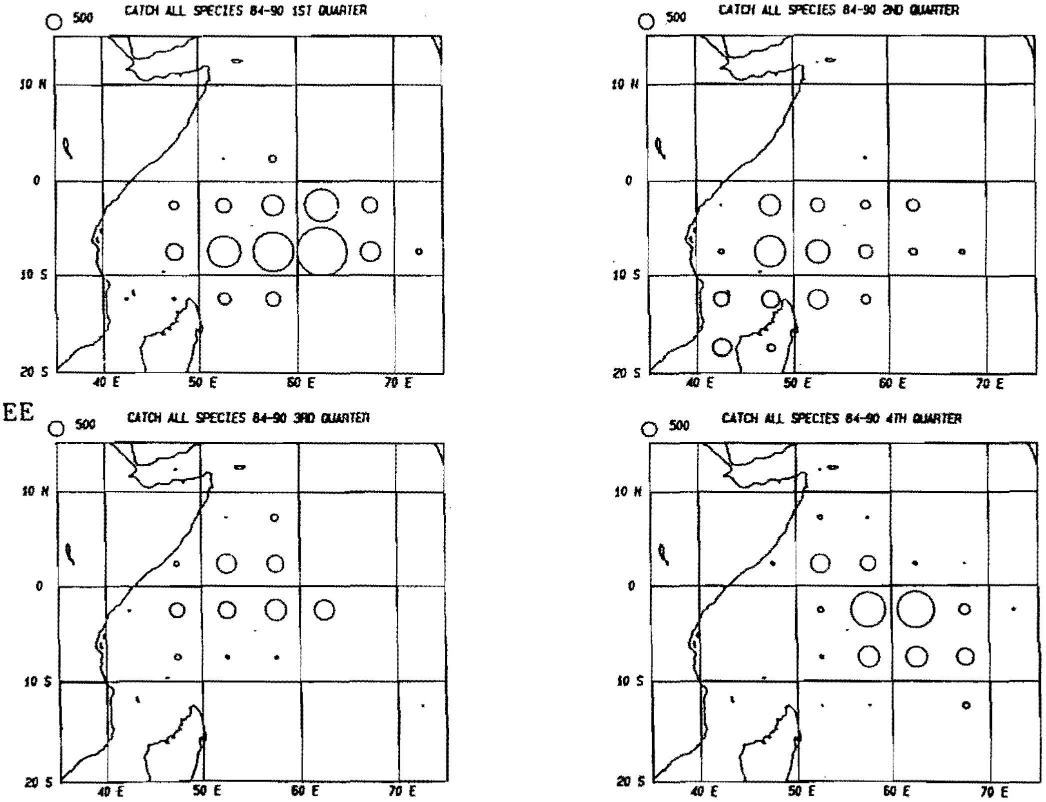


Figure 11. Average catch per 5-degree square/ quarter per type of school. in the Western Indian Ocean for the overall purse-seine fleet (1984-1990).

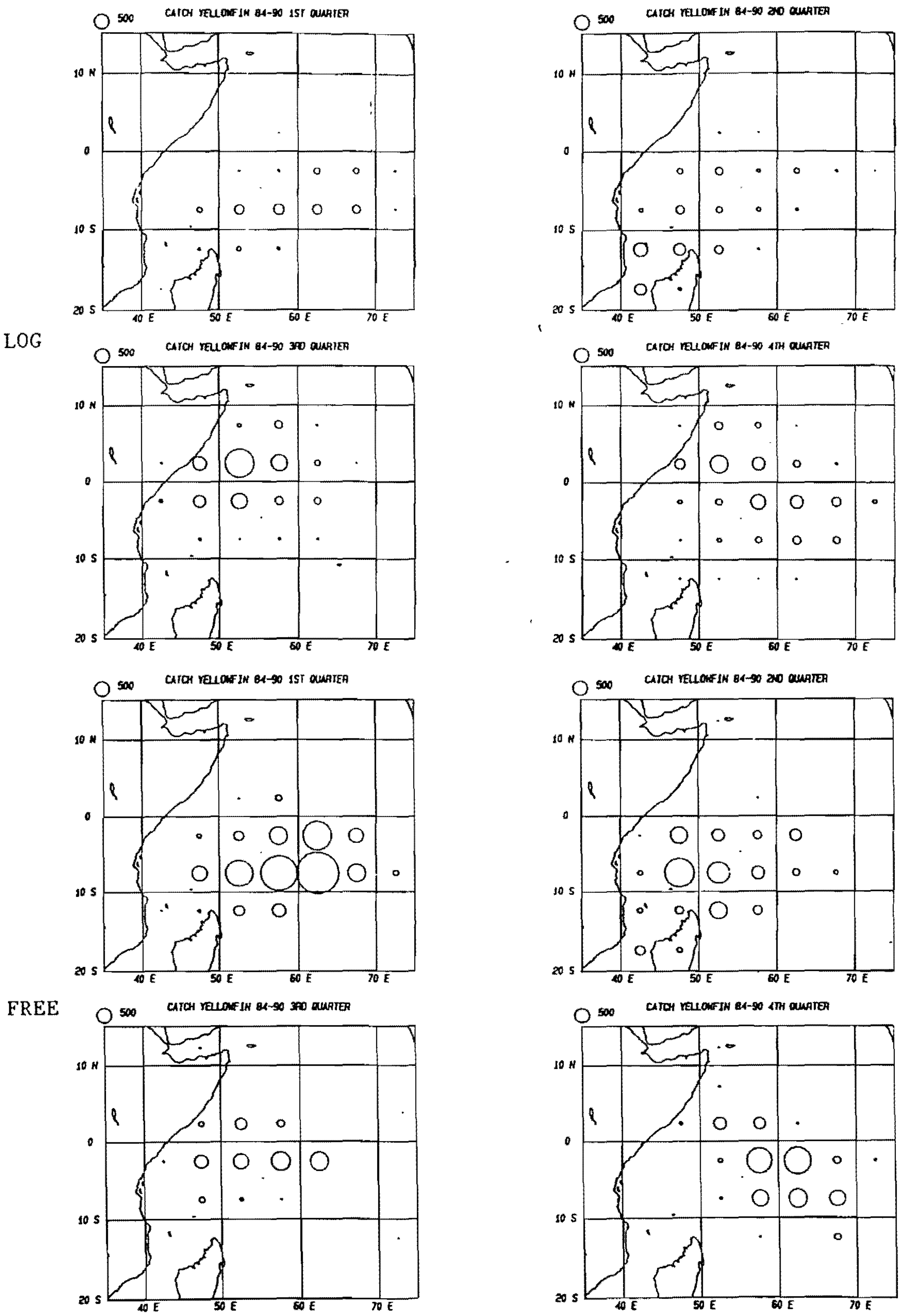


Figure 12. Yellowfin average catch per 5-degree square/ quarter per type of school. in the Western Indian Ocean for the overall purse-seine fleet (1984-1990).

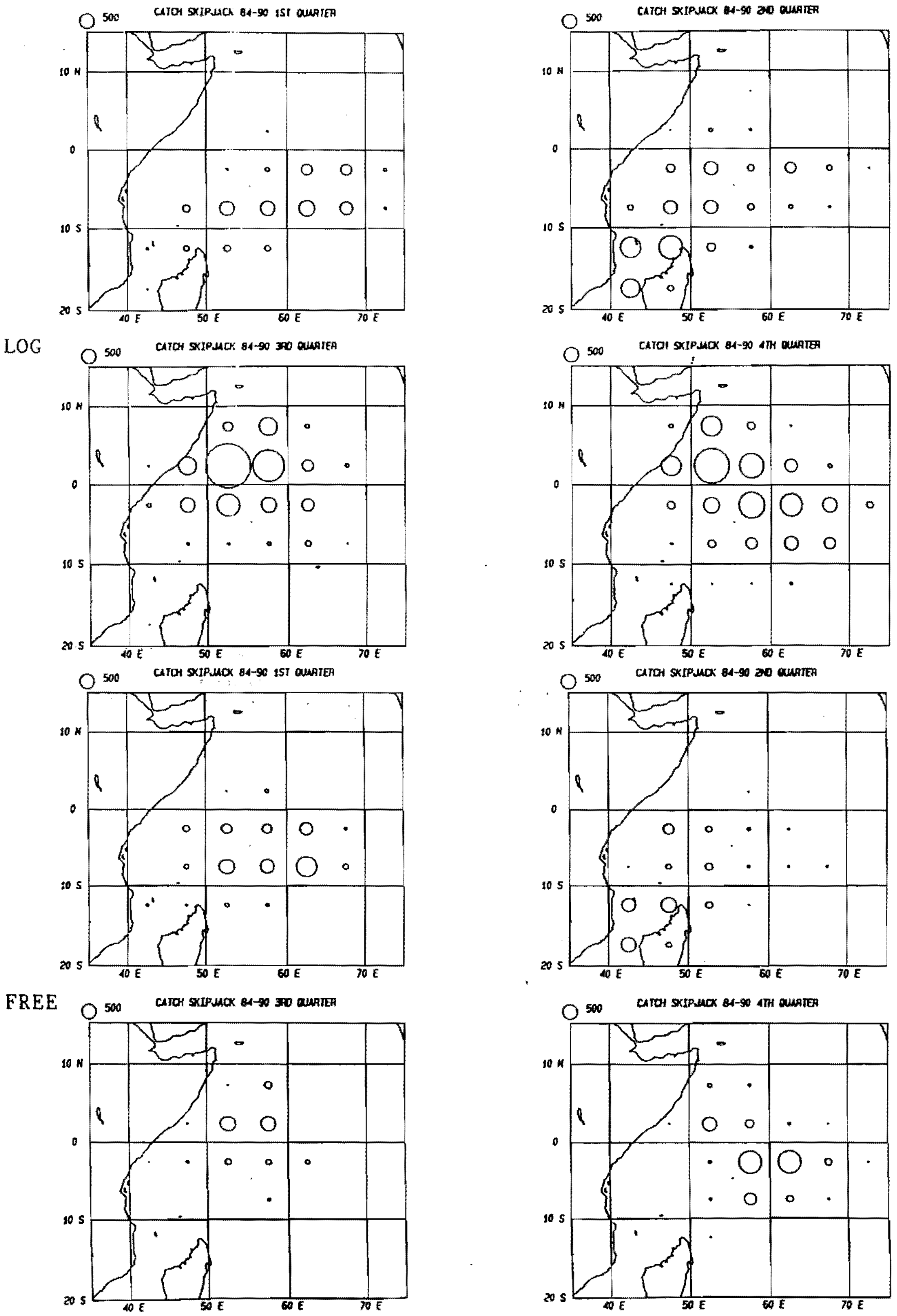


Figure 13. Skipjact average catch per 5-degree square/ quarter per type of school. in the Western Indian Ocean for the overall purse-seine fleet (1984-1990).

LOG

FREE

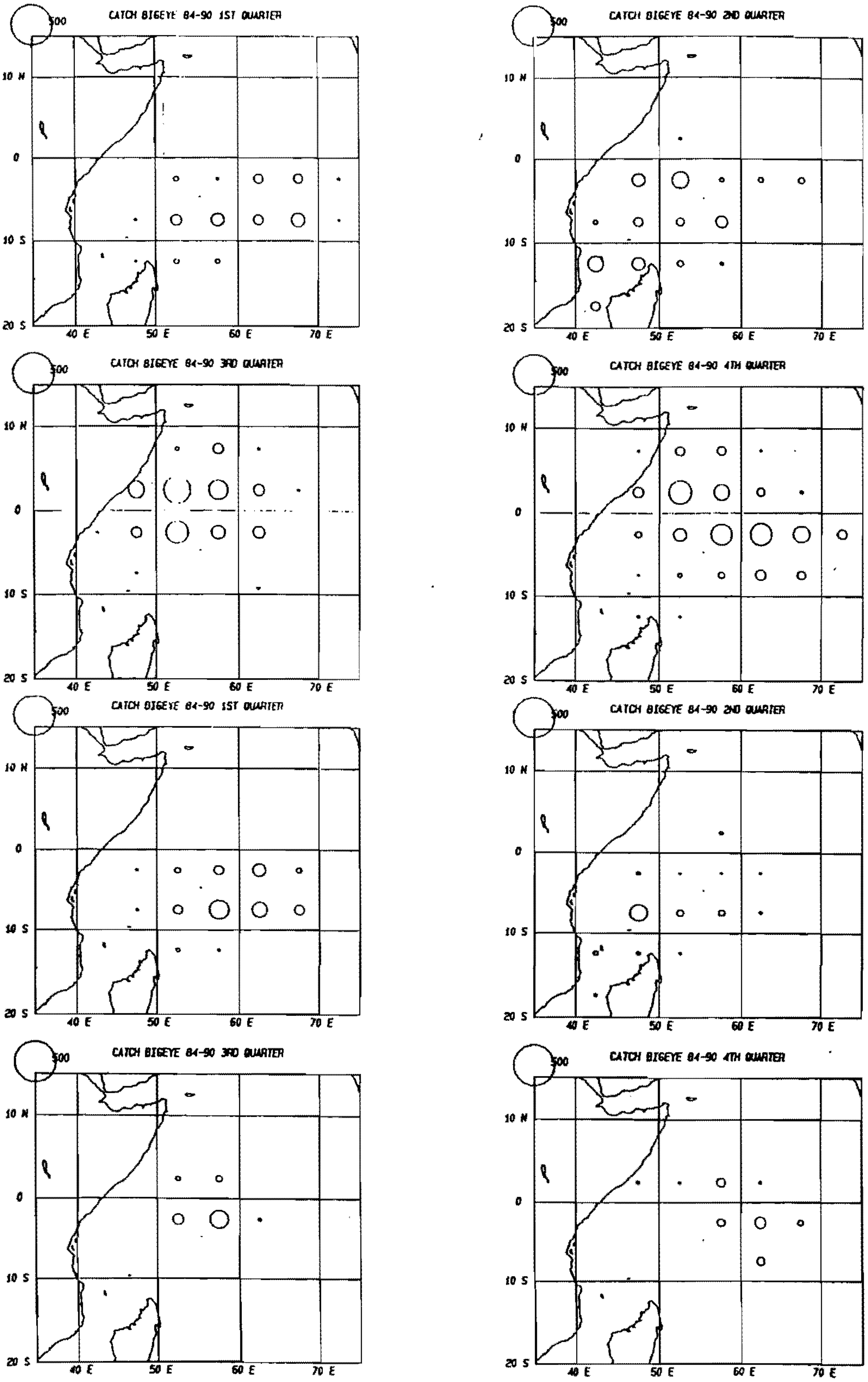
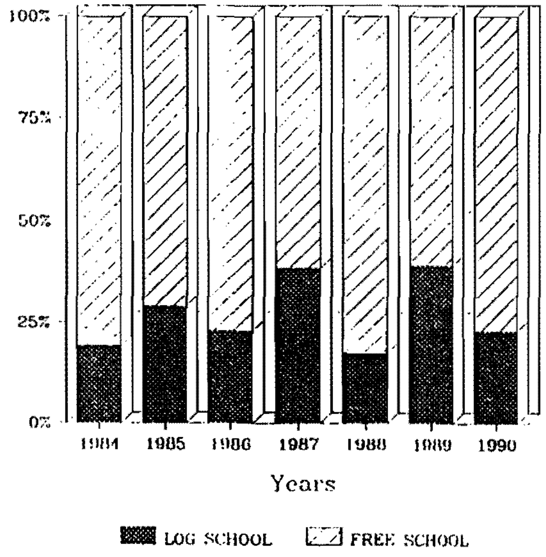


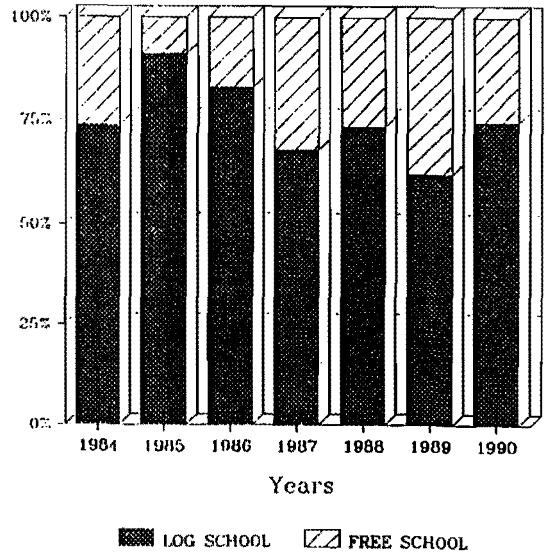
Figure 14. Bigeye average catch per 5-degree square/ quarter per type of school. in the Western Indian Ocean for the overall purse-seine fleet (1984-1990).

FIGURE 15:YELLOWFIN CATCH DISTRIBUTION
BETWEEN LOG AND FREE SCHOOLS
(1984 - 90)



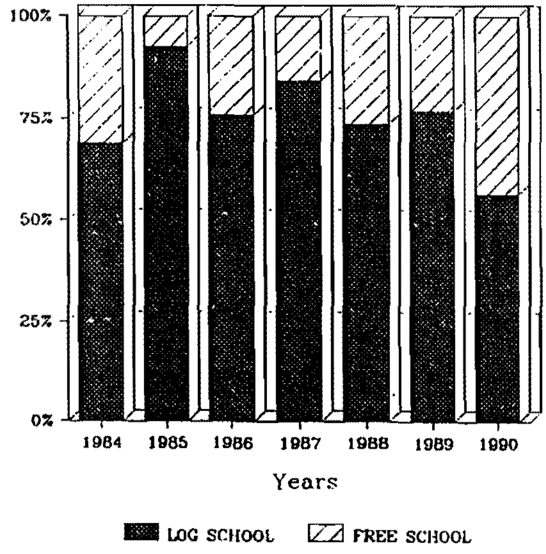
French purse seiners,
Western Indian Ocean

FIGURE 16 : SKIPJACK CATCH DISTRIBUTION
BETWEEN LOG AND FREE SCHOOLS
(1984 - 90)



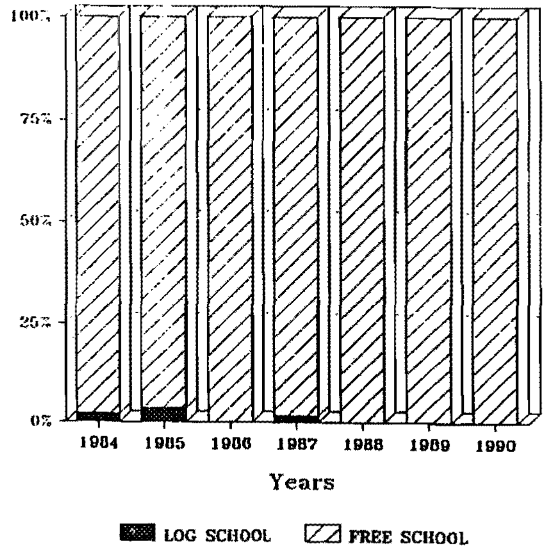
French purse seiners,
Western Indian Ocean

FIGURE 17 : BIGEYE CATCH DISTRIBUTION
BETWEEN LOG AND FREE SCHOOLS
(1984 - 90)



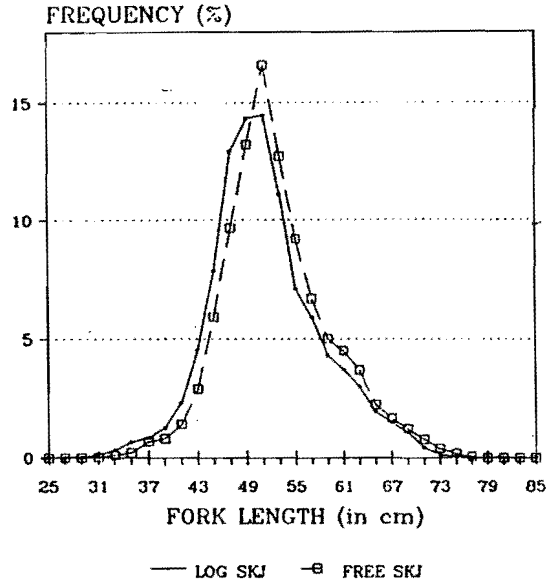
French purse seiners,
Western Indian Ocean

FIGURE 18 : ALBACORE CATCH DISTRIBUTION
BETWEEN LOG AND FREE SCHOOLS
(1984 - 90)



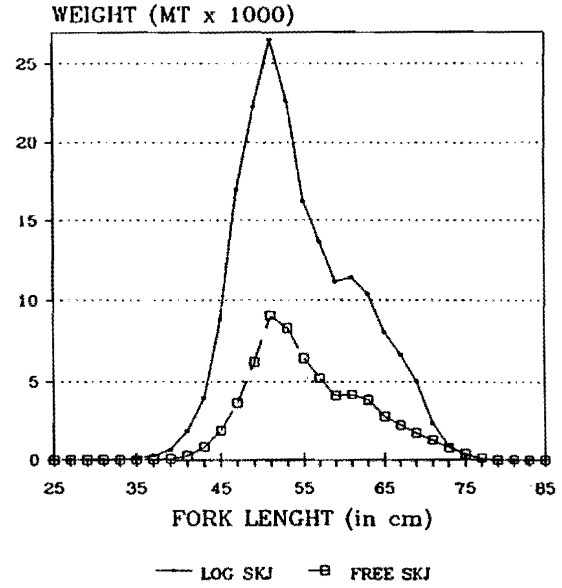
French purse seiners,
Western Indian Ocean

FIGURE 19 : SIZE FREQUENCY DISTRIBUTION OF SKIPJACK FROM LOG AND FREE SCHOOLS



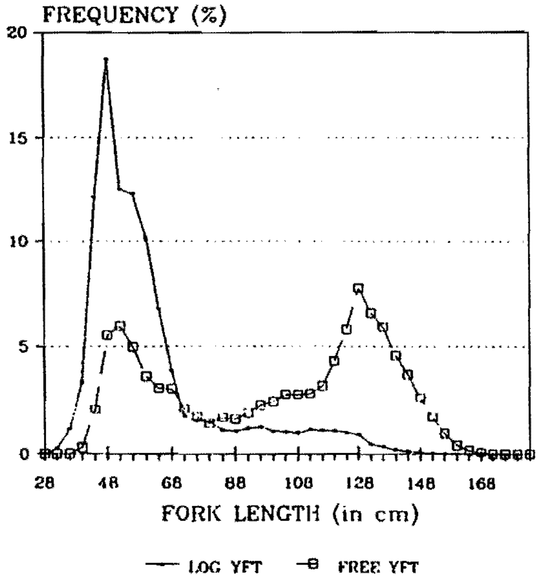
French purse seiners,
Western Indian Ocean, 1984-90.

FIGURE 20 : WEIGHT OF SKIPJACK BY SIZE CLASSES OF 2CM ON LOG AND FREE SCHOOLS



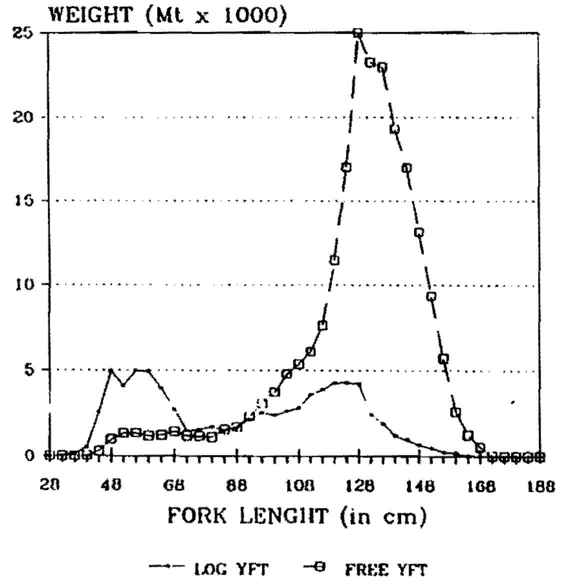
French purse seiners,
Western Indian Ocean, 1984-90.

FIGURE 21 : SIZE FREQUENCY DISTRIBUTION OF YELLOWFIN FROM LOG AND FREE SCHOOLS



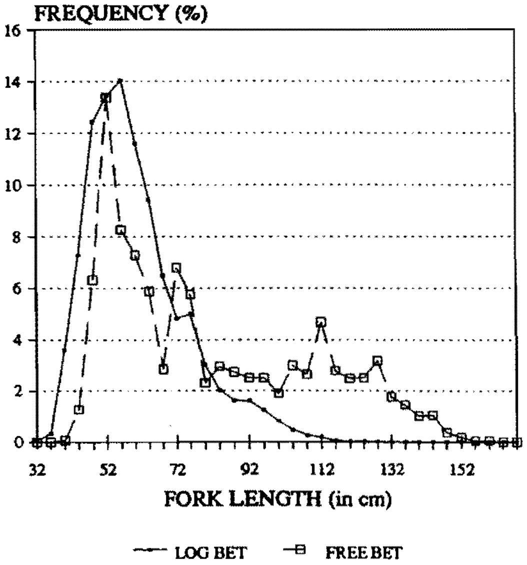
French purse seiners,
Western Indian Ocean, 1984-90.

FIGURE 22 : WEIGHT OF YELLOWFIN BY SIZE CLASSES OF 4CM ON LOG AND FREE SCHOOLS



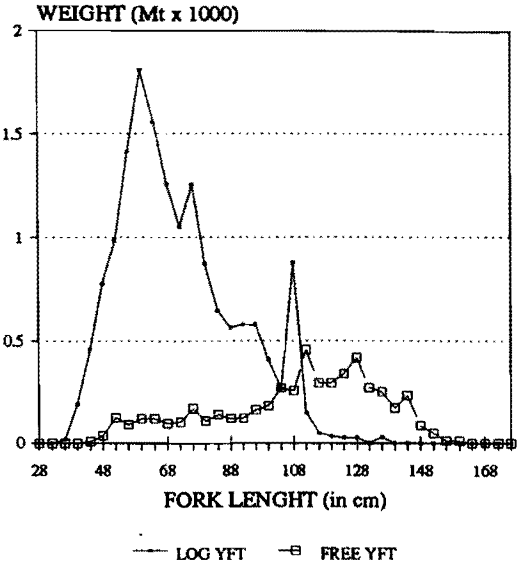
French purse seiners,
Western Indian Ocean, 1984-90.

FIGURE 23 : SIZE FREQUENCY DISTRIBUTION OF BIGEYE FROM LOG AND FREE SCHOOLS



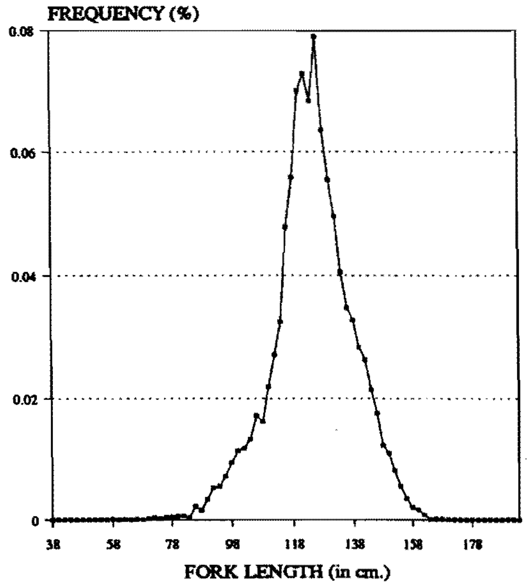
French purse seiners,
Western Indian Ocean, 1984-90.

FIGURE 24 : WEIGHT OF BIGEYE BY SIZE CLASSES OF 4CM ON LOG AND FREE SCHOOLS



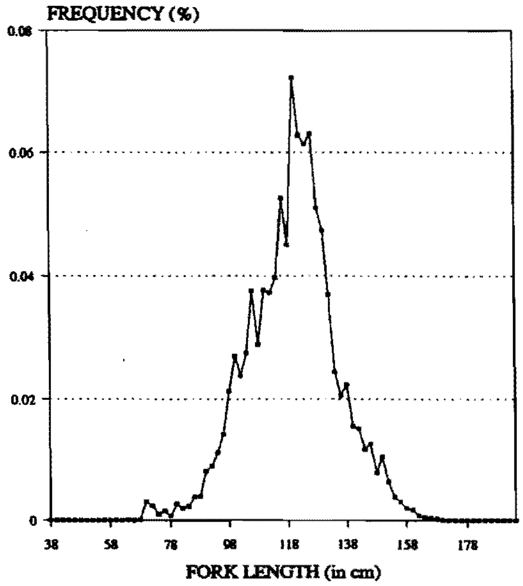
French purse seiners,
Western Indian Ocean, 1984-90.

FIGURE 25 : SIZE FREQUENCY DISTRIBUTION OF YELLOWFIN CAUGHT ON JAPAN LONGLINERS BY 2 CM CLASSES (1976 - 1989)



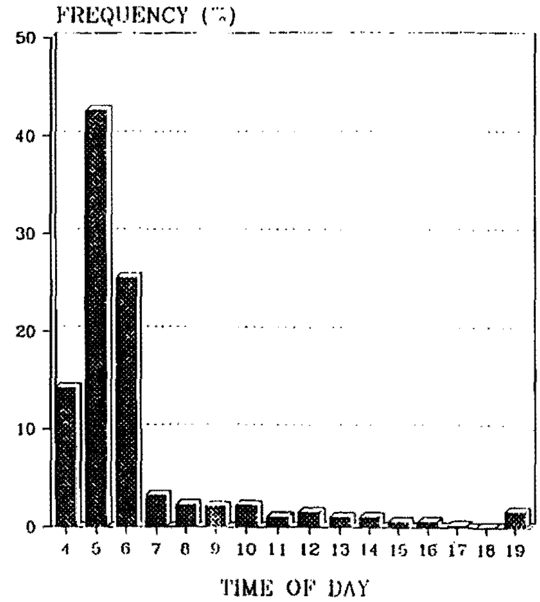
Western Indian Ocean 05°N-05°S/55°E-75°E

FIGURE 26 : SIZE FREQUENCY DISTRIBUTION OF YELLOWFIN CAUGHT ON JAPAN LONGLINERS BY 2 CM CLASSES (1976-89)



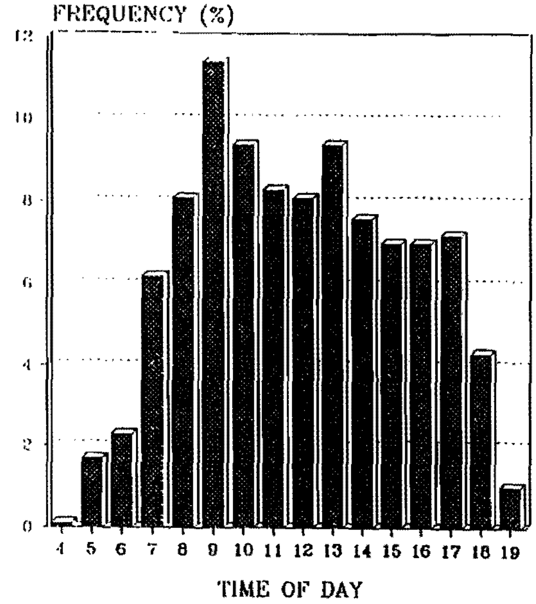
Western Indian Ocean 15°N-00 /45°E-55°E

FIGURE 27 : SETTING TIME FOR LOG SCHOOL SETS



Western Indian Ocean purse seiners, 1981-89

FIGURE 28 : SETTING TIME FOR FREE SCHOOL SETS



Western Indian Ocean purse seiners, 1981-89

FIGURE 29 : DURATION AGAINST CATCH FOR FRENCH POSITIVE SETS ON LOG AND FREE SCHOOLS

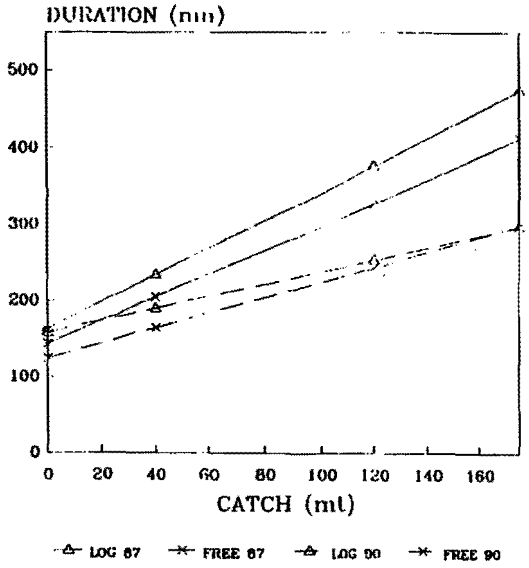
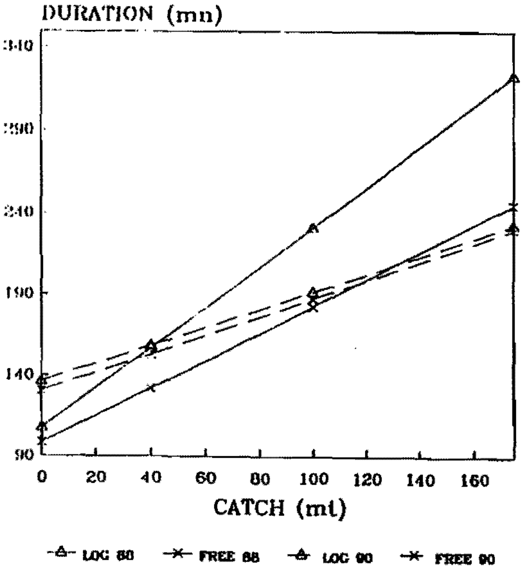


FIGURE 30 : DURATION AGAINST CATCH FOR SPANISH POSITIVE SETS ON LOG AND FREE SCHOOLS



FISHING FOR TUNAS ASSOCIATED WITH FLOATING OBJECTS: REVIEW OF THE WESTERN PACIFIC FISHERY

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ABSTRACT

The tuna fishery in the western and central Pacific Ocean (WPO) is currently the world's largest, with a total catch in 1990 of approximately 1.2 million mt. The purse seine fleet, comprised of vessels from Australia, Indonesia, Japan, Korea, Philippines, Solomon Islands, Soviet Union, Taiwan and USA, accounted for about 700,000 mt in 1990. Purse seiners set on a variety of floating objects with which tuna tend to associate. In the WPO, these include logs, drifting and anchored fish aggregation devices (FADs and marine animals (mostly sei whales, and occasionally, minke whales and whale sharks). Sets are also made on tuna associated with oceanographic and geographic features such as current lines and seamounts, as well as unassociated tuna schools. Sets on dolphin schools are virtually unknown in the WPO. Log sets and sets on unassociated tuna or tuna associated with oceanographic or geographic features ("school" fish) generally account for more than 90% of sets made in a quarter. Sets on FADs are common only in the Philippine and Solomon Islands fleets. Most animal sets are made by the Japanese and Korean fleets, but have accounted for less than 5% of their total sets. The highest skipjack catches per set tend to come from log and school sets, whereas higher yellowfin catches per set are made from anchored FAD and animal sets. School and animal sets tend to be on either pure skipjack or yellowfin schools, whereas log and FAD sets commonly have a mixed species composition. Sampling data indicate that 5-16% of the quarterly US purse seine "yellowfin" catch (by weight) from log sets is actually bigeye. In contrast, this percentage is less than 2% for school sets.

Information on by-catch is sparse. By-catch is known to be more extensive for log and FAD sets than for school and animal sets, commonly comprising such species as rainbow runner, mahi-mahi, triggerfish and silky sharks. Blue marlin is often caught in log sets in small numbers.

Sampling of US purse seine catches indicates that larger sized yellowfin (>80 cm) are regularly caught in school sets but are less common in log sets. Also, large skipjack (>60 cm) are more common in school than in log sets. Large bigeye (>80 cm) are much less common than large yellowfin, and are more frequently caught in log sets than in school sets. Sampling data from the Regional Tuna Tagging Project (RTTP) indicate than very small skipjack, yellowfin and bigeye <40 cm) often occur beneath logs and FADs. These small fish are probably also

caught, and discarded, by purse seiners, and therefore do not appear in commercial catch samples.

School and log sets tend to be concentrated in two latitudinal bands, 2°N-2°S and 3-6°N, corresponding respectively to the Equatorial Current (EC) and North Equatorial Counter Current (NECC). The frequency of log sets appears to increase as the eastward flowing NECC strengthens. Logs and associated tuna are also transported by the seasonal monsoonal currents flowing to the east in the first half of the year and to the west in the second half of the year to the north of Papua New Guinea and Indonesia. The size of tuna aggregations associated with logs increases towards the east, possibly related to log age and relative scarcity in this area. Animal sets (mainly on live whales) are most common to the north of Papua New Guinea in the first and fourth quarters. This association may be mediated by the presence of a common prey species, the ocean anchovy.

Most sets on logs and FADs are made just before dawn and occasionally at dusk. School and live animal sets mostly occur in daylight hours. School and log sets show little overall seasonal variation; however FAD sets are more common the third and fourth quarters, while animal sets occur mainly during the first quarter. The most apparent long-term trend is an increase in school sets, particularly by US and Korean vessels. Skipjack and yellowfin catch per set for FAD and animal sets has been variable over time, but catch per log set has been more stable, particularly for yellowfin. Catch per school set for skipjack and yellowfin show opposite cyclical patterns that may be related to El Niño conditions in the WPO.

The sizes of tuna aggregations associated with logs may sometimes exceed 300 mt, but are more often less than 50 mt. Similar sized unassociated schools are caught. Frequently fished FADs probably support smaller aggregations due to the limited time for recruitment between successive sets. Tagged tuna may disperse rapidly or remain associated with logs for some days after tagging. Substantial displacements can occur while associated with logs drifting with the current. Distortion of the spatial distribution of tuna and difficulties in the quantification of log or FAD fishing effort are two problems encountered in the assessment of fisheries that exploit tuna associations with floating objects. Mathematical models that incorporate the dynamics of tuna attraction to floating objects are required.

1. INTRODUCTION

1.1 Background Information on the Tuna Fisheries of the Western and Central Pacific Ocean

The tuna fisheries of the western and central Pacific Ocean (WPO) are extremely diverse, ranging from artisanal/subsistence fishing in Pacific Island and Southeast Asian countries, through small-scale commercial tuna fishing in several of those countries, to the large, distant-water purse seine, pole-and-line and longline fisheries active on the high seas and, by way of licensing agreements, in the exclusive economic zones (EEZs) of many countries.

These fisheries can be generally classified as surface or longline. WPO surface fisheries, comprising pulse seine, pole-and-line and various artisanal fishing methods, extend from the

Philippines and eastern Indonesia (about 120°E) across to at least the Phoenix Islands of Kiribati (about 170°W). Catches are predominantly skipjack and yellowfin, with a small quantity of bigeye, which is generally not distinguished from yellowfin on logbook or cannery records. These fisheries are concentrated in tropical waters, although seasonal catches are made in waters adjacent to Japan, southeastern Australia and the North Island of New Zealand. The longline fishery, targeting large bigeye and yellowfin in tropical waters and albacore in subtropical waters, extends throughout the Pacific Ocean. Juvenile albacore are also targeted by a troll fishery in the vicinity of the Subtropical Convergence Zone (35°-45°S) to the east of New Zealand and in the Tasman Sea, and were also, until last year, the subject of a driftnet fishery in the same areas.

Skipjack and yellowfin catches in the WPO have increased rapidly since the early 1970s. The development of pole-and-line fisheries in Solomon Islands, Papua New Guinea and the tropical WPO generally (by the Japanese distant-water pole-and-line fleet) resulted in the first large increases in skipjack catch. In the late 1970's, development of large-scale purse seining in the WPO, first by Japan and the United States, and subsequently by other distant-water fishing nations (DWFNs) such as Taiwan and Korea, led to further increases in skipjack catch. This trend continued in the 1990's with the continued expansion of the Taiwanese and Korean fleets and the relocation of some US vessels from the eastern Pacific as a result of restrictions in that area in catching tuna associated with dolphins. In the face of these changes, longline catches of yellowfin. bigeye and albacore have remained relatively stable. These trends are depicted in Fig. 1.

The developments in the surface fisheries noted above have led to a doubling of the WPO tuna catch during the last decade, and the 1990 estimated total catch of 1.2 million mt (Lawson 1991) makes the WPO the world's largest tuna fishery. By weight, skipjack is the most important of the four major species, accounting for 66% of the 1990 catch. Yellowfin accounted for 28% of the 1990 catch, while bigeye and albacore each made up about 3%.

1.2 Scope and Purpose of Review

The purpose of this review paper is to provide information on tuna attraction to floating objects in the WPO and the influence of this behavior on the fisheries in that region. The main fisheries that are influenced by tuna attraction to floating objects are the pulse seine and, to a lesser extent, the pole-and-line fisheries. Pole-and-line fisheries based in Indonesia rely primarily on fishing around fish aggregation devices (FADs). In the Solomon Islands and Fiji, pole-and-line vessels also fish regularly in the vicinity of FADs. The Japanese distant-water pole-and-line fleet also fishes tuna associated with floating objects. However, sufficiently detailed data from these fleets are not available for analysis. Therefore, in this review, emphasis is given to the purse seine fishery firstly because of its importance in terms of total catch and secondly because detailed logbook data specifying the type of association fished are available.

Section 2 provides a general review of the purse seine fishery in the WPO, with information on the development of the fishery, historical catches and other statistics. In section 3, various characteristics of the purse seine catch, including species composition, size composition, catch per set, by-catch and spatial and temporal patterns are described in relation to associations with various categories of floating objects. This information is based on daily logbook data provided to the SPC by member countries, published data and the first hand experiences of SPC staff (KB and David G. Itano) as observers and crew members on US purse seiners. Some information on tuna dynamics in relation to floating objects is provided in section 4. Much of this information is based on the results of SPC's large-scale Regional Tuna Tagging Project (RTTP) currently in progress. Finally, several research questions arising out of the attraction of tuna to floating objects in the WPO, and its influence on the fisheries, are discussed.

2. WESTERN PACIFIC PURSE SEINE FISHERY

The purse seine fishery in the WPO began in the early 1970s (after exploratory fishing as early as 1967) as Japanese vessels, mostly 500 GRT-class single seiners, began to fish the equatorial area to the north of Papua New Guinea. In 1980, several group seine operations joined the fleet (Doulman 1987). During the first few years, the Japanese fishery was based almost entirely upon sets around floating logs and other naturally occurring debris. However, by the 1980s, sets on free-swimming tuna schools became more successful due to improvements in gear and setting techniques. Also, sets on tuna aggregations associated with whales and whale sharks also occurred, largely during the first quarter of the year. Tanaka (1989) presents some detailed statistics on Japanese purse seine activity, by set type, from 1976 to 1985. During the latter part of this period, log sets accounted for about 50-70% of all sets, school sets about 15-45% of all sets, and animal sets about 1-10% of all sets on a quarterly basis. More details of set characteristics are given in the next section.

By 1980, purse seine vessels from USA, Korea and Taiwan had joined the WPO fishery. Korean and Taiwanese vessels were similar to Japanese single seiners and concentrated mostly on log sets. USA seiners were mostly in the super-seiner class, up to 2,000 GRT, and concentrated their activities on both log and free-swimming school fishing. Smaller numbers of seiners from 7 other countries have fished in the WPO at various times since 1980.

The purse seine fleet had expanded to 115 vessels by 1984 (Doulman 1987). Currently, 189 purse seiners are estimated to be actively fishing in the WPO: 9 Australian, 3 Indonesian, 39 Japanese, 38 Korean, 4 New Zealand, 11 Philippines, 5 Solomon Islands, 5 Soviet Union, 32 Taiwanese and 43 USA (Lawson 1991). The trend in vessel numbers is shown in Fig. 2 (a). The total purse seine catch shows a similar trend to vessel numbers (Fig. 2b) and had reached nearly 700,000 mt by 1990. Indications are that vessel numbers and total catch will continue to increase in coming years.

The current extent of the fishery is approximately 10°N-10°S and from eastern Indonesia (about 120°E) to the Phoenix Islands of Kiribati (about 170°W), although the actual distribution of fishing within this area is influenced by many factors, including the distribution of skipjack and yellowfin, environmental variables and the status of access agreements between DWFNs and Pacific Island Countries. The distribution of purse seine effort in 1990, based on logbook data submitted to the SPC, is shown in Fig. 3.

The WPO purse seine fishery targets both skipjack and yellowfin tunas. For the entire fishery, the percentage of skipjack has varied annually between 60% and 85% (Fig. 4). Bigeye is usually recorded as yellowfin on purse seine logbooks and therefore reliable catch statistics are not available. Therefore, it should be born in mind that references to yellowfin catches based on logbook records made in this paper are actually referring to the combined catch of yellowfin and bigeye, unless otherwise indicated.

The size of tuna caught varies in time and space, with some evidence of an increasing trend in skipjack and yellowfin size from west to east. Overall, skipjack sizes range from 30-80 cm and yellowfin sizes from 30-150 cm (see section 3.6). Unknown quantities of smaller fish of both species are often caught but are discarded because they are generally considered to be unsuitable for canning.

3. CHARACTERISTICS OF THE PURSE SEINE CATCH, BY ASSOCIATION TYPE

3.1 Types of Association

Purse seiners routinely fish tuna associated with a range of floating objects in the WPO. These include logs and other naturally occurring debris, drifting and anchored FADs, and, less commonly, other marine animals such as whales (alive and dead) and whale sharks. In addition, sets are made on tuna schools not associated with floating objects; these may be unassociated or free swimming schools that are usually feeding on baitfish or schools associated with geographic features such as seamounts and islands, or with oceanographic features such as current interfaces and upwellings. Such sets are collectively termed school sets, and are referred to in this paper as an association category, even though they are, in many cases, not associated with any obvious physical or biological feature.

3.1.1 Log Associations

Logs and other naturally occurring floating debris are found throughout the WPO, and because of the schools of tuna that aggregate under them for a variety of reasons (*e.g.*, feeding, shelter, orientation) these objects contribute a significant part of the purse seine catch. Logs can consist of sections of trunk, groups of branches or entire trees. Other debris includes almost any floating object that is washed or drifts out to sea or is lost over board from ships, *e.g.*, drums, cable spools, canoes and boats, polystyrene floats, containers, and even funeral rafts. Most occurrences within this association are, however, of logs.

Although logs come in various shapes and sizes, a number of inter-related attributes make them effective for aggregating tuna and other fish. In the experiences of Bailey (1985), these are:

(a) Minimum size,
(b) Area underwater,
(c) Time at sea, and
(d) Distance apart.

Observations in the WPO suggest that logs must be at least 1.0-1.5 m long and 0.1 m in diameter before tuna will be attracted. Related to size is the distance that logs are apart. A minimum-sized log will probably not hold a large volume of fish in a situation where other, larger logs are only a few km away, but have been known to hold in excess of 100 mt of tuna if it is the only floating object within a radius of 50 nmi (about 90 km). Generally though, the larger logs tend to support larger quantities of tuna and other fish. An extreme example of this is an 80 m long tree that yielded 1,500 mt of tuna over a period of two weeks of consecutive-day seining in 1982 (KB, pers. obs.).

Also related to size is the area underwater, which in turn is often related to the log's time at sea. Logs with a large, submerged, surface area, be it roots, branches or trunk, offer substrate for algae, crabs and barnacles. These plants and invertebrates form the basis of a food web that includes numerous species of fish (collectively known as "bait' by purse seine fishermen), sharks, billfish, marine reptiles and tunas (Table 5). The submerged parts of logs also afford shelter for the bait from tuna and other predators, and even for large tunas when marlin are nearby. Logs that float high in the water, such as coconut and Nipa palms, and logs that have only recently drifted out to sea, offer little substrate for settlement and are usually devoid of associated fish. This may also relate to drifting speed, as such objects are usually more subject to the influence of wind than current and may drift away from productive areas.

With time, a log slowly becomes waterlogged, begins to sink and is influenced by currents rather than wind. The increase in underwater area directly influences settlement and aggregation of fish. Trees or tapering trunks often sink at the heaviest end first, and gradually move into a vertical position. Such "vertical logs" may stand 5 m out of the water and extend 20 m below. This extensive underwater section can enhance fish aggregation but unfortunately vertical logs are so near to sinking that few are ever encountered. US fishermen consider such logs to be the most productive, and attach floats to prolong their use.

Logs need to be at least 5 km (about 3 nmi) apart to be effective aggregators; if they are closer together, the associated tuna tend to move amongst the various logs, scattering the available resource and making it difficult to determine which log to set on. One strategy used by seiners in areas with numerous logs is to tow the largest logs to a center point and rope them together into a single raft. Smaller logs are taken on board so that the tuna have only one object to aggregate under, and are often later deployed in areas where there are no logs. This strategy usually results in limited catches, presumably because the amount of activity before the set disturbs the tuna. If the raft is left for a number of days, however, the catches often improve.

Schools of tuna exhibit a distinct daily movement pattern around logs that determines their vulnerability to purse seining. During the hours of daylight, schools usually stay within a mile or so of the log, and are often seen on the surface upwind from it. Towards late afternoon, the school will move back to the log and aggregate under it, but at some depth, for most of the night. In the one or two hours before dawn the tuna slowly rise toward the log, making this the time when they are most vulnerable since the fish are within the fishing depth of the seine and because of the dark are unaware of the activity going on around them. After dawn, the school usually stays close to the log for two to three hours, possibly involved in feeding, and are also vulnerable, although to a lesser degree because the net is now visible and can be evaded. Seiners encountering log schools during the remainder of the day usually mark the logs with radio and light buoys and stand-off until the following morning for what is considered a guaranteed catch rather than attempt daylight sets that are often unsuccessful.

There is some evidence of vertical stratification of the tuna under logs, with skipjack swimming in the upper 10-20 m, yellowfin further below, and bigeye down to 100 m. The latter species also appears to form the strongest association, as schools of bigeye are apparent under logs throughout the day and night. Seiners often use the rise of these schools in the early morning as a signal to begin setting. The reverse of this stratification occurs in the purse seine sack prior to brailing, with bigeye floating to the surface because of their large gas bladders, skipjack, being the heaviest, settling to the bottom, and yellowfin appearing in the middle. This has obvious ramifications for the sampling of catches directly from the holds of seiners, particularly in the determination of species composition from log sets.

3.1.2 FAD Associations

FADs in the WPO operate very much like logs in terms of fish aggregation, how the tuna behave in their vicinity, and the general strategies used by seiners to set on them. Two basic types of FAD association are recognized: the first involving FADs that are anchored in place, usually within a network of similar units that are 5-10 nmi apart, and the second involving FADs that have broken loose from their mooring lines and drifted away or have been deliberately deployed without mooring lines. Within the second category, the Japanese appear to include associations with logs and debris that have been roped together, as described in the preceding section (Tanaka 1989). The Japanese are also known to anchor FADs near small islands and release them to drift after a suitable "aging" period has resulted in the accumulation of encrusting life and a population of reef fish (D.G. Itano, pers. comm.).

FADs in use include rafts made from bamboo or plastic pipe, steel pontoons that are either unprotected or sheathed in bamboo, and drums, all of which have been described extensively in the literature (*e.g.*, Preston 1982; SPC 1989; Malig *et al.* 1991). Most, if not all, of these styles are deployed with underwater appendages such as coconut fronds, netting or plastic streamers, to enhance aggregation, and a connecting point to the mooring line so that the raft can be disconnected and towed away for setting on.

3.1.3 Animal Associations

Animal associations commonly consist of two distinct association types and an intermediate type; tuna aggregating and feeding with sei *(Balaenoptera borealis)* and, to a lesser extent, minke whales (*B. acutorostrata)* on balls of ocean anchovy *(Stolephorus punctifer)*, schools aggregating around the floating carcasses of sperm whales *(Physeter catodon)*, and schools associating with the slow moving whale shark *(Rhincodon typus)*. The schools found with live whales do not form long-term associations with the whales; they seem only to come together to feed and separate once the anchovy are consumed. In this sense, these schools are identical to the unassociated schools described below, and are set on in the same way. The seiner will, however, attempt to keep the whale inside the circle of net until it is pursed, in the belief that the tuna will stay with the whale. Once pursed, the whale escapes by punching a hole through the net.

In comparison, dead whale associations are similar to log associations, with attendant schools of bait fish that help to attract and concentrate tuna. Dead whales are rarely encountered but when so, are treated like logs, marked with radio and light buoys for tracking and set on before dawn.

Whale shark associations appear to be intermediate between live whales and logs in that the shark and tuna often come together to feed on anchovy but are able to maintain the association for some time, very much like tuna aggregating under logs. Whale sharks are usually set on during the day, as it is impractical to mark them with buoys and therefore difficult to locate in the dark.

Unfortunately it is not possible to separate the animal set data from logbooks into components, although an approximate separation is made in section 3.8.1 by examining set time. With regard to dolphins, there is little evidence to suggest that purse seiners make dolphin-associated sets in the WPO. The dolphin species that form associations with large yellowfin tuna in the eastern Pacific, primarily the spotted dolphin *(Stenella attenuata)* and to a lesser extent the spinner (S. *longirostris)* and common *(Delphinus delphis)* dolphins (Wild 1991), are present in the WPO, but appear to be rare in the main area of purse seine activity. In a series of exploratory charters between 1974 and 1984, ten US seiners experienced in dolphin fishing recorded 190 dolphin pods over a period of 772 searching/ fishing days, of which 61 were of the preferred three species (PTDF 1977; Souter and Broadhead, 1978; Burns and Souter 1980; Salomons and Souter 1980, Souter and Salomons 1980a,b; Bailey and Souter 1982; Lambert 1984). In two instances dolphin-tuna associations were encountered but not set on (PTDF 1977). More recent reports on Japanese and US vessels support this evidence, with none of the authors recording dolphin sets (Gillett 1986a,b; Farman 1987; Tanaka 1989; Itano 1991). In addition, of the 1201 tuna schools sighted and fished by the SPC tagging vessel, *Te Tautai,* in the WPO (excluding Indonesia and the Philippines) over the last two years only one school, found in northern Papua New Guinea waters, was associated with dolphins. These dolphins were tentatively identified as spinners. This vessel has, however, fished on six dolphin associated tuna schools (out of 139 schools) in the archipelagic waters of Indonesia and the Philippines, suggesting that the association is more common in these areas. It should be noted that none of these associations involved the large yellowfin typical of the eastern Pacific association but involved either skipjack or mixed schools of skipjack and small yellowfin.

In addition to the differences in dolphin abundance, it appears that the oceanographic and biological conditions in the eastern Pacific that may 'assist' in the formation of the association between dolphins and yellowfin (*e.g.*, shallow thermocline, abundance of ommastrephid squid) are not usually present in the WPO.

3.1.4 Unassociated Schools and Geographic/Oceanographic Associations

Unassociated schools are typically surface schools that range in activity from fast moving "breezers" that appear like a faint breeze blowing across the sea to stationary "boilers" and "foamers" that churn the surface into a white froth while feeding on balls of ocean anchovy and other bait. The latter types of schools are most preferred for setting on as the tuna are usually too distracted by their feeding frenzy to notice the activity going on around them. In comparison, breezing schools are more erratic in behavior and are often moving at speeds of 5-10 knots, making them difficult to encircle and catch. During the development of the purse seine fishery in the WPO, this has resulted in the nets being made longer and deeper, with a typical US net currently measuring 1,500 m by 220 m, and increases in winch power, so that net can be pursed in less than 15 minutes.

Subsurface schools are also set on occasionally, usually after a surface school has dived and then been located with sonar or depth sounder. “Fireball" schools are surface or subsurface schools visible at night as they pass through areas of phosphorising plankton. These schools appear to be extremely rare in the WPO as no records exist in the purse seine literature of such occurrences.

Geographic/oceanographic associations involve schools that aggregate near submerged reefs, banks and seamounts, emerged islands, and areas of current convergence and divergence, presumably because of the increased productivity associated with these features. It is not possible to determine from the SPC database what proportion of school sets are made on such features. As a number of these features tend to concentrate logs and other floating debris, it is probable that data on log sets include sets made on schools that have formed a geographic or oceanographic association.

3.2 Purse Seine Sets

The types of tuna associations fished in the WPO varies greatly with vessel nationality. Of the larger fleets, the Japanese fish both school fish (31% of all sets by Japanese seiners recorded on the SPC database - Table 1 and Fig. 5) and log fish (65% of sets), with much smaller numbers of sets on tuna associated with FADs (1% of sets) and animals (3% of sets). The US fleet, particularly in the last few years, has concentrated mostly on school fish (75% of all sets), with smaller numbers of log sets (24% of sets). The Korean fleet fishes both school (39% of all sets) and log fish (55% of sets), but the Taiwanese fleet targets almost exclusively (94% of sets) on log fish. By contrast, the Philippine fleet fishes tuna associated with either drifting (49% of all sets) or anchored FADs (26% of sets), in addition to log fish (24% of sets). As the Philippine fleet deploys the largest number of FADs in the WPO, it is likely that many of the drifting FAD sets recorded in the database for this fleet are in fact on FADs that have been disconnected from their mooring lines rather than having broken loose naturally. Thus many of these sets should be considered as anchored FAD sets, but cannot be easily separated in the database. Similarly, the drifting FAD sets made by the New Zealand vessels were probably all on anchored FADs that were unhooked for setting (G. Preston, pers. comm.).

The historical changes in set preference shown in Fig. 5 reflect increased competition for logs and improvements in fishing gear, notably in the hauling power of purse winches and power-blocks, that have enabled the more advanced fleets to move from log-fishing to school-fishing. Such a move allows vessels to operate more efficiently by fishing throughout the day and targeting large yellowfin, rather than making one set each day on a log, and has enabled fishing in areas where logs are known to be uncommon. Recent large effort by US seiners on school-fishing grounds in the vicinity of the Phoenix and Howland/Baker groups of islands, first fished in the mid-1980's, is a case in point. The US fleet was the first to move to school fishing, followed closely by the Korean fleet and, to a lesser extent, the Japanese fleet. The Korean fleet is currently undergoing a modernization program, with state-of-the-art US built super seiners slowly replacing the 10-20 year old ex-US seiners the fleet began fishing with. Within a few years this will probably result in a set profile very much like the present US set profile. The

Taiwan fleet dominates log fishing at present but is also modernising and may increase its proportion of school sets in the future. The Philippines fleet, in contrast, has shifted a FAD-based fishery from the Philippines to the WPO, and as a consequence the vessels and gear are only suitable for fishing on floating objects. There is no indication that this fleet will, or needs to, modernize for school fishing.

For the purse seine fleet as a whole, school fish (38% of all sets) and log fish (54% of sets) are the most common associations fished (Table l), generally comprising greater than 90% of all purse seine sets in any year quarter (Fig. 6). Sets on tuna associated with animals and FADs are significant in some quarters, but generally make up only a few percent of the total purse seine sets (about 2% and 6%, respectively).

3.3 Total Catch

The proportions of estimated total catches of skipjack and yellowfin attributable to sets on different tuna associations are shown in Fig. 7. Most of the catches of both species are taken from sets on log fish and school fish. Most of the increase in catch in recent years has resulted from increased catches of school fish, and, to a much lesser extent, FAD fish. Although the contribution of FAD and animal sets to the total catches of skipjack and yellowfin is small, it is relatively higher for yellowfin, possibly indicating a higher vulnerability of yellowfin for these associations.

3.4 Catch per Set

There is substantial variation in catch per set among school associations and vessel nationalities (Table 2). Of the larger fleets, Japan and Korea have recorded the highest total catch per set from drifting FADs, although these make a very small percentage of total sets by these fleets (Table l). The US fleet also records high total catch per set from sets on drifting FADs, with slightly higher catch per set from log sets. The Taiwanese fleet has its highest total catch per set from animal sets, although these sets are very infrequent.

It is interesting to note that, for the four major fleets (Japan, Korea, Taiwan and US), sets on drifting FADs (which comprise less than 1% of total sets in each case) perform well compared to log sets. However, the Philippine fleet, which deploys mainly log and FAD sets, obtains higher total catch per set from logs than drifting FADs.

The highest skipjack catches per set generally come from school and log sets. In contrast, the highest yellowfin catches per set are recorded from anchored FAD and animal sets, where skipjack catches are lower. There are some indications that yellowfin are more commonly associated with live whales than are skipjack (PTDF 1977; Souter and Broadhead 1978; KB, pers. obs.).

Histograms of set success for all vessel nationalities combined (Fig. 8) provide additional information on the nature of the various tuna associations. In terms of total catch, 50% of all sets on school fish are unsuccessful, *i.e.*, they result in catches of less than 1 mt . In contrast, less than 10% of log and FAD sets are unsuccessful, with most sets resulting in 1-10 mt. Animal sets are similar to school sets, with nearly 50% of sets being unsuccessful. This suggests that most animal sets involve live whales. Some differences between skipjack and yellowfin are apparent.

A larger percentage of school sets (80%) result in less than 1 mt of yellowfin than sets that result in less than 1 mt of skipjack (60%), suggesting that pure skipjack schools are fished more often than pure yellowfin schools or that pure yellowfin schools are less vulnerable to purse seine gear. Similarly, 30% of log sets result in less that 1 mt of yellowfin, whereas only 10% yield less than 1 mt of skipjack. This may simply reflect the greater abundance of skipjack in the WPO. Sets on drifting FADs, anchored FADs and animals show similar patterns of set success for skipjack and yellowfin, although all associations (apart from school) show higher percentages of sets yielding 1-10 mt of yellowfin than for skipjack.

Time series of skipjack and yellowfin catch per set for all vessel nationalities combined are shown in Fig. 9. No distinct trends are evident in any of the time series. A comparison between school and log sets (which represent most of the data) reveals much greater temporal variability in catch per set for school sets than for log sets. In particular, for yellowfin, catch per set from schools shows strong cyclical variability that may be related to broad-scale oceanographic conditions in the WPO. High catches per set were recorded in 1982, 1987 and 1990, at least the first two years of which correspond well with El Niño conditions in the WPO (Fig. 10). The El Niño is thought to enhance the catchability of yellowfin in the WPO because of the shallower mixed layer that is characteristic of the phenomenon. Skipjack and yellowfin catch per set for school sets show some evidence of an inverse correlation. Whether this occurs because of a biological interaction between the species or because of opposite effects of oceanographic conditions on catch per set is unknown.

3.5 Species Composition

3.5.1 Commercial Species

As noted earlier, the purse seine fishery targets both skipjack and yellowfin, with smaller catches of bigeye tuna usually being reported as yellowfin. These three species may therefore be considered to be the commercial species making up the purse seine catch. Schools may be either pure skipjack, pure yellowfin (bigeye) or mixed. Frequency histograms of the percentage of skipjack in purse seine sets show very different patterns for the different school associations (Fig. 11). The great majority of school sets are either on pure skipjack (59% of all school sets) or pure yellowfin (bigeye) (23%), with relatively few mixed schools. Similarly, sets on schools associated with animals produce mainly pure skipjack (26%) or pure yellowfin (bigeye) (30%). On the other hand, 25% of log sets yield pure skipjack, but only 6% yield pure yellowfin (bigeye). Skipjack is generally the dominant species in log sets with 84% of sets containing greater than 50% skipjack Both categories of FAD set show higher frequencies of mixed schools.

Time series plots of the percentage skipjack in purse seine sets show no overall trends but substantial temporal variability (Fig. 12). The exception to this is log sets, which have shown a remarkably constant species composition over time. The variation in percentage skipjack in school sets reflects the catch per set time series in Fig. 8.

The contribution of bigeye to the logged catch of yellowfin in the WPO is not known in great detail, although some information is available from various sampling and observer programs. Tanaka (1989) presents statistics indicating that bigeye comprised 1-4% (by weight) of the total Japanese purse seine catch between 1976 and 1985. These data would suggest that 3-15% of the declared yellowfin catch is in fact bigeye.

More recent data are available from the port sampling of US purse seiners unloading in Pago Pago, American Samoa (Table 3). These data show that bigeye can comprise from 1-28% of the quarterly yellowfin catch from log sets in terms of weight, but usually within the 5-16% range. In comparison, the bigeye percentage from school sets is much less, ranging between 0.1% and 1.3% of the yellowfin catch.

3.5.2 By-catch Species

Information on the level of by-catch in the purse seine fishery is very limited, both in terms of data held by SPC and from the literature. By-catch data held on the Regional Tuna Fisheries Database are summarized in Table 4 by fleet and school association, while Table 5 is an attempt at synthesizing the literature and experiences of various SPC staff into a list of by-catch species and their relative abundances in the different associations.

The information in Table 4 is indicative only of the amount of by-catch taken for sets in which some by-catch has been declared. In fact, the level of by-catch reporting is thought to be extremely low and is not likely to be representative. In a number of the cases, it appears that by-catch may only be reported when it is particularly high and presumably noticeable. This is apparent for school sets declaring by-catch, where four of the five fleets all have catches of over 5 mt per set from a total of 18 sets. In comparison, observer reports show that school sets quite often have by-catch, but it is usually limited to a small number of apex predators such as blue or black marlin, and silky and oceanic whitetip sharks (*e.g.*, various PTDF reports; Gillett 1986a,b; Itano 1991) that may approach 1 mt per set. On rare occasions, sets may be made on schools, particularly those near reefs, that have a large proportion of rainbow runners or small tunas (frigate tuna, kawakawa), and such sets may produce relatively large amounts of by-catch.

Log schools produce the highest overall by-catch, 5.2 mt per set from 514 sets in which a by-catch is declared, with a range of 1.0-7.1 mt per set. For anyone who has witnessed such sets, this level of catch is not surprising. Not only do most logs have a large attendant population of fish (a possible 42 species, as listed in Table 5), dominated by rainbow runners, mahi-mahi, ocean triggerfish, mackerel scad, and silky sharks, but in addition the purse seine operation does not allow for an easy escape. Attempts are made to reduce the by-catch because of the extra work involved in cleaning the net of gillers and sorting the catch of unwanted species in the limited time available before the catch in the sack begins to deteriorate in the high temperatures. It is also disadvantageous to the productivity of the log to remove the bait that ultimately act to attract the tuna. Thus, once pursing is complete, the main boom is lowered to one side so that a gap forms between the vessel and the net through which the log can be towed and bait can escape. While this operation can he successful, most sets usually end with the species listed above that typically swim furthest from the log turning back into the net and consequently becoming mixed with the tuna. The high by-catch and proportion of recorded sets for the Philippines fleet (7.1 mt per set) may relate in part to the fact that many of these vessels retain by-catch for sale in the Philippines.

Observer reports show that blue marlin are commonly associated with logs, with at least one marlin usually being caught in each log set (*e.g.*, Gillett, 1986ab). Other billfish species are rarely taken in these sets.

Pilot whales *(Globicephala* spp.) are often seen in the vicinity of logs, particularly in the early morning when they give a characteristic sonar signal. These whales tend to disrupt the usual aggregation pattern at this time of day, resulting in the tuna schools dispersing rather than forming fishable spots. Because of this few if any sets are made on logs with pilot whales in attendance and no records exist of these whales being caught.

FAD by-catch ranges from an average of 1.9 mt per set for drifting FADs (33 sets with declared by-catch) to 3.1 mt for anchored FADs (286 sets with declared by-catch). FADs produce a similar range of by-catch species to logs, dominated by the same five or six species. The difference in catch rates between logs and FADs is possibly related to the volume of repeated sets that FADs undergo; although logs are set on repeatedly, after a certain point they become unproductive - usually because all the tuna and most of the bait have been caught - and are left to drift away. FADs, in comparison, are fished repeatedly over their lifetime, thus keeping the bait biomass to a minimum.

Four animal sets by Korean seiners produced an average of 1.0 mt of by-catch per set; it is not possible however to determine what types of animals were set on. In terms of by-catch species, live whale sets produce a similar range of species as school sets, particularly the oceanic whitetip and silky sharks. Dead whale sets are similar to log and FAD sets, with the same predominant species. Information on the species taken in dead whale sets is limited, with only nine species recorded. It is possible that many of the species found with logs and FADs also occur with this association. There is also little information for whale shark sets; RTTP records list three species but probably some of the species found with schools and logs (*e.g.*, silky sharks, rainbow runner, mahimahi) also occur with whale sharks.

3.6 Size Composition

The length frequency distributions of yellowfin, bigeye and skipjack sampled from school and log sets of US seiners unloading in American Samoa are shown in Fig. 13. The distributions for school and log associated yellowfin are almost reverse situations, with school yellowfin being dominated by fish between 80 and 140 cm, with a smaller peak between 40 and 70 cm (mean = 96.7 cm), while log fish exhibit a major peak from 40-70 cm and a minor peak from 80-110 cm (mean = 65.8 cm). Yellowfin larger than 120 cm are rare in log sets but common in school sets. The bigeye distributions for the two set types are similar, both being dominated by fish measuring 45-65 cm (school. mean = 58.4 cm, log mean = 59.9 cm). One difference is the pronounced tail of large bigeye (75-110 cm) seen in log sets, which is typical of this association where small schools of large bigeye often occur at some depth under the log and are occasionally caught. The skipjack distributions differ in that school fish have a larger proportion of fish over 60 cm in length (school mean = 58.0 cm, log mean = 51.3 cm).

The length frequency distributions of tuna tagged during the RTTP, classified by eight association types (school, log, drifting FAD, anchored FAD, animal (whale shark, dolphin and dead whale), current line, seamount and island/reef), are shown in Figs 14-16. Because this project employs a pole-and-line vessel as its principal tagging platform, few of the large school yellowfin and large log associated bigeye have been tagged. The majority of large yellowfin and bigeye tagged have come from a seamount and related feeding association that occurs seasonally in the Coral Sea. Thus, the distributions for yellowfin and bigeye are comparable with the US purse seine data when considering the smaller sized fish. The major difference is that RTTP data indicate that very small skipjack, yellowfin and bigeye (<40 cm) are also common associates of logs and FADs. These small fish do not appear in commercial purse seine samples presumably because they are discarded after capture; however some avoidance of aggregations comprised mostly of small fish takes place.

3.7 Spatial Patterns

The spatial patters of purse seine sets are shown in Figs 17-21 by association and quarter, while Figs 22-23 show effort and catch per set, respectively, by longitudinal bands. Most sets are made between 140° and 160°E, with school, animal and log sets concentrated in the 140°-150°E band and FAD sets concentrated in the 150°-160°E band.

With these longitudinal bounds, school and log sets appear to be concentrated in two main areas, from 2°N-2°S, particularly to the south of the Equator, and from 3°-6°N. In the simplest terms, these areas represent the respective positions of the westward flowing Equatorial Current (EC), and the eastward flowing North Equatorial Counter Current (NECC) and convergence zone between the NECC and EC. It has been suggested that these areas concentrate tuna because of their relatively high productivity, resulting from meridional circulation of nutrient-rich, upwelled water from the zone of divergence along the Equator to the north and south (Grandperrin 1978; Bour *et al.* 1981).

There appears to be no distinct seasonal pattern in the distribution of school sets, although there is an increase in effort in the first and third quarters in northern Papua New Guinea. Tanaka (1989) notes that Japanese seiners fishing to the north of the equator make school sets throughout the year, but increase such sets between January and March in response to a decline in the availability of logs (see below). Catch per set for schools is relatively constant throughout the main area of fishing, but increases significantly to the east of 170°E. This increase has come from the recent large effort on productive fishing grounds, particularly in the vicinity of the Phoenix and Howland/Baker groups of islands. These grounds are primarily fished in the second to fourth quarters.

The two main areas of log fishing appear to be directly influenced by major surface currents and the seasonal changes they undergo; the northern area by the NECC and the southern area by the EC and the Northwest and Southeast Monsoon Currents (Pacific Islands Pilot 1988).

The NECC appears to be the major carrier of logs to the east, but as it weakens and strengthens seasonally, there is a distinct pattern in effort which presumably relates to log availability. The NECC is at its weakest in terns of speed and width from the end of the fourth quarter to the beginning of the second quarter, particularly in March and April. This corresponds to a period of low effort on logs and, as Tanaka (1989) mentions, in log availability. As the current intensifies during the remainder of the year, there is a corresponding increase in the number of log sets. Tanaka (1989) notes that Japanese effort on logs increases from July to

September. The logs carried by the NECC probably originate in the Philippines, Indonesia and, to a lesser extent, Palau. The current may also entrap logs that have come from Papua New Guinea and the Solomon Islands and been carried west by the EC.

The area of convergence between the NECC and EC results in the formation of current lines, where logs and other debris collect and become relatively stationary. Tuna may aggregate in these areas but be impossible to catch with purse seine because of the large quantities of logs. Such current lines can be disrupted by shifts in current pattern or wind, resulting in the logs becoming entrained once again in either an eastward or westward flowing current.

Logs found to the north of the PNG mainland in the first quarter are subject to the eastward flowing Northwest Monsoon Current that runs parallel to the Irian Jaya/PNG coastline. Most of these logs probably originated in Irian Jaya and the Indonesian archipelago. The Northwest Monsoon Current weakens in the second quarter and is replaced in the remaining two quarters with the westward flowing Southeast Monsoon Current. This current coupled with an intensified EC results in a westward drift of logs that originated in PNG and the Solomon Islands, and logs that first came from the east in the Northwest Monsoon Current. There may also be logs that first traveled in the NECC.

Catch rates for log sets show an increase from slightly over 20 mt per set in the west to 30 mt per set by 180° (Fig. 23). This suggests that log schools are larger in the east, which is also seen with the school catch rate distribution. An alternative explanation is that logs found in the east have been at sea for a considerable time, having drifted from the east (as there are no large land masses in the area to act as a source), and simply aggregated more fish than "younger" logs in the west. Also, the abundance of logs decreases from west to east, and therefore logs in the eastern area may be better tuna attractors simply by virtue of their relative scarcity.

Anchored FADs are concentrated in the Solomon Sea, Bismarck Sea and around Bougainville Island (all in PNG waters), and in the archipelagic waters of the Solomon Islands. The distribution of sets on anchored FADs shows no obvious seasonal pattern. However, if drifting FAD sets in the same areas are also considered, it appears that a considerable amount of effort occurs in the third and fourth quarters to the north of Bougainville Island and in the Bismarck Sea. Catch rates for anchored FADs are highest in the eastern Bismarck Sea, Solomon Sea and Solomon Islands, averaging over 20 mt per set. A small number of sets to the east of 160°E but still in the Solomons produced a similar catch rate. Anchored FADs deployed to the north of Irian Jaya and east Papua New Guinea between 130°-140°E yield an average of 18 mt per set, while the lowest catch rate, 12 mt per set, occurs in the western Bismark Sea. Catch rates for drifting FADs are at a similar level; the peak seen in the 160°-170°E band is from a small number of sets.

Drifting FAD sets near and to the north of the Equator represent deployments of rafts and logs tied together, as well as FADs that have broken loose from their moorings and have become entrained in the major currents. Effort in this area is very low, so that it is not possible to discern a seasonal pattern, although a pattern similar to logs probably exists.

Animal sets are concentrated in the area to the north of PNG and are most frequent in the first and fourth quarters. Japanese seiners are known to concentrate on whale sets from January to March, at a time when schools of ocean anchovy are common (Tanaka 1989). However, a seasonal relationship between animal sets and anchovy abundance cannot be confirmed because of a lack of detailed information on the seasonal abundance of the anchovy. Catch rates for these sets are relatively constant in the main area of fishing, averaging 20 mt per set, but increase both to the east and west where fewer sets are made.

3.8 Temporal Patterns

3.8.1 Diel Patterns

The diel patterns for each school type are shown in Fig. 24 as percentage of sets (by all fleets) against time of day and in Fig. 25 as catch per set against time. School sets are predominantly made during the hours of daylight with an increase in set number towards dusk. Such "sundowners" are considered the most favorable for catching school fish because the tuna are unable to see the net and therefore do not try to escape by diving or "charging the boat." A small percentage of school sets are made during the night, probably on sonar-located spots of tuna and/or bait fish. Catches on school sets appear to be relatively constant throughout the hours of daylight, although there is a slight increase apparent in yellowfin catch per set toward dusk. One large catch of over 150 mt made in the early morning may have been a sonar assisted set.

Over 90% of all log sets are made in the early morning between 0400 and 0700 hours, with most sets occurring immediately before dawn so that the net is pursed (and the school captured) by dawn. Log fishing strategy is to set the net at a time when the tuna are concentrated under the log and, as with sundowners, are unaware of the net's presence. Small numbers of log sets are made throughout the day when surface schools are found near to the logs. Catch rates are highest for dawn and dusk sets, reaching 20 mt for skipjack and slightly over 5 mt for yellowfin. Catch rates during the remainder of the day are relatively stable, at about half that achieved at dawn and dusk.

Log fishing strategy is taken a step further with FADs, with sets by mainly Philippines vessels being made at dawn and dusk. The Philippines fleet is able to fish in this way because of the large numbers of FADs that it deploys and their close proximity. As mentioned in section 3.2, many of the drifting FAD sets made by the Philippines are probably anchored FAD sets. It is therefore interesting to note the large percentage of drifting FAD sets that are made at dusk. The highest catch rates for both anchored and drifting FADs occur at dawn, with slightly lower catch rates at dusk. The high mid-day catch rates observed with drifting FADs are due to single sets that yielded large catches and are therefore not representative of the association.

Over 70% of animal sets are made during the hours of daylight, with a gradual climb in the number of sets towards late afternoon. Most of these late-afternoon sets are probably on live whales; as with school sets, this is the best time of day to set on such associations. Yellowfin catch rates exceed those for skipjack during this time, which supports the view that these are whale sets, assuming that yellowfin are more frequently found in this association than skipjack (section 3.4). The large percentage of sets made between 0300 and 0400 (28%) provides an indication of the number of times that dead whales have been fished (537 sets, or 0.66% of all purse seine sets in the SPC database), as such associations will usually be treated in a similar manner to logs and set on before dawn. Catch rates for skipjack are highest at this time. Whale sharks are probably set on throughout the day, with a preference to early morning and late afternoon when the tuna schools are in close proximity.

3.8.2 Seasonal Patterns

There appears to be little seasonal variation in the numbers of school and log sets (Fig. 26); the decrease in school sets and the increase in log sets in the third and fourth quarters noted by Tanaka (1989) is only slightly evident. Drifting and anchored FAD sets are higher in the third and fourth quarters, while most animal sets occur in the first quarter. The distributions of catch per set by quarter for the different associations are unremarkable.

3.8.3 Long-term Patterns

As noted in section 3.2, there is an increasing trend in the number of school sets, particularly by the US, Korean and, to a lesser extent, by the Japanese fleets (Fig. 5). Cyclical patterns in catch per set are most noticeable for school sets (see section 3.4), and may be related to large-scale oceanographic phenomena.

4. TUNA DYNAMICS AND FLOATING OBJECTS

4.1 Aggregation Sizes and Recruitment to Floating Objects

Various indications of aggregation sizes are available. Logbook records give some indication of the minimum sizes of aggregations (the percentage of the total aggregation taken in a set is not recorded); frequency histograms of set sizes are given in Fig. 8. While most sets yield catches of less than 50 mt, it is possible that the actual aggregation size is much larger in some cases. The largest individual set catch records on the SPC database for the different association types are shown in Table 6. Maximum set sizes generally approach or exceed 300 mt, which is probably indicative of the maximum size of aggregations. The somewhat smaller maximum set sizes for anchored FADs may reflect the fact that these associations are usually fished on a regular basis, and therefore may not be given sufficient time to accumulate the large amounts of fish seen in other associations.

Some estimates of aggregation sizes are available from tag recapture data for several cases where fish were tagged from an association, which was fished again a short time later. On the basis of the number of fish originally tagged, and the number of tagged and untagged fish captured on re-sampling the association, Petersen-type estimates of population size can be constructed, assuming perfect mixing of tagged and untagged fish and minimal emigration, immigration and natural mortality (Table 7). The estimates are given in numbers of fish, but based on the average size of fish tagged, none of the four aggregations would have been substantially in excess of 50 mt.

Other anecdotal indications of aggregation sizes, particularly large ones, are available. As mentioned earlier, the most extreme example of large tuna aggregations in the WPO to our knowledge is the case of 1,500 mt of tuna taken over a two-week period from sets on a large tree. During the day, this aggregation was observed to disperse into a number of surface schools that roamed in the vicinity of the log. At night, the aggregation re-formed and was fished before dawn. Recruitment of schools from outside the immediate vicinity of the log is likely to have occurred over the fishing period. Unfortunately, we have no set by set data for fishing on this log, which may have been useful for estimating biomass, recruitment and loss rates, using a method such as that described by Ianelli (1986). The structure of purse seine log forms does not normally allow the identification of repeated sets on the same log, FAD or other floating object, and therefore data of that type are relatively rare. Available data for the WPO have been compiled and are given in Table 8. These data have not yet been analysed, and are listed here for the benefit of researchers interested in this topic.

The dynamics of aggregation size, recruitment to the aggregation and movement away from the aggregation are likely to be affected by a variety of factors. Some of these were noted in section 3.1 for the various association types. For logs and FADs, characteristics of the floating objects are important, along with their density in the fishing area and the local biomass of fish not associated with floating objects. Modeling of the dynamics of tuna associations with floating objects (*e.g.*, Ianelli 1986; Hilborn and Medley 1989) is required to gain more information on these influencing factors and their interaction with purse seine fishing.

4.2 Movement Dynamics

SPC's Regional Tuna Tagging Project has provided the opportunity to observe movement patterns in relation to the type of association in which tagged tuna are released. As noted earlier, tagged fish have been released from log, drifting and anchored FAD, animal, current line, seamount and island associations, as well as from unassociated schools. Displacement rate histograms for skipjack, yellowfin and bigeye (Figs 28-30, respectively) tagged from different types of association give some insight into their movement dynamics. For skipjack, most fish tagged from unassociated schools have had displacement rates of less than 6 nmi/day, although the distribution has a long tail of large displacement rates. In contrast, substantial numbers of skipjack tagged from log and drifting FAD associations have large displacement rates in excess of 15 nmi/day. This may result from some tagged skipjack remaining associated with logs or FADs drifting substantial distances with the current. The scarcity of large displacement rates for fish tagged from stationary associations and from unassociated schools lends support to this conclusion.

Skipjack associated with anchored FADs and seamounts seem to show the smallest displacement rates, indicating that most fish tagged in these stationary associations remained with the association for some time after tagging. Similar displacement rate patterns are evident for yellowfin and bigeye, although the actual rates are generally somewhat less than those for skipjack (Table 10).

The interpretation of Figs 28-30 and Table 10 is complicated by the different effort regimes applied to the different tuna associations. More detailed analyses of tagged tuna dispersal from individual floating objects in relation to the distribution of fishing effort will be carried out in due course.

However, it may be useful at this point to recount our experience with one log school tagged during the RTTP, which demonstrates the dispersal of tuna from a log association over time. School # 615 was encountered on 10 July 1991 at 4°39N 153°20E and 1,862 skipjack, 194 yellowfin and 1 bigeye were tagged. Over the next 21 days, 202 of these releases were recaptured by Japanese vessels and the tags returned. On days 2-5 after tagging, 39 fish were recaptured in an area about 90 nmi south of the release point, including 25 skipjack and 9 yellowfin in one set on day 5. Also, 3 skipjack were caught in a set 212 nmi south of the release point on day 4. Given the large displacements involved and that the NECC usually sets in an easterly direction at 0.75-1.5 kt at that time of year (Pacific Islands Pilot 1988), it is likely that these displacements resulted from active swimming. Similarly, 3 skipjack recaptured in two sets about 300 nmi southeast of the release point on days 7 and 8 are likely to have moved to that location in an active swimming mode. Starting on day 10 after release, tagged tuna began to be recaptured in an area 300-400 nmi due east of the release point. On day 12, 25 skipjack were recovered in a single set, on day 13, 74 skipjack and 1 yellowfin were recovered in a single set and on day 14, 30 skipjack were recovered in a single set. Smaller numbers of tagged tuna from school # 615 were also recaptured in nearby sets on these days. On day 17, 8 skipjack were recaptured from a set further to the east (>600 nmi from the release point) and another in a separate set to the north. Also on day 17, one skipjack was recovered from a set >700 nmi to the west of the release point. It is therefore apparent that tuna associated with the log encountered on 10 July 1991 dispersed rapidly, some in large, cohesive schools, to the east, west and south soon after tagging. At least some of the eastward displacements could have resulted through passive drift with the current, possibly in association with the original log or with other logs in the vicinity at the time of tagging. Unfortunately, data on the types of set (school or log) that resulted in the recoveries are not yet available.

5. RESEARCH PROBLEMS

The major impact on purse seine fisheries of tuna associations with floating objects is the effect that these associations have on the spatial distribution of the tuna. Where the distribution of floating objects can be accurately predicted (*e.g.*, anchored FADs), the associated tuna can also be more efficiently located and harvested. This behavior, both of the fish and the fishing fleet, complicates stock assessment. Traditional catch-effort models usually assume that fishing effort randomly samples the population under consideration. Depending on the distribution of fishing effort on associated and unassociated tuna and the concentration effects of the floating objects, this assumption will be violated to some extent. More sophisticated statistical techniques are needed to estimate fish density from catch-effort data.

A more fundamental problem concerns the measurement of effective fishing effort in purse seine fisheries exploiting tuna associations with floating objects. Standard purse seine log forms only give information relating to individual log sets, with usually no indication of sets on logs that have been previously marked with radio beacons. Therefore, the usual searching time measure of purse seine fishing effort cannot be derived as searching will have occurred in the location of logs for the first time, but effectively no searching will have occurred for repeat sets on marked logs. Similarly with sets on anchored FADs and other stationary, charted attractors, the usual notions of searching time do not apply.

This situation can best be remedied by the development of appropriate mathematical models that explicitly incorporate the dynamics of attraction to floating objects as well as the other population dynamics parameters of interest. The analysis of a skipjack tagging experiment carried out recently in the Solomon Islands provides an example of such a model. This experiment was designed to assess the interaction between pole-and-line and purse seine fleets as well as to provide information on appropriate total catch levels The purse seine fleet operates almost exclusively by sets on anchored FADs. The pole-and-line fishery also fishes around FADs but also fishes unassociated and log schools. During preliminary data analyses, it became apparent that the distribution of tag releases and fishing effort in relation to FAD location was biasing tag recapture numbers to a large extent. To deal with this situation, a model of diffusive fish movement was developed, and FAD attraction coefficients incorporated to realistically alter the spatial distribution of skipjack. This model is currently being fitted to the tagging and fishing effort and catch data.

This type of approach might usefully be extended to other situations involving associations with other types of floating objects (in which the movement of the floating objects themselves might also need to be modelled) and other models based primarily on catch-effort data.

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LITERATURE CITED

Bailey, K. 1985. Log fishing in the western Pacific. *New Zealand Fishing Industry Board Bulletin 82:* 8-11.

Bailey, K. and D. Souter. 1982. Tuna purse seine cruise report, June 2-August 10, 1982. M/V Western Pacific final report. Pacific Tuna Development Foundation, Honolulu.

Bour, W., J. Marcille and J.P. Rebert. 1981. Peche thoniere et conditions hydrologiques dans le Pacifique tropical Ouest. *La Peche Maritime* (December).

Burns, F. and D. Souter. 1980. Tuna purse seine cruise report, June-August 1980. *White Star.* Living Marine Resources, San Diego.

Doulman, D. 1987. Distant-water fleet operations and regional fisheries cooperation. *In* Doulman, D.J. (Ed.), The development of the tuna industry in the Pacific islands region: an analysis of options, pp. 33-52. East-West Center, Honolulu.

Farman, R.S. 1987. Report on observer activities on board a Japanese group purse-seining operation (24 March-20 April 1984). *South Pacific Commission Tuna and Billfish Assessment Programme Technical Report No.* 19.

Gillett, R.D. 1986a. Observer trip on United States purse-seine vessel (November-December 1984). *South Pacific Commission Tuna and Billfish Assessment Programme Technical Report No.* 15.

Gillett, R.D. 1986b. Observations on two Japanese purse-seining operations in the equatorial Pacific. *South Pacific Commission Tuna and Billfish Assessment Programme Technical Report No. 16.*

Grandperrin, R. 1978. Influence of currents on the production of tropical seas: consequences for fisheries. SPC *Fisheries Newsletter No.* 17: 14-20.

Hilborn, R. and P. Medley. 1989. Tuna purse seine fishing with fish-aggregating devices (FAD): Models of tuna FAD interactions. *Canadian Journal of Fisheries and Aquatic Sciences* 46:28-32.

Ianelli, J. 1986. A method for estimating recruitment patterns of tunas to floating objects using removal data. *South Pacific Commission Tuna and Billfish Assessment Programme Internal Report No. 11.*

Itano, D.G. 1991. Tuna tagging and observations on a Japanese group purse seine vessel (9-28 April 1990). *South Pacific Commission Tuna and Billfish Assessment Programme Technical Report No.* 23.

Itano, D. and T. Buckley. 1988. Report on the Fish Aggregation Device (FAD) program in American Samoa (1979 to November 1987). Office of Marine and Wildlife Resources, American Samoa Government.

Lambert, J.F. 1984. Tuna purse seine cruise report, July 21-November 9, 1983. M/V *Jo Ann* final report. Pacific Fisheries Development Foundation, Honolulu.

Lawson, T. 1991. Status of tuna fisheries in the SPC area during 1990, with annual catches since 1952. *South Pacific Commission Tuna and Billfish Assessment Programme Technical Report No.* 27.

Malig, J.B., A.S. De Jesus and J.O. Dickson. 1991. Deep-sea Fish Aggregating Devices (FADs) in the Philippines. Indo Pacific Fishery Commission, Papers presented at the Symposium on artificial reefs and Fish Aggregating Devices as tools for the management and enhancement of marine fishery resources, Colombo, Sri Lanka, 14-17 May 1990. *RAPA Report* 1991/11: 214-228.

Pacific Islands Pilot. 1988. Solomon Islands, Papua New Guinea: Northeast coast and adjacent islands, Caroline Islands, Mariana Islands. Hydrographer of the Navy, Ministry of Defense, Taunton, NP 60, Volume 1.

Preston, G.L. 1982. The Fijian experience in the utilisation of Fish Aggregation Devices. *South Pacific Commission Fourteenth Regional Technical Meeting on Fisheries Working paper No.* 25.

PTDF. 1977. Final report tuna purse-seine charter to the western Pacific, June-November 1976. Pacific Tuna Development Foundation, Honolulu.

PTDF. 1978. Purse-seine fishing for yellowfin and skipjack in the western Pacific. 1978 PTDF purse-seine charter. *Bold Venture* cruise report. Pacific Tuna Development Foundation, Honolulu.

Salomons, R. and D. Souter. 1980. Tuna purse seining cruise report, June-September, 1980. *Island Princess*. Living Marine Resources, San Diego.

Seber, G.A.F. 1973. The estimation of animal abundance and related parameters. Griffin, London.

Souter, D. and G. Broadhead. 1978. Purse seine fishing for yellowfin and skipjack in the southern waters of the central and western Pacific. *Jeanette C* charter. *Pacific Tuna Development Foundation Technical Bulletin No. 2.*

Souter, D. and R. Salomons. 1980a. Tuna purse seining *Island Princes* cruise report, June-October 1979. Pacific Tuna Development Foundation, Honolulu.

Souter, D. and R. Salomons. 1980b. Tuna purse seining cruise report - Jeanette C, May-September, 1979. Pacific Tuna Development Foundation, Honolulu.

SPC. 1989. A review of small scale tuna purse seine operations in Fiji. *South Pacific Commission Twenty-first Regional Technical Meeting on Fisheries Information paper 17.*

Tanaka, T. 1989. Shift of the fishing ground and features of shoals caught by purse seine fishery in the tropical seas of the western Pacific Ocean. *Bulletin of the Tohoku Regional Fisheries Research Laboratory* 51: 75-88. (Translation by M. Izumi, SPC).

Wankowski, J.W.J. and D.W. Witcombe. (undated). Fish associated with floating debris in the western equatorial western Pacific purse seine fishery. *Papua New Guinea Department of Primary Industry Fisheries Archive Paper.* P. 67.

Wild, A. 1991. A review of yellowfin tuna biology and fisheries in the eastern Pacific Ocean. *FAO Expert Consultation on Interactions of Pacific Tuna Fisheries Background Paper No. 5.*

Table 1. Percentages of total sets recorded on the SPC Regional Tuna Fisheries Database for each vessel nationality, by school association.

Vessel nationality	Type of association				
	School	Log	Drifting FAD	Anchored FAD	Animal
Australia	38.70	55.17	0.77	0.77	4.60
Indonesia	9.66	87.73	0.78	0.00	1.83
Japan	31.26	65.28	0.44	0.28	2.75
Korea	39.01	55.42	0.32	0.10	5.16
Mexico	27.61	69.33	0.00	0.00	3.07
New Zealand	0.00	0.00	100.00	0.00	0.00
Philippines	0.71	24.25	49.20	25.80	0.04
Solomon Islands	0.84	2.32	0.00	96.83	0.00
Soviet Union	95.33	4.46	0.00	0.00	0.20
Taiwan	4.77	93.86	0.90	0.20	0.27
United States	75.32	24.39	0.17	0.00	0.12
TOTAL	37.66	54.12	3.45	2.90	1.88

Table 2. Skipjack, yellowfin and total catch per set (mt) for all sets recorded on the SPC Regional Tuna Fisheries Database, by vessel nationality and school association.

		Type of association				
Vessel nationality		School	Log	Drifting FAD	Anchored FAD	Animal
Australia	Skipjack	9.85	16.97	16.50	15.00	7.25
	Yellowfin	2.46	3.53	0.00	0.00	11.00
	Total	12.31	20.51	16.50	15.00	18.25
Indonesia	Skipjack	47.95	20.23	15.00	----	2.57
	Yellowfin	4.65	4.07	0.00	----	7.43
	Total	52.59	24.30	15.00	----	10.00
Japan	Skipjack	16.80	20.11	20.37	5.20	11.74
	Yellowfin	4.29	4.02	4.94	2.75	8.21
	Total	21.08	24.13	25.31	7.95	19.95
Korea	Skipjack	14.75	15.56	31.85	3.67	9.64
	Yellowfin	6.65	4.60	6.15	0.00	8.28
	Total	21.39	20.16	38.00	3.67	17.92
Mexico	Skipjack	17.09	11.04	----	----	0.00
	Yellowfin	0.44	10.17	----	----	0.00
	Total	17.53	21.21	----	----	0.00
New Zealand	Skipjack	----	----	7.89	----	----
	Yellowfin	----	----	4.31	----	----
	Total	----	----	12.20	----	----
Philippines	Skipjack	9.19	15.83	10.72	7.20	3.00
	Yellowfin	6.38	5.80	5.51	3.27	0.50
	Total	15.56	21.63	16.23	10.47	3.50
Solomon Islands	Skipjack	7.38	12.14	----	17.69	----
	Yellowfin	20.75	7.45	----	15.17	----
	Total	28.13	19.59	----	32.86	----
Soviet Union	Skipjack	8.80	1.73	----	----	5.00
	Yellowfin	2.78	1.05	----	----	0.00
	Total	11.59	2.77	----	----	5.00
Taiwan	Skipjack	18.41	12.99	10.86	14.47	33.35
	Yellowfin	3.96	2.33	1.64	6.13	3.10
	Total	22.38	15.32	12.50	20.60	36.45
United States	Skipjack	14.99	23.14	15.63	----	8.32
	Yellowfin	7.13	9.96	14.80	----	8.05
	Total	22.12	33.10	30.43	----	16.36
TOTAL	Skipjack	15.68	18.69	11.43	11.50	11.38
	Yellowfin	5.77	4.47	5.42	8.19	8.13
	Total	21.45	23.16	16.86	19.70	19.51

Table 3. Species composition (%) of US purse seiners sampled by NMFS while unloading in Pago Pago, American Samoa. The last two columns show the bigeye composition as a percentage of the yellowfin and bigeye catch. (+ = < 0.1).

Year	Qtr	School type	Skipjack		Yellowfin		Bigeye		Bigeye/Big. + Yfn	
			%No.	%Wght	%No.	%Wght	%No.	%Wght	%No.	%Wght
1988	3	Log	82.5	62.3	15.8	36.2	1.7	1.5	9.6	4.0
		Sch	98.4	95.0	1.6	5.0	+	+	0.4	0.1
1988	4	Log	84.8	67.5	12.7	29.6	2.5	2.9	16.2	8.9
		Sch	96.1	87.1	3.7	12.6	0.2	0.2	3.3	1.3
1989	1	Log	83.3	77.7	15.8	21.1	0.9	1.1	5.4	5.1
		Sch	91.5	74.5	8.3	25.3	0.2	0.2	2.0	0.7
1989	2	Log	88.3	83.2	11.0	15.8	0.7	1.0	6.3	5.9
		Sch	97.1	92.4	2.8	7.5	+	0.1	1.1	0.8
1989	3	Log	78.1	61.1	20.3	36.2	1.6	2.7	7.2	7.0
		Sch	86.2	60.5	13.7	39.4	0.1	0.1	0.8	0.2
1989	4	Log	74.8	54.5	18.0	32.8	7.2	12.7	28.5	27.9
		Sch	81.6	48.4	18.4	51.6	+	+	0.1	+
1990	1	Log	84.0	64.2	14.3	32.1	1.7	3.7	10.5	10.3
		Sch	95.8	80.4	4.2	19.6	+	+	0.1	+
1990	2	Log	87.2	64.1	11.5	32.1	1.3	3.8	9.9	10.5
		Sch	84.5	47.3	15.3	52.6	0.2	0.1	1.2	0.2
1990	3	Log	87.0	85.8	11.5	12.5	1.5	1.7	11.3	11.8
		Sch	83.6	50.7	16.3	49.2	0.1	0.1	0.8	0.2
1990	4	Log	88.4	81.1	10.4	17.0	1.1	1.9	9.8	9.9
		Sch	92.5	68.3	7.5	31.7	+	+	0.2	+
1991	1	Log	77.5	58.8	19.3	35.7	3.2	5.5	14.3	13.4
		Sch	96.6	83.9	3.3	16.0	0.1	+	1.6	0.3
1991	2	Log	83.4	63.3	16.3	36.4	0.3	0.3	1.6	0.9
		Sch	88.1	58.3	11.9	41.7	+	+	0.2	0.1
1991	3	Log	90.9	70.6	6.6	24.6	2.5	4.7	27.3	16.1
		Sch	100.0	100.0	0	0	0	0	0	0

Table 4. Mean by-catch per set (mt) for each association type. Figures are tonnes per set for sets on the SPC Regional Tuna Fisheries Database that contain records of by-catch, number of sets with by-catch, and the percentage of by-catch sets against all sets for each association type. (+ = < 0.1%)

Vessel nationality		School	Log	Drifting FAD	Anchored FAD	Animal
Indonesia	By-catch/set	-	1.0	-	-	-
	No. by-catch sets	-	2	-	-	-
	% by-catch sets	-	0.6	-	-	-
Japan	By-catch/set	6.0	2.7	0.1	2.0	-
	No. by-catch sets	3	79	2	1	-
	% by-catch sets	+	0.3	1.2	0.8	-
Korea	By-catch/set	5.7	1.7	-	-	1.0
	No. by-catch sets	12	44	-	-	4
	% by-catch sets	0.5	1.2	-	-	1.2
New Zealand	By-catch/set	-	-	2.3	-	-
	No. by-catch sets	-	-	17	-	-
	% by-catch sets	-	-	13.9	-	-
Philippines	By-catch/set	-	7.1	1.7	2.7	-
	No. by-catch sets	-	151	14	123	-
	% by-catch sets	-	13.4	0.8	10.6	-
Solomon Islands	By-catch/set	-	2.8	-	4.1	-
	No. by-catch sets	-	11	-	162	-
	% by-catch sets	-	50.0	-	17.7	-
Soviet Union	By-catch/set	9.5	4.5	-	-	-
	No. by-catch sets	2	2	-	-	-
	% by-catch sets	0.4	9.1	-	-	-
Taiwan	By-catch/set	10.0	4.3	-	-	-
	No. by-catch sets	1	3	-	-	-
	% by-catch sets	0.2	+	-	-	-
United States	By-catch/set	2.0	6.3	-	-	-
	No. by-catch sets	33	222	-	-	-
	% by-catch sets	0.2	4.9	-	-	-
TOTAL	By-catch/set	3.6	5.2	1.9	3.1	1.0
	No. by-catch sets	51	514	33	286	4
	% by-catch sets	0.2	1.2	1.5	12.8	0.3

Table 5. By-catch species from purse seine sets on different school associations. (R - rare, <1/set; S - common in small numbers, 1-10/set; M - common in moderate numbers, 10-100/set; L - common in large numbers, >100/set; - not present)

Species	School	Log	Drifting FAD	Anchored FAD	Animal associations Live whales	 Dead whales	 Whale sharks
Sharks and Rays							
Oceanic whitetip (*Carcharhinus longimanus*)	S	S	S	S	S	S	-
Silky shark (*C. falciformis*)	S	M	M	M	M	M	-
Tiger shark (*Galeocerdo cuvier*)	-	R	-	-	-	-	-
Whale shark (*Rhincodon typus*)	-	R	-	-	R	-	(S)
Manta ray (*Mobula japanica, Manta* spp.)	S	S	-	-	S	-	-
Stingray (*Dasyatis* sp.)	-	R	-	-	-	-	-
Scombrids							
Frigate tuna (*Auxis thazard*)	S	S	S	S	-	-	-
Kawakawa (*Euthynnus affinis*)	S	S	S	S	-	-	-
Wahoo (*Acanthocybium solandri*)	S	M	M	M	-	-	-
Billfish							
Black marlin (*Makaira indica*)	R	R	R	R	-	-	-
Blue marlin (*Makaira mazara*)	S	S	S	S	-	-	-
Broadbill swordfish (*Xiphias gladius*)	-	R	-	-	-	-	-
Sailfish (*Istiophorus platypterus*)	R	-	-	-	-	-	-
Shortbill spearfish (*Tetrapturus angustirostris*)	-	-	-	R	-	-	-
Carangids							
Amberjack (*Seriola rivoliana*)	-	L	L	L	-	-	-
Bar jack (*Carangoides ferdau*)	-	R	-	-	-	-	-
Bigeye trevally (*Caranx sexfasciatus*)	-	M	M	M	-	-	-
Bigeye scad (*Selar crumenophthalmus*)	-	-	-	L	-	-	-
Caranx spp. (*ignobilis, lugubris, melampygus*)	-	R	R	R	-	-	-
Golden trevally (*Gnathanodon speciosus*)	-	S	-	-	-	-	-
Greater amberjack (*Seriola dumerili*)	-	S	S	S	-	-	-
Mackerel scad (*Decapterus macarellus*)	-	L	L	L	-	-	-
Pilotfish (*Naucrates ductor*)	S	S	S	S	S	S	S
Rainbow runner (*Elagatis bipinnulata*)	S	L	L	L	-	L	-
Other fish							
Batfish (*Platax teira*)	-	S	S	S	-	-	-
Bramid (*Brama* sp.)	-	R	-	-	-	-	-
Drummer (*Kyphosus cinerascens*)	-	L	L	L	-	L	-
Filefish (*Aluterus monoceros*)	-	M	M	M	-	-	-
Filefish (*Aluterus scriptus*)	-	S	-	-	-	-	-
Flutemouth (*Fistularia* sp.)	-	R	-	-	-	-	-
Great barracuda (*Sphyraena barracuda*)	-	S	S	S	-	-	-
Mahimahi (*Coryphaena hippurus*)	S	L	L	L	-	L	-
Man-o-war fish (*Psenes cyanophrys*)	-	M	M	M	-	-	-
Ocean anchovy (*Stolephorus punctifer*)	L	-	-	-	L	-	L
Ocean triggerfish (*Canthidermis maculatus*)	-	L	L	L	-	L	-
Porcupine fish (*Diodon hystrix*)	-	R	-	-	-	-	-
Porcupine fish (*Cyclichthys echinatus*)	-	R	-	-	-	-	-
Sargeant major (*Abudefduf saxatilis*)	-	M	M	M	-	-	-
Sea bream (*Rhabdosargus sarba*)	-	R	-	-	-	-	-
Seahorse (*Hippocampus* sp.)	-	R	-	-	-	-	-
Sharksucker (*Remora remora*)	S	S	S	S	S	S	S
Therapon perch (*Therapon* sp.)	-	R	-	-	-	-	-
Tripletail (*Lobotes surinamensis*)	-	S	S	S	-	S	-
Marine reptiles							
Green turtle (*Chelonia mydas*)	-	R	R	R	-	-	-
Hawksbill turtle (*Eretmochelys imbricata*)	-	R	R	R	-	-	-
Olive ridley turtle (*Lepidochelys olivacea*)	-	R	-	-	-	-	-
Sea snake (*Pelamis platurus*)	-	R	-	-	-	-	-

Sources: Bailey and Souter, 1982; Farman, 1987; Gillett, 1986a,b; Itano, 1991, pers. obs.; Itano and Buckley, 1988; A.D. Lewis, pers. obs.; Preston, 1982; SPC RTTP records; Wankowski and Witcombe, no date; authors pers. obs.

Table 6. Maximum set sizes (mt) recorded on the SPC Regional Tuna Fisheries Database.

Association	Skipjack	Yellowfin	Total
School	300	308	318
Log	327	272	354
Drift. FAD	235	294	300
Anch. FAD	138	123	165
Animal	280	220	280

Table 7. Some estimates of population sizes of tuna aggregations under floating objects. The data used are from SPC tagging experiments where the tagging vessel revisited the aggregation soon after tagging. The method used to calculate population sizes and standard deviations is Bailey's bionomial model (Seber 1973, p.61).

Country	Association	Species	No. tagged (1st occasion)	Sample caught (2nd occasion)	No. recaptured (2nd occasion)	Population estimate (no.)	Standard deviation
Philippines	Anch. FAD	skipjack	690	217	8	16,713	5,822
Philippines	Anch. FAD	skipjack	282	966	78	3,452	370
		yellowfin	91	497	10	4,120	1,176
Indonesia	Anch. FAD	skipjack	408	670	10	24,888	7,125
		yellowfin	608	345	15	13,148	3,114
FSM	Log	skipjack	13	1,111[1]	3	3,614	1,613
		yellowfin	51	500[1]	7	3,194	1,056
		bigeye	19	167[1]	1	1,596	916

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[1] Estimated catch in numbers based on logbook catch weight estimate and average weight estimate.

Table 8. Catches (mt) of repeated purse seine sets on individual logs in the western tropical Pacific.

Vessel	Day	Yellowfin	Skipjack	Bigeye	Total	Source
Jeanette C	1	26.3	85.3	0	111.6	Souter & Broadhead (1978)
	2	9.1	33.6	0	42.7	
	3	9.1	43.6	0	52.7	
Jeanette C	1	18.2	36.3	0	54.5	Souter & Salomons (1979)
	3	4.5	3.6	0	8.1	
Bold Venture	1	0.9	2.7	0	3.6	PTDF (1978)
	3	0	3.6	0	3.6	
	1	4.5	16.3	0	20.8	"
	3	2.7	18.2	0	20.9	
Apollo	1	-	-	-	17.0	PTDF (1977)
	2	-	-	-	17.7	
Mary Elizabeth	6	-	-	-	24.3	
	7	-	-	-	11.6	
Apollo	1	-	-	-	80.7	"
	2	-	-	-	11.4	
	1	-	-	-	19.4	"
	2	-	-	-	6.7	
	1	-	-	-	44.8	"
	2	-	-	-	30.0	
Zapata Pathfinder	1	-	-	-	6.4	"
	2	-	-	-	4.3	
	1	-	-	-	20.0	"
	2	-	-	-	23.1	
	3	-	-	-	0	
Mary Elizabeth	1	-	-	-	30.2	"
	2	-	-	-	6.3	
	1	-	-	-	22.4	"
	2	-	-	-	10.6	
Western Pacific	1	-	-	-	77.2	D.G. Itano (pers. obs.)
	4	-	-	-	40.7	
	1	-	-	-	181.6	"
	2	-	-	-	81.7	
	5	-	-	-	18.2	
	1	-	-	-	104.4	"
	2	-	-	-	34.5	
	1	-	-	-	227.0	"
	2	-	-	-	7.3	

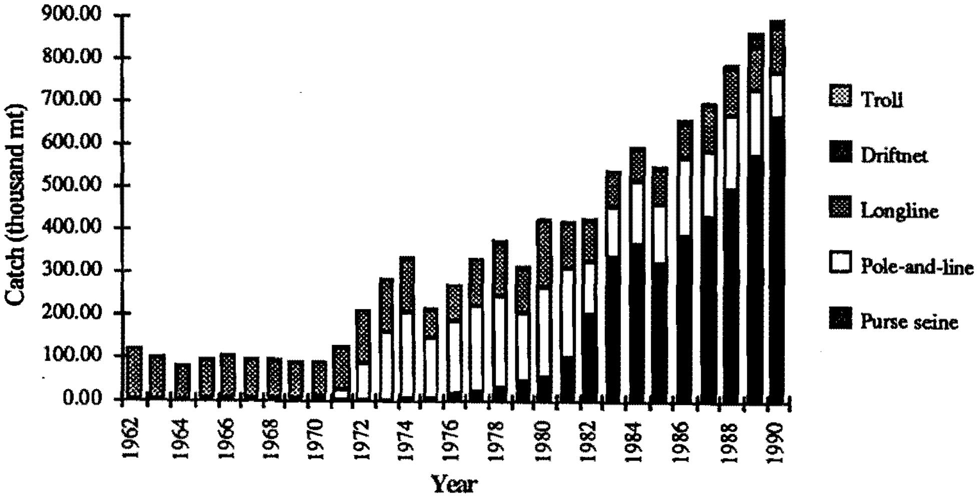
Table 8. Continued.

Vessel	Day	Yellowfin	Skipjack	Bigeye	Total	Source
Western Pacific (continued)	1	-	-	-	45.4	"
	3	-	-	-	13.6	
	1	-	-	-	172.5	"
	2	-	-	-	49.9	
	5	-	-	-	5.4	
	7	-	-	-	13.6	
	1	-	-	-	49.9	"
	2	-	-	-	36.3	
	4	-	-	-	36.3	
Western Pacific	1	-	-	-	1.8	K. Bailey (pers. obs.)
	6	-	-	-	2.7	
	1	-	-	-	145.3	"
	3	-	-	-	118.0	"
	6	-	-	-	27.2	"
	7	-	-	-	1.8	"
	1	-	-	-	63.6	"
	2	-	-	-	4.5	
	1	-	-	-	40.9	"
	4	-	-	-	127.1	
	1	4.5	22.7	0	27.2	"
	18	27.2	136.2	0	163.4	
	1	27.2	45.4	0	72.6	"
	3	13.6	22.7	0	36.3	
	8	4.5	13.6	0	18.1	
	1	9.1	18.2	0	27.2	"
	4	4.5	18.2	0	22.7	
	9	0	4.5	0	4.5	
Kotobuku 23	1	5.0	12.0	1.0	18.0	Itano (1991)
	2	1.0	3.0	<1.0	4.0	
	1	-	-	-	45.0	"
	1	-	-	-	60.0	

Table 9. Mean displacement rates for tuna tagged from different associations.

Association	Skipjack		Yellowfin		Bigeye	
	Displacement rate (nmi/day)	No. of recoveries	Displacement rate (nmi/day)	No. of recoveries	Displacement rate (nmi/day)	No. of recoveries
School	8.0	1,117	3.8	207	2.3	63
Log	17.0	423	13.6	311	12.4	33
Drift. FAD	17.2	25	16.0	42	22.5	25
Anch. FAD	2.7	1,480	1.6	662	2.3	16
Animal	3.3	29	2.5	15	---	---
Current line	4.4	27	1.3	65	---	---
Seamount	2.4	249	1.1	155	---	---
Island	6.7	17	12.4	14	---	---

(a) Total catch by gear



(b) Total catch by species

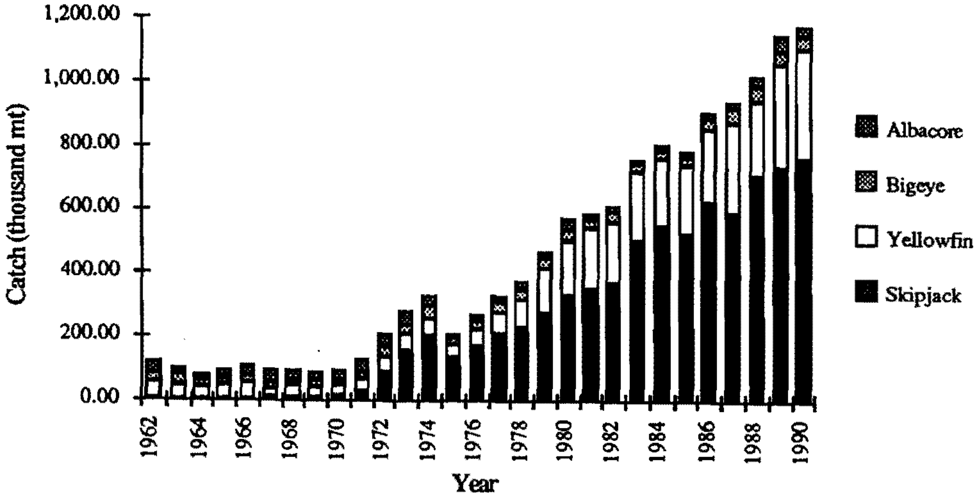


Figure 1. Tuna catch trends (a) in the Pacific Islands area (excluding Philippines and Indonesia) by gear type, and (b) in the WPO (including Philippines and Indonesia) by species. Source: South Pac. Comm. (1991).

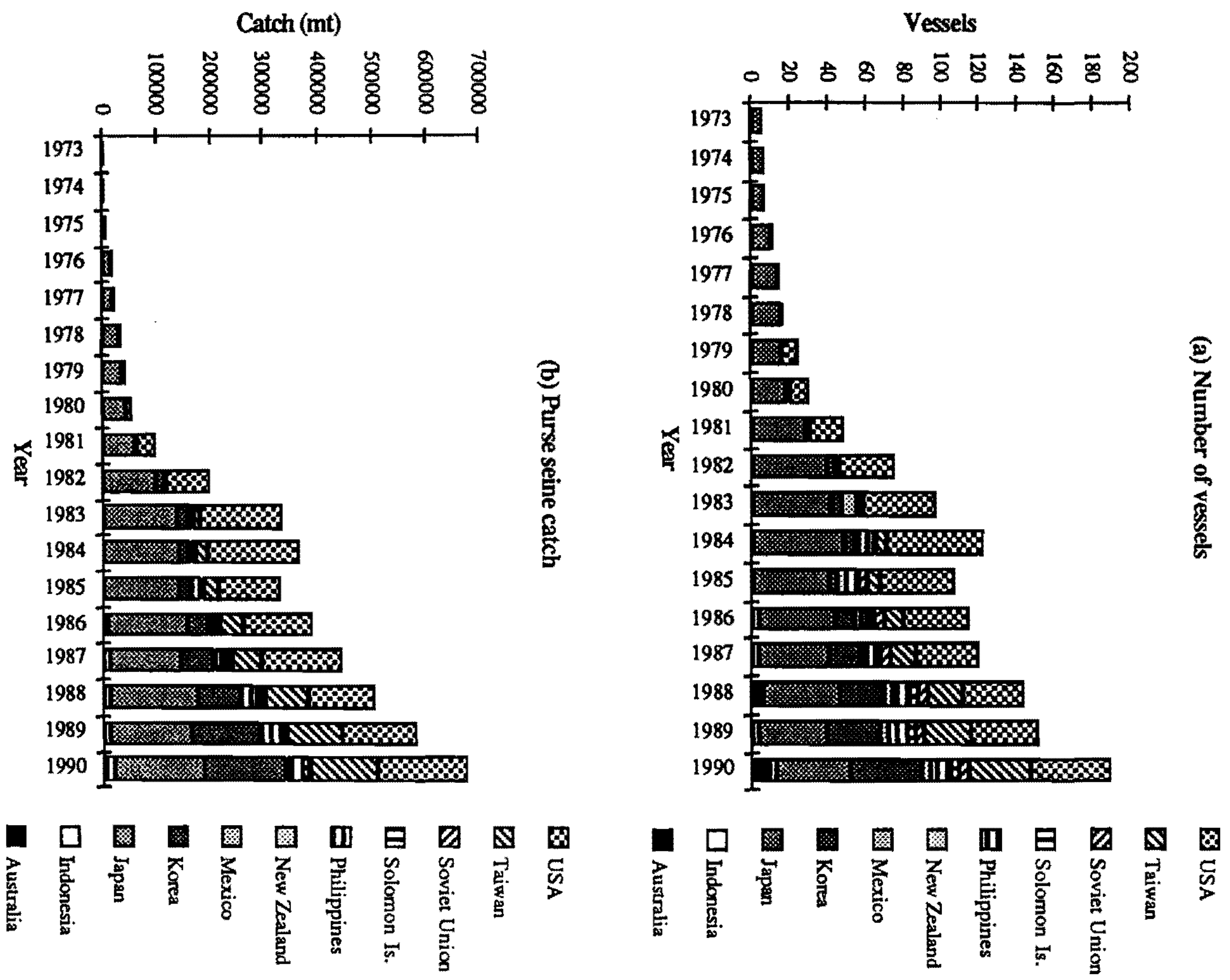


Figure 2. Time series of vessel numbers and total catch by vessel nationality.

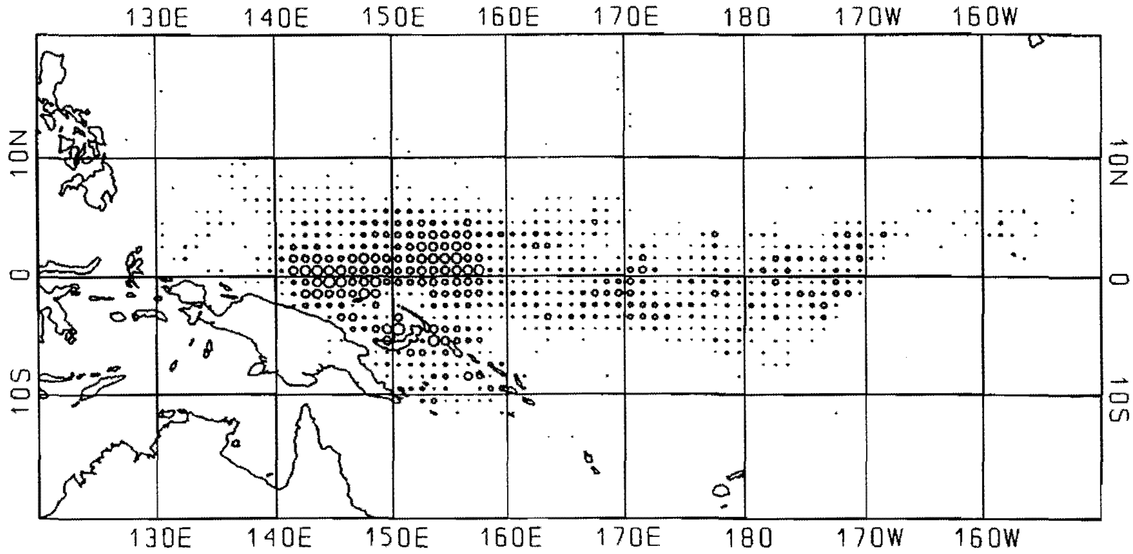


Figure 3. Distribution of purse seine effort in 1990, as indicated by logbook data submitted to SPC.

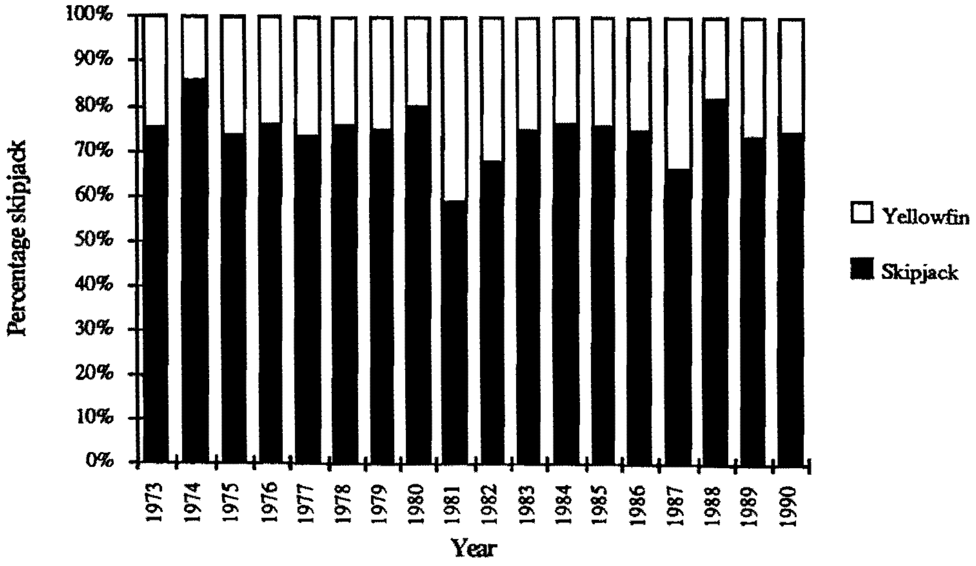


Figure 4. Species composition of the WPO purse seine catch as recorded on logbooks.

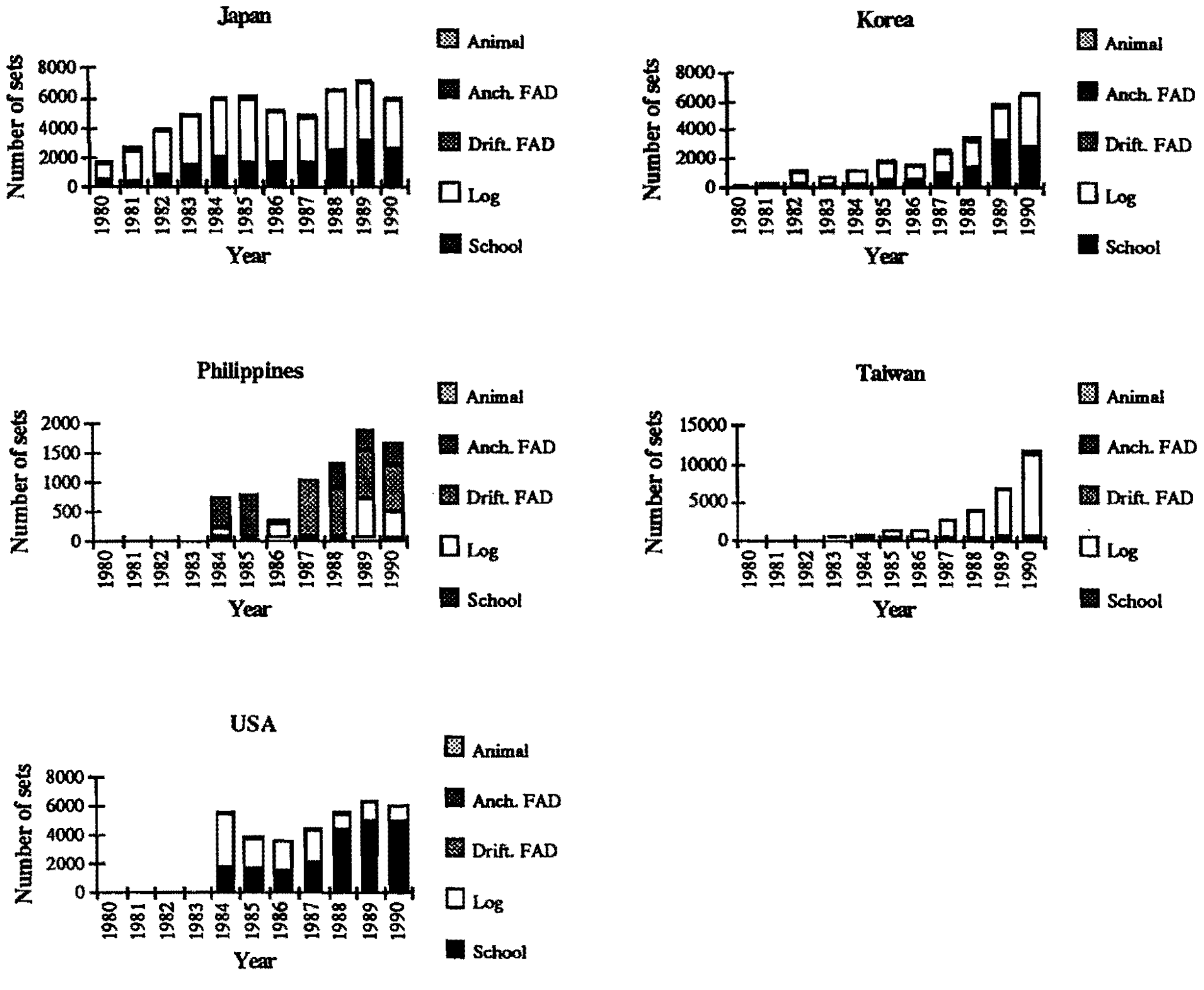


Figure 5. Total estimated sets, by school association, for selected purse seine fleets of the WPO.

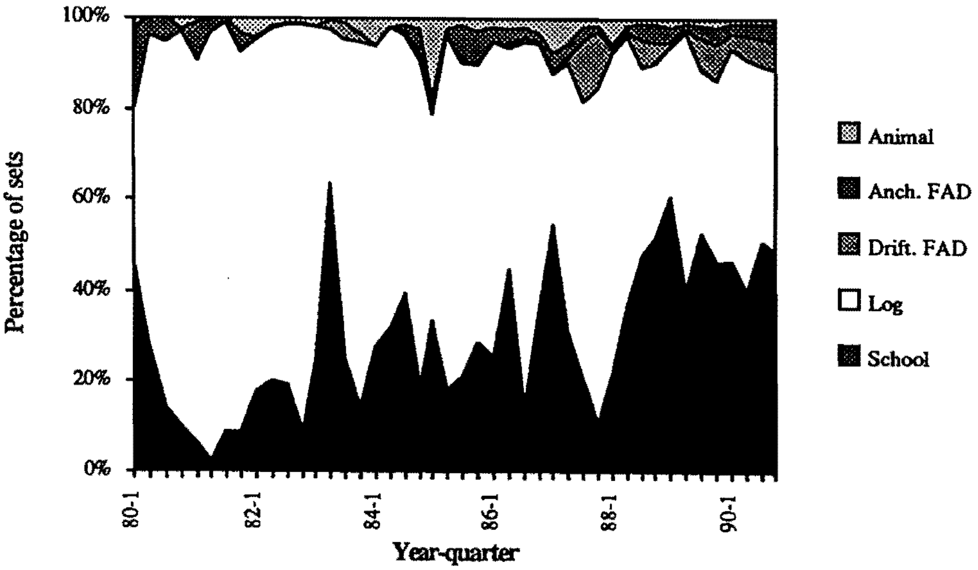
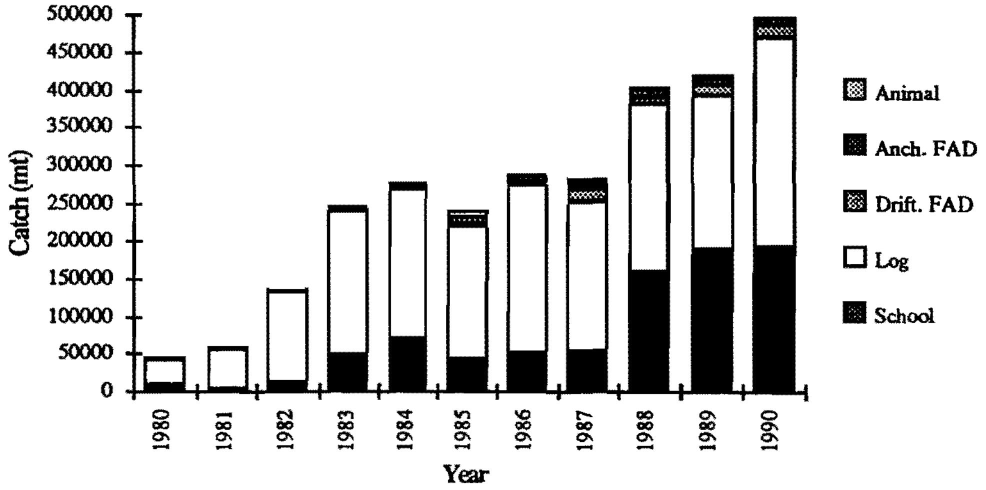
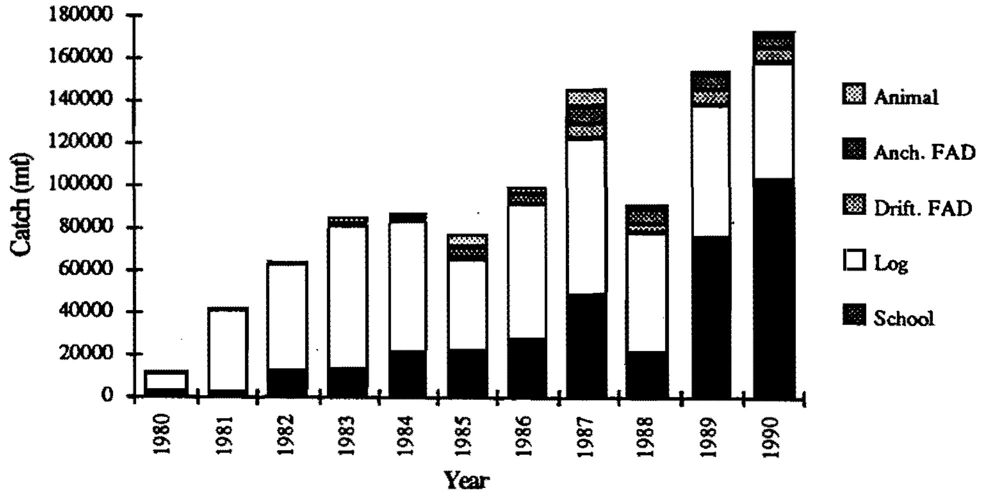


Figure 6. Relative number of sets, by association, on a quarterly basis.

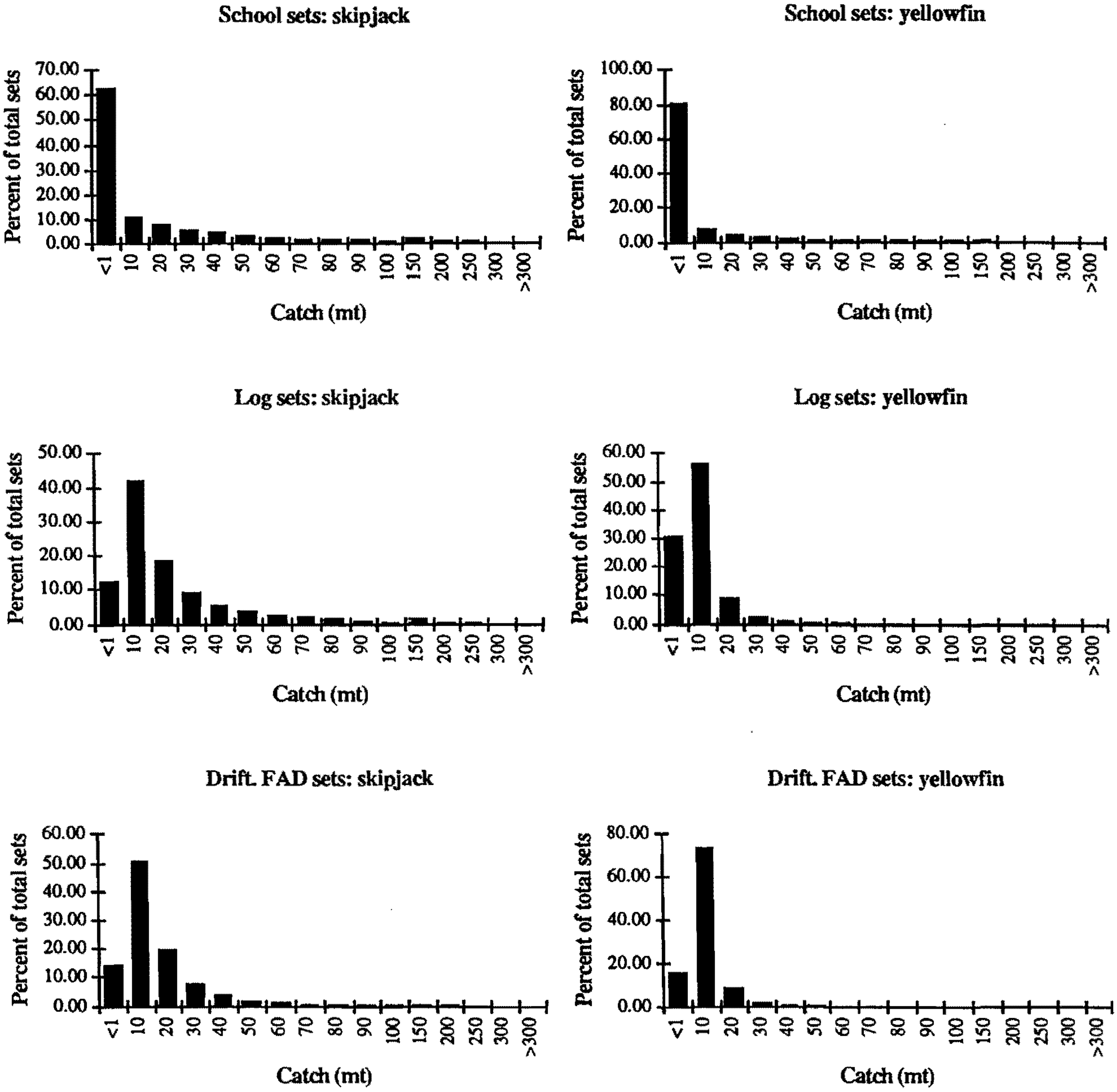


(a) Skipjack



(b) Yellowfin

Figure 7. Estimated total skipjack and yellowfin catches, by school association.



School sets: skipjack

School sets: yellowfin

Log sets: skipjack

Log sets: yellowfin

Drift. FAD sets: skipjack

Drift. FAD sets: yellowfin

Figure 8. Set success histograms for the WPO purse seine fishery.

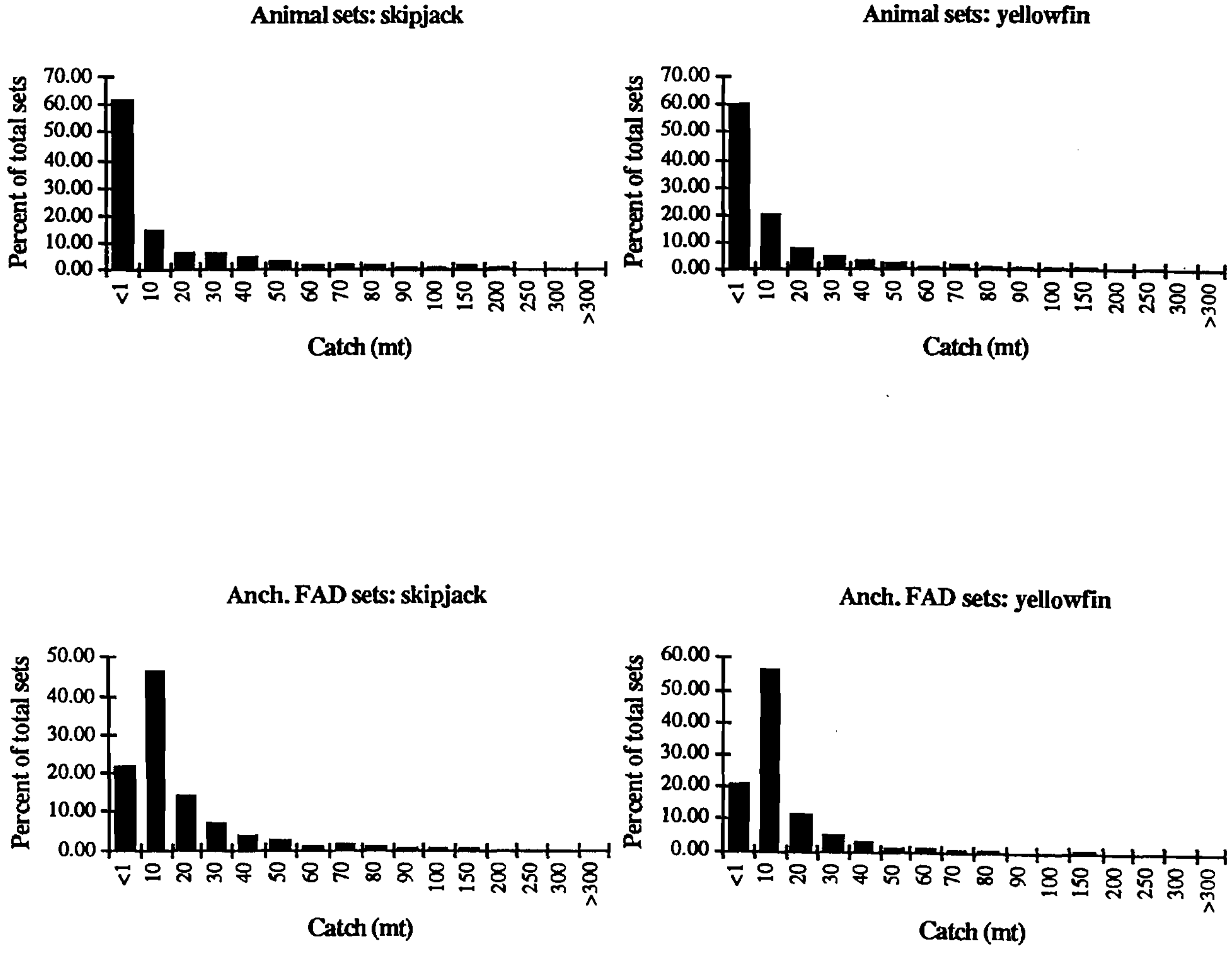


Figure 8. Continued.

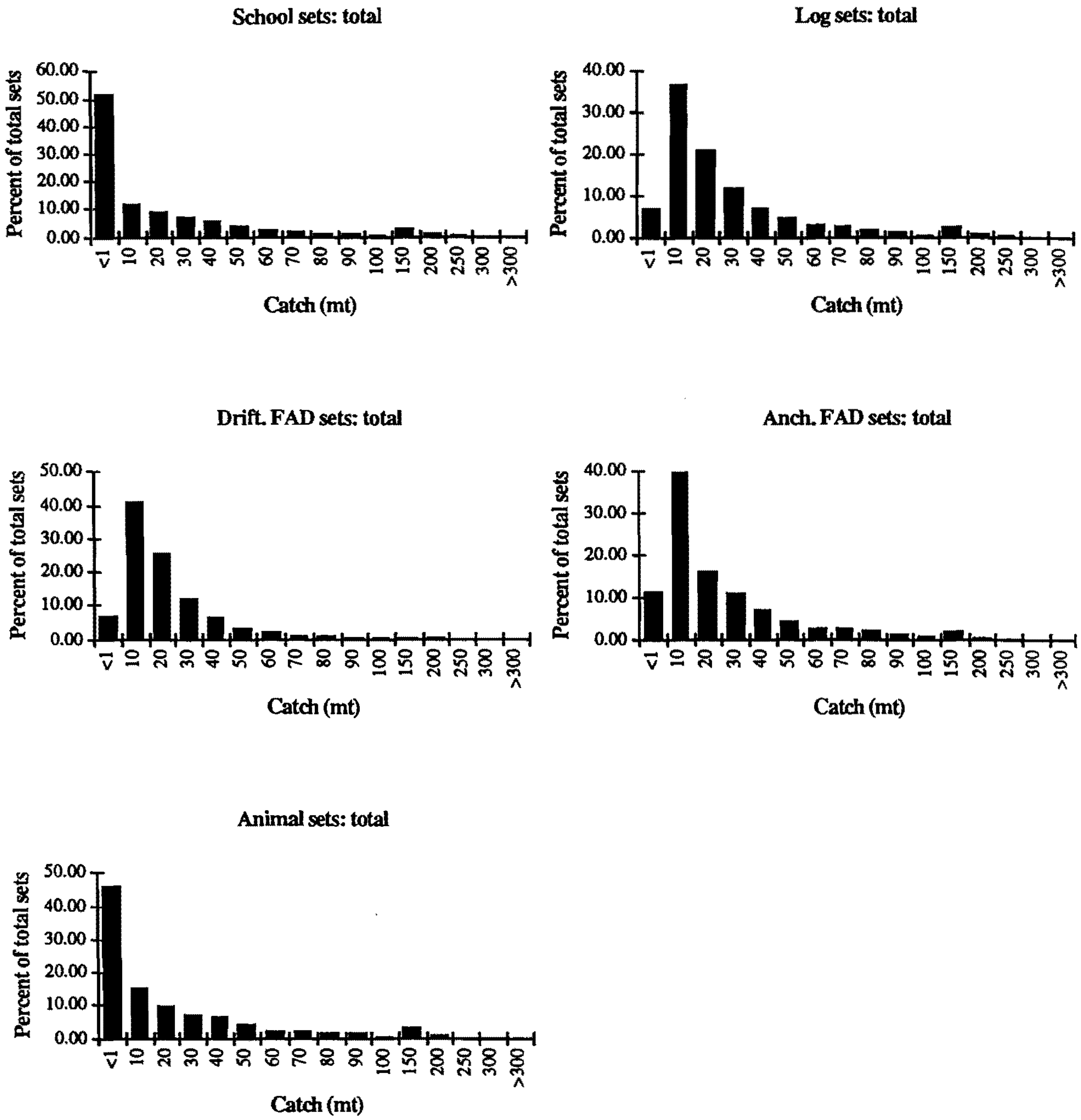


Figure 8. Continued.

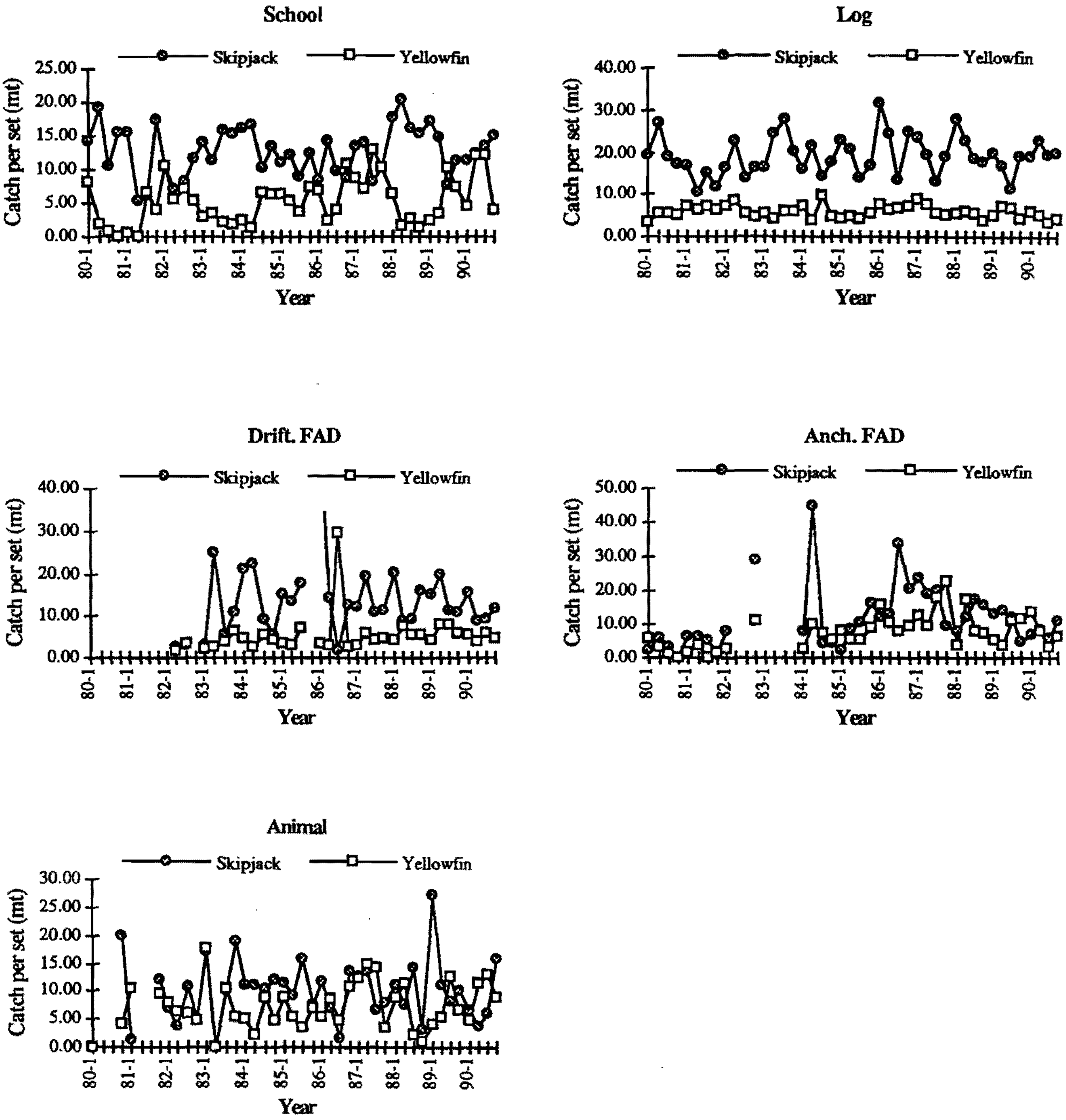


Figure 9. Average catch per set, by association.

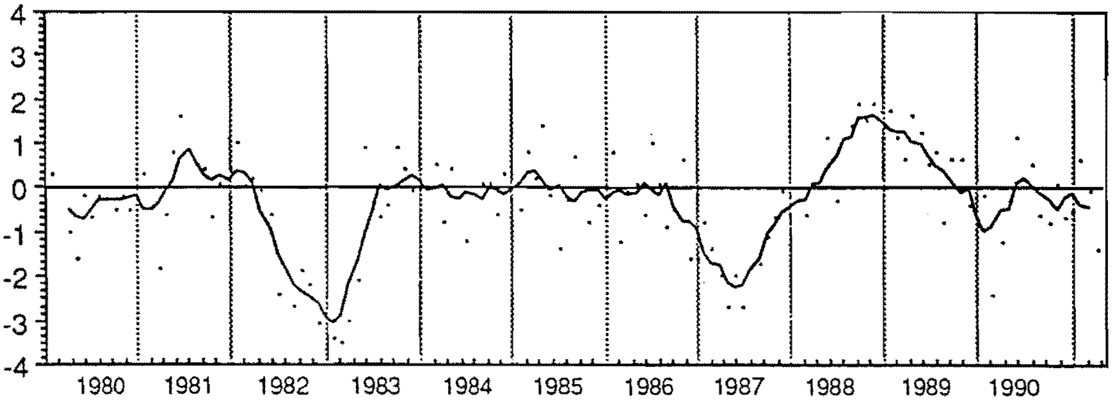


Figure 10. Southern Oscillation Index in the tropical WPO, 1980-1990. Dot points are actual index values and the line indicates the indices smoothed by a 5-month running average. Periods of positive indices represent *La Niño* events, and periods of negative indices represent *El Niño* events.

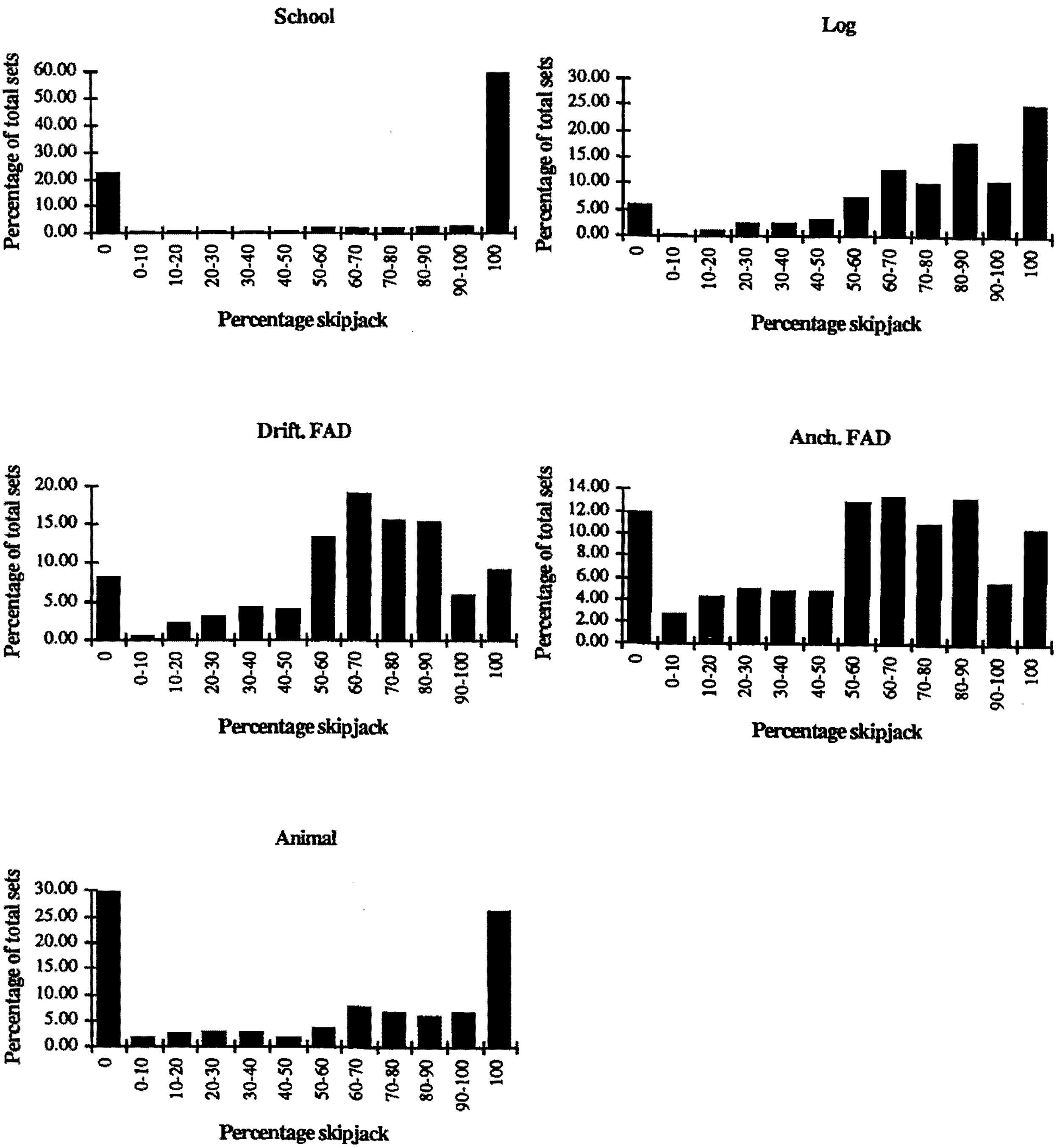
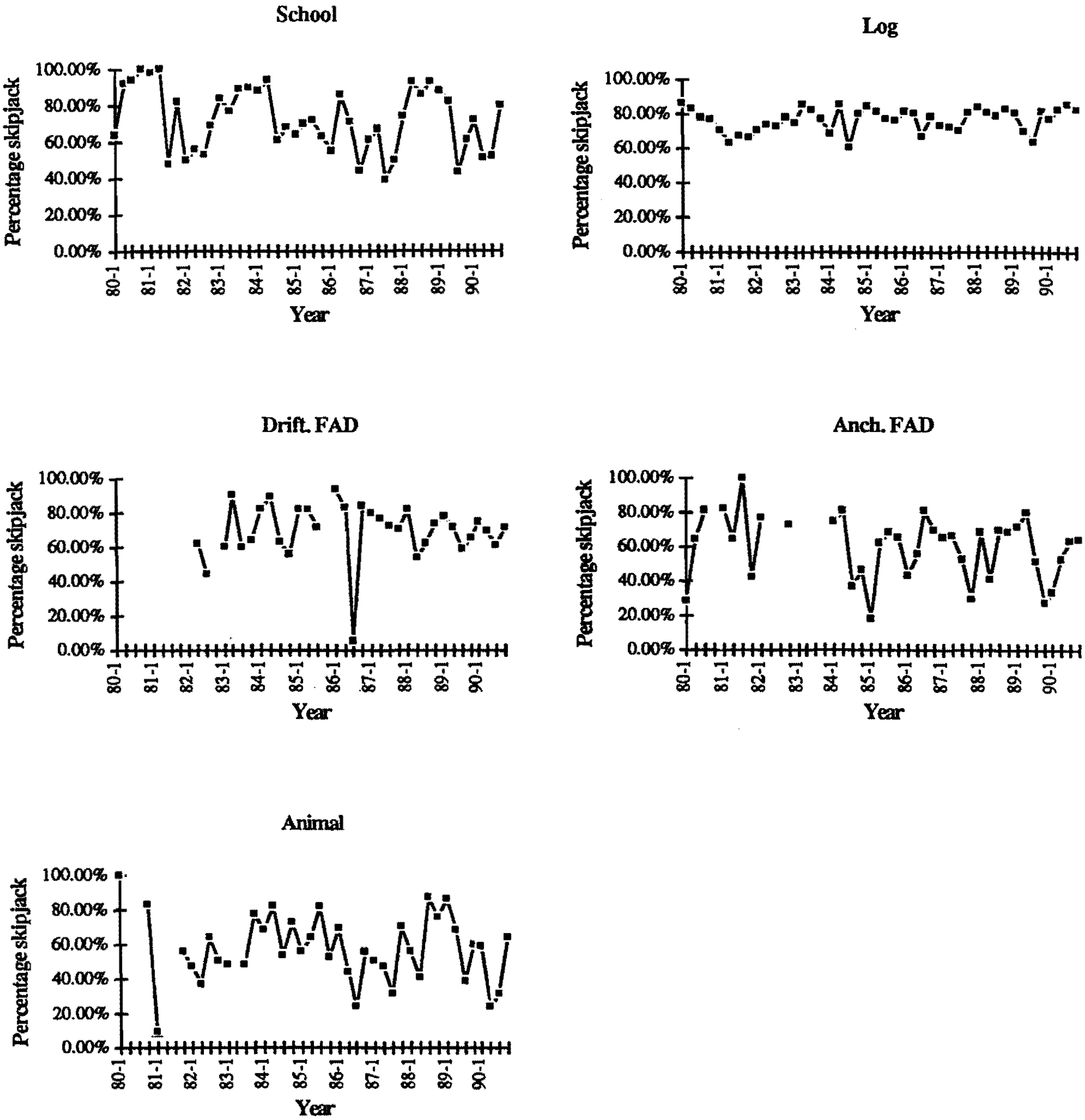


Figure 11. Frequency distributions of the percentage of skipjack in purse seine sets, by association.



School

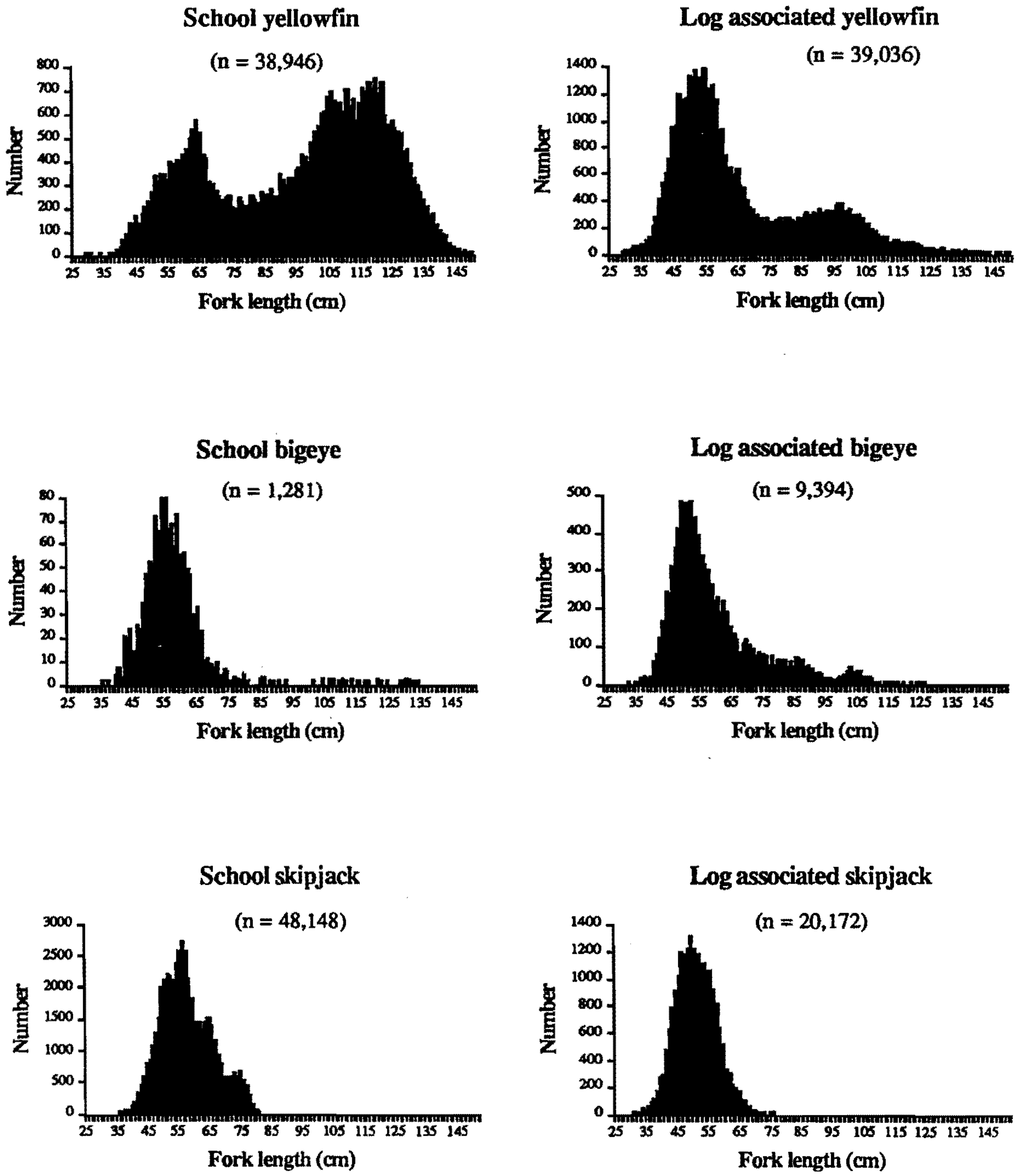
Log

Drift. FAD

Anch. FAD

Animal

Figure 12. Percentage of skipjack in purse seine sets, by association, on a quarterly basis.


School yellowfin (n = 38,946)

Log associated yellowfin (n = 39,036)

School bigeye (n = 1,281)

Log associated bigeye (n = 9,394)

School skipjack (n = 48,148)

Log associated skipjack (n = 20,172)

Figure 13. Size composition of yellowfin, bigeye and skipjack from school and log sets by US purse seiners, 1988-1991.

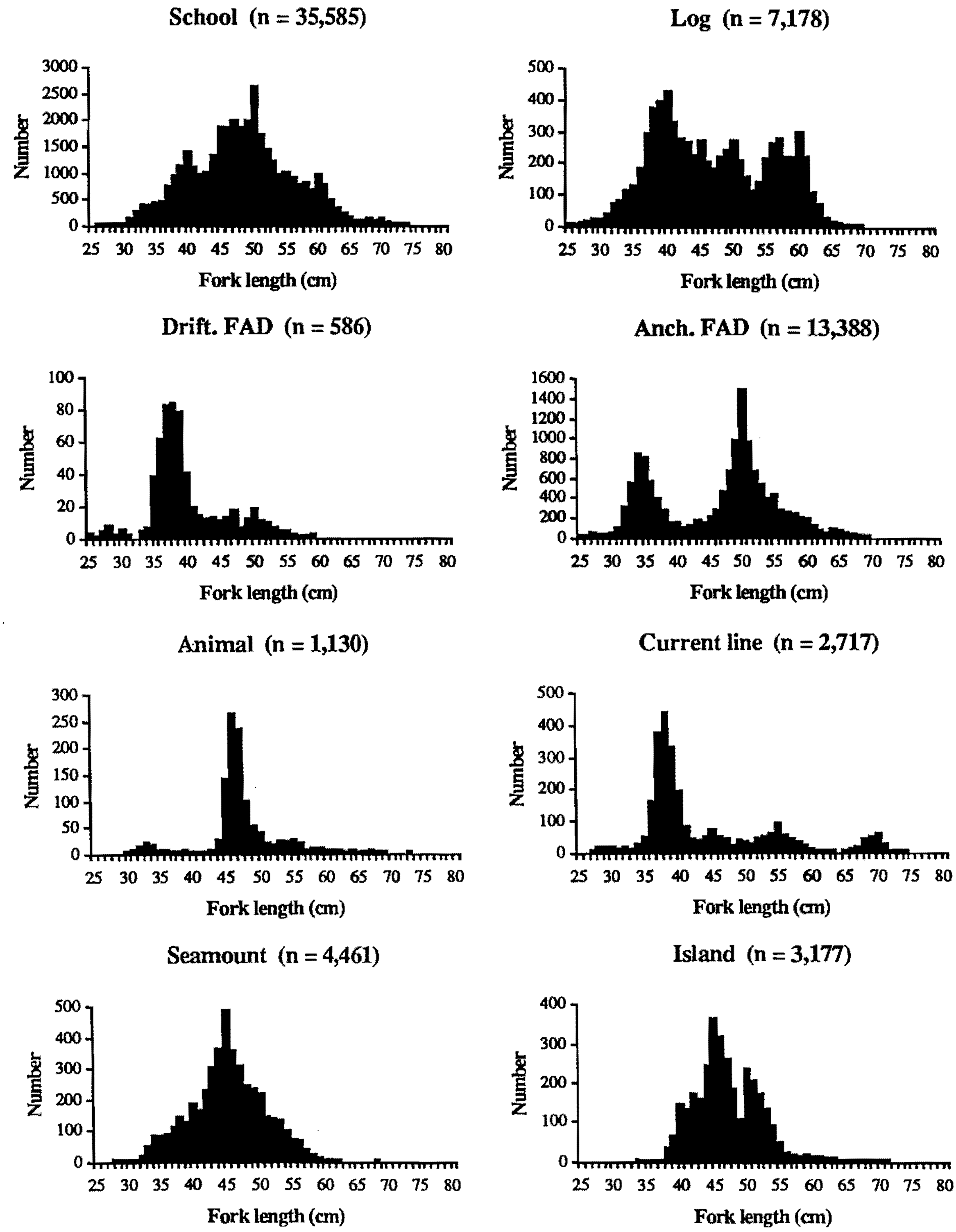


Figure 14. Size composition of skipjack from different school associations encountered by the SPC RTTP tagging vessel.

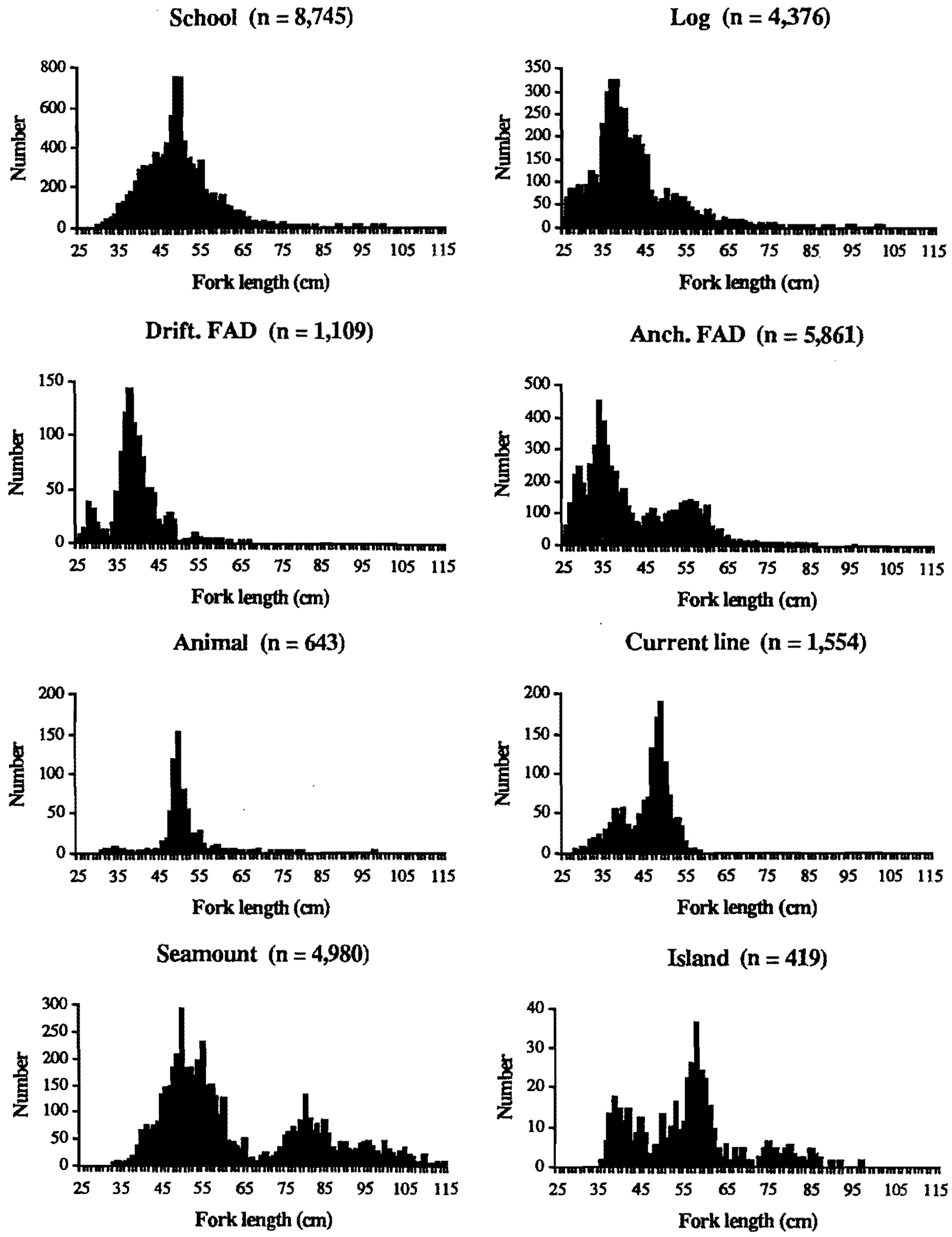


Figure 15. Size composition of yellowfin from different school associations encountered by the SPC RTTP tagging vessel.

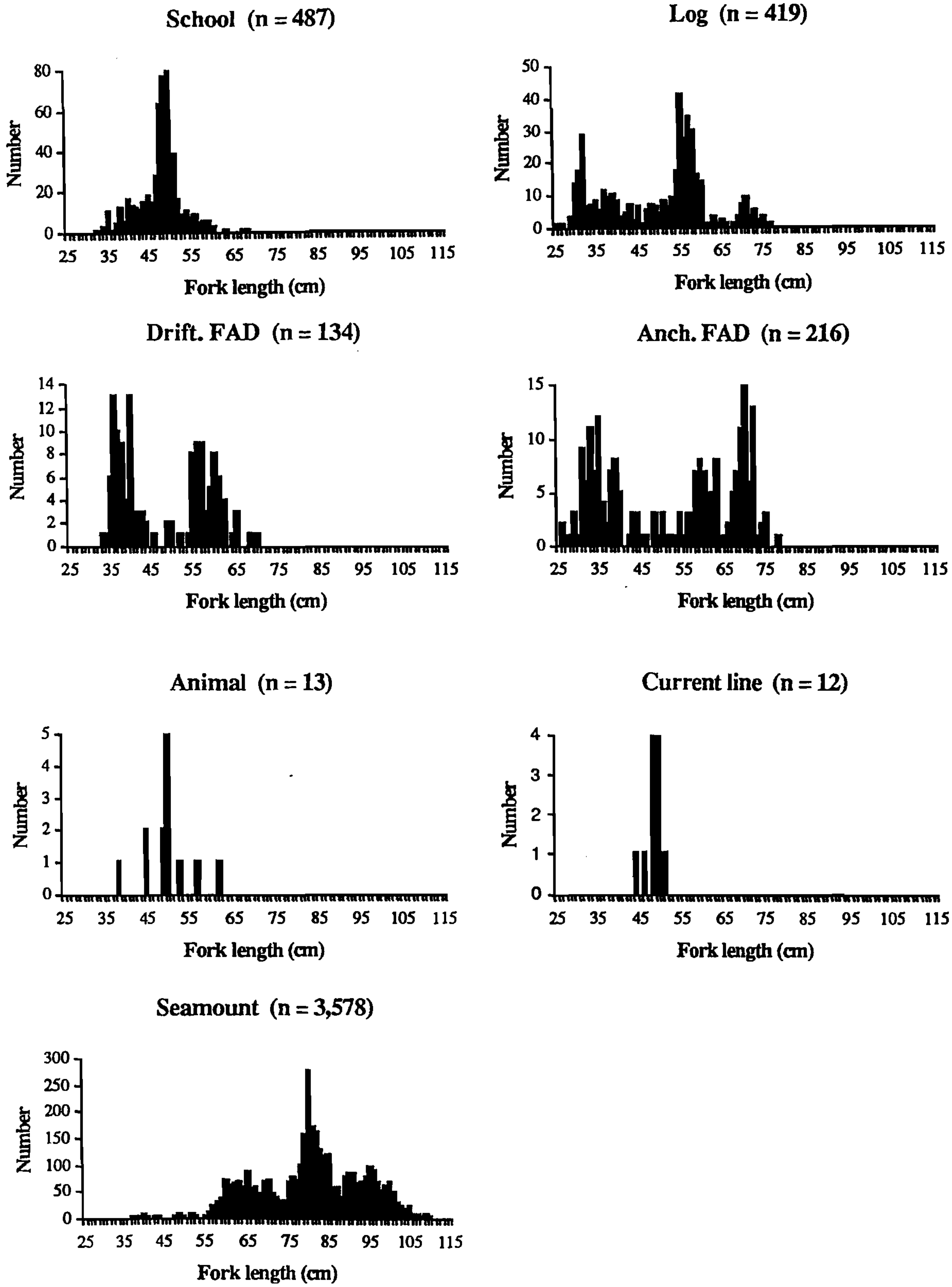


Figure 16. Size composition of bigeye from different school associations encountered by the SPC RTTP tagging vessel.

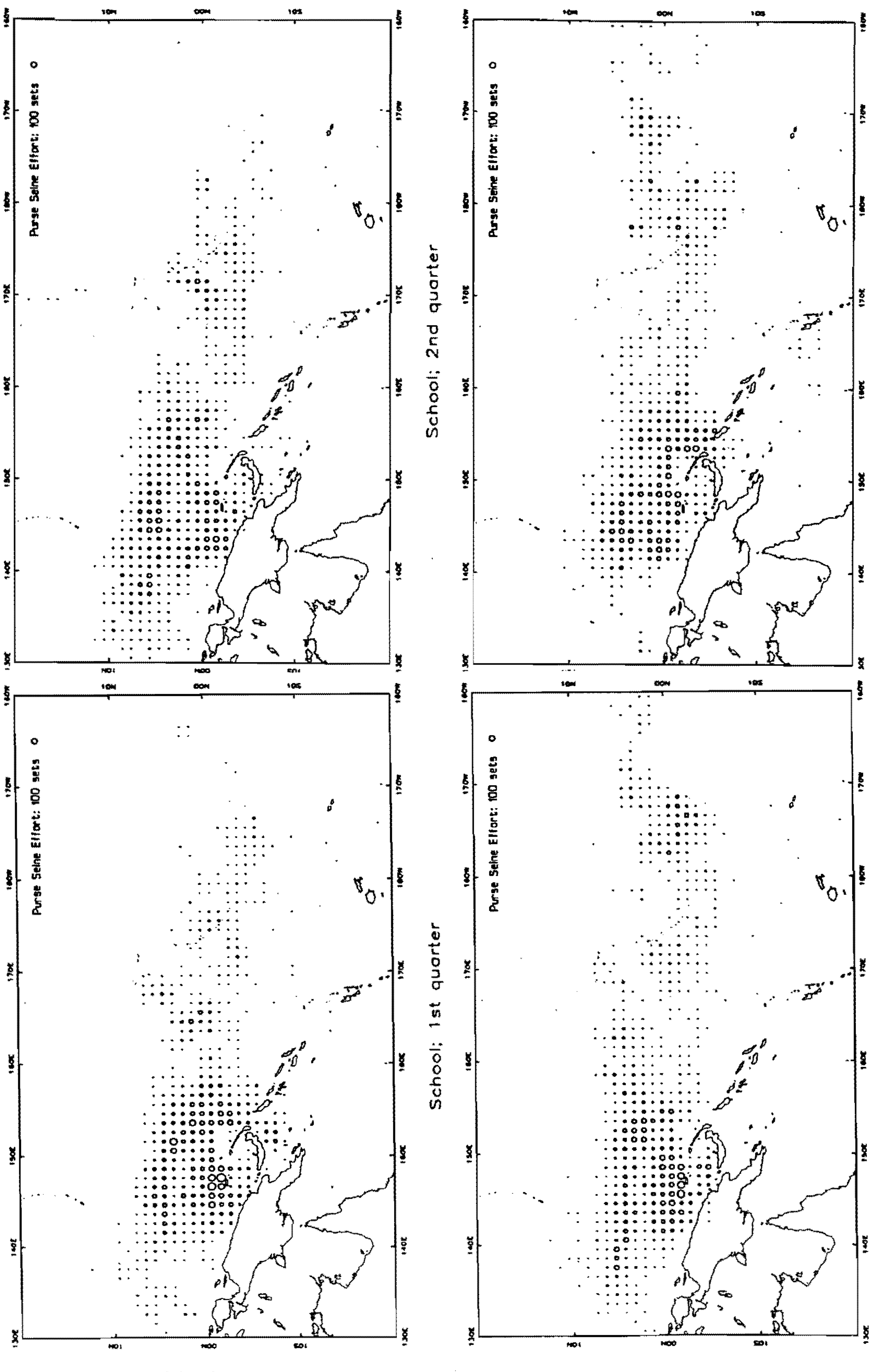


Figure 17. Geographical distribution of school sets by purse seiners, by quarter, 1979-1991.

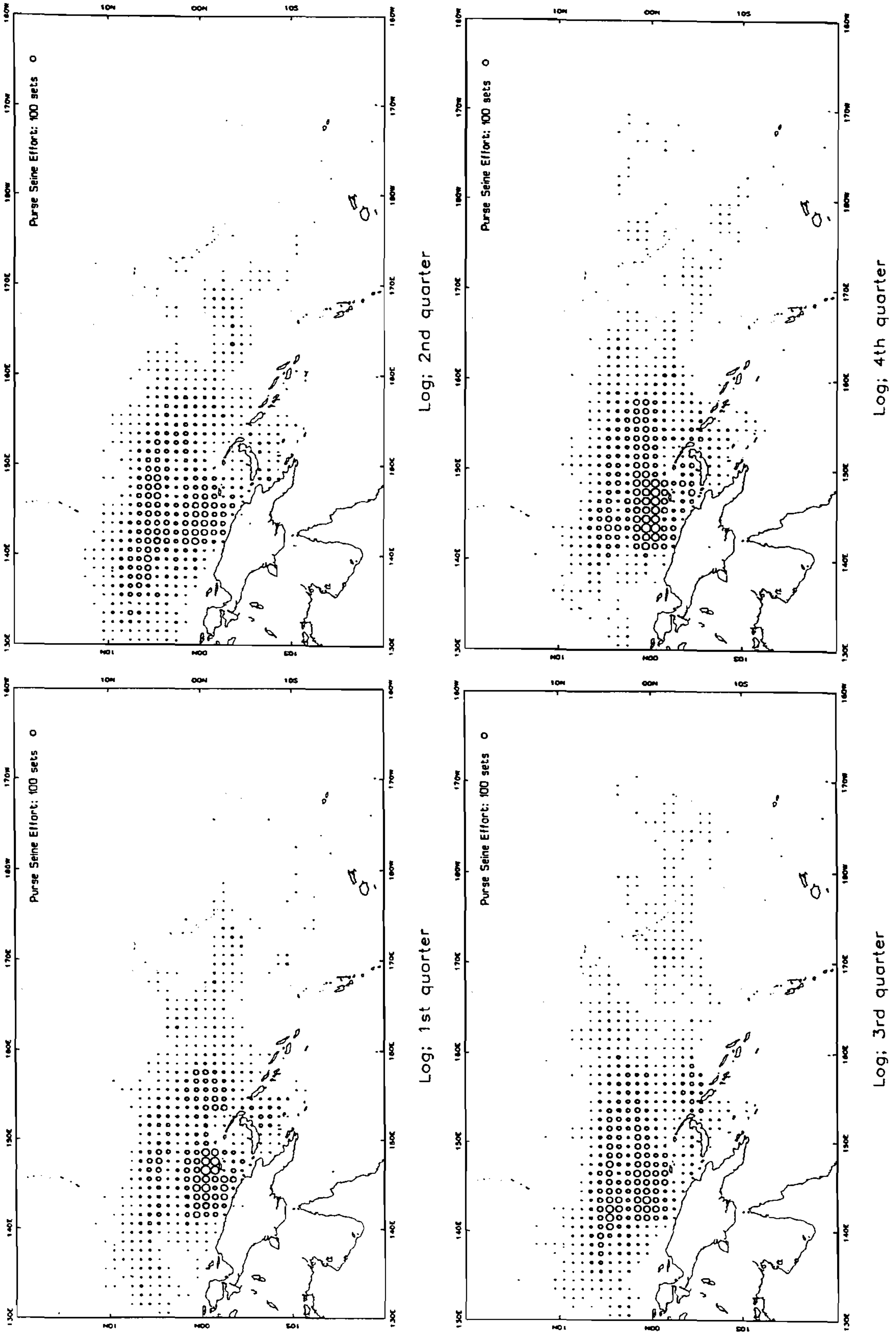
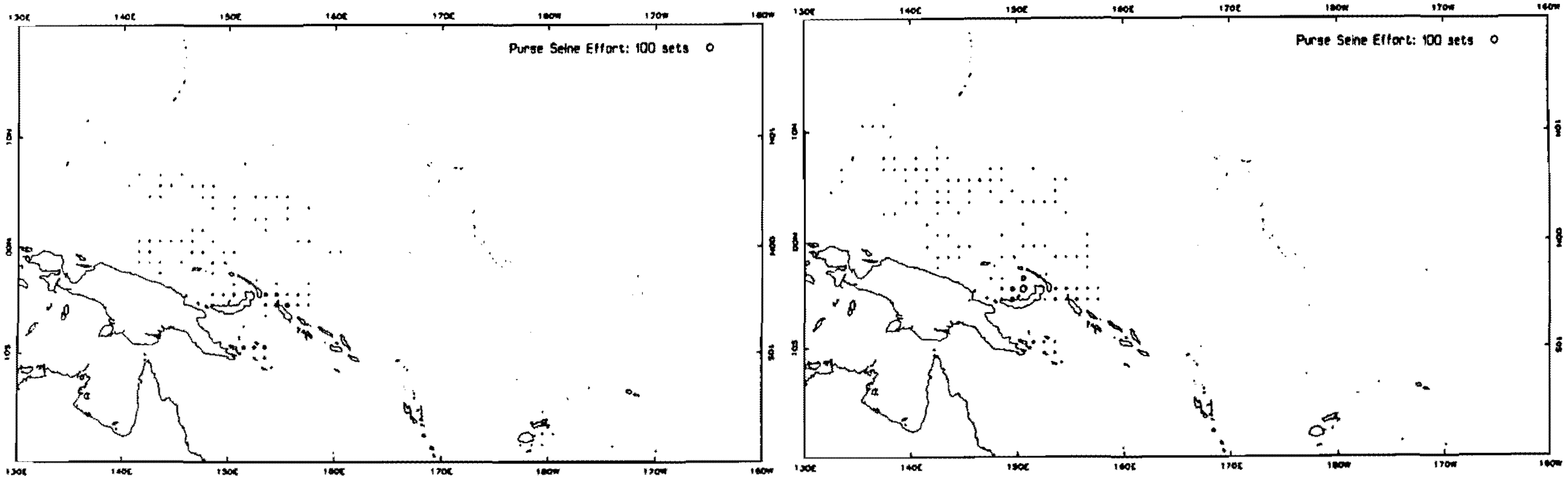
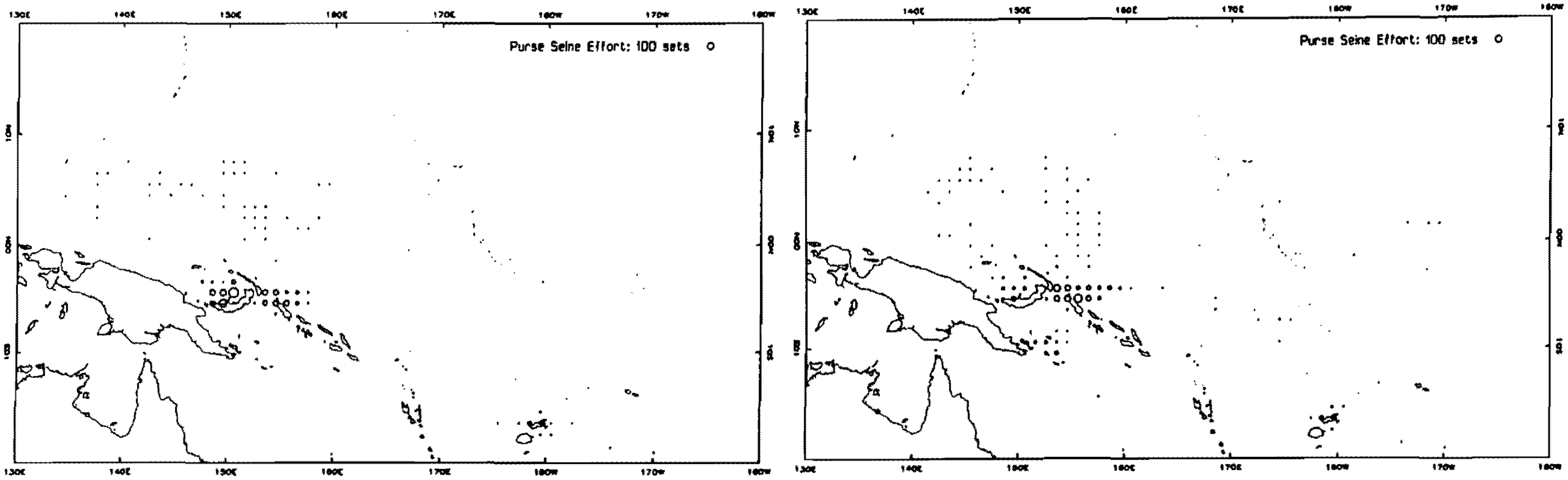


Figure 18. Geographical distribution of log sets by purse seiners, by quarter, 1979-1991.



Drifting FAD; 1st quarter

Drifting FAD; 2nd quarter

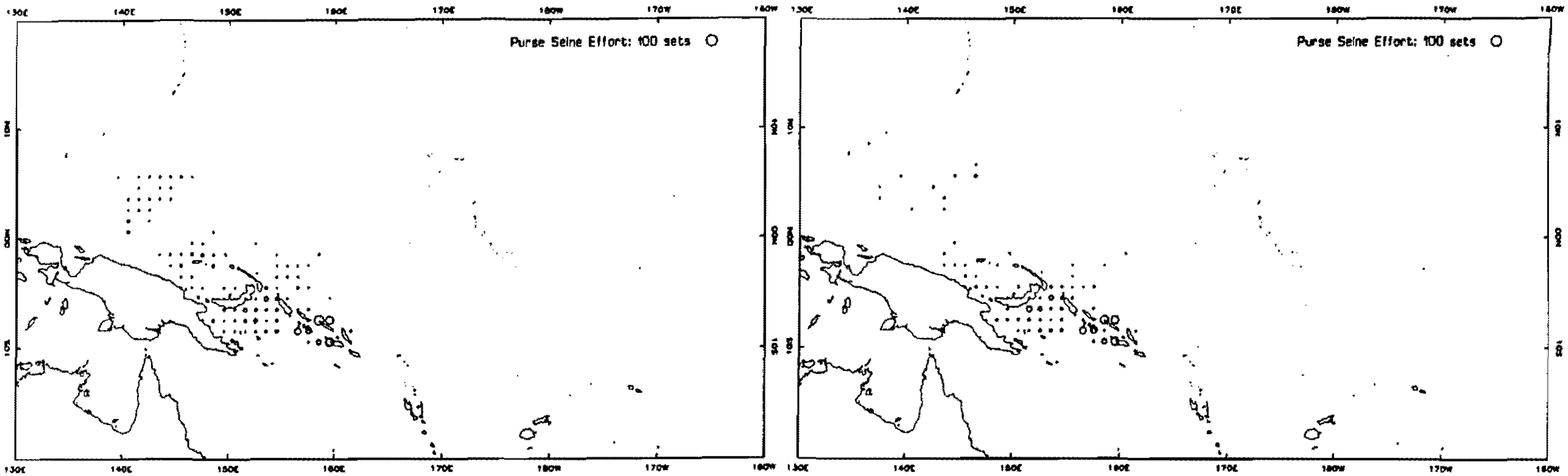


Drifting FAD; 3rd quarter

Drifting FAD; 4th quarter

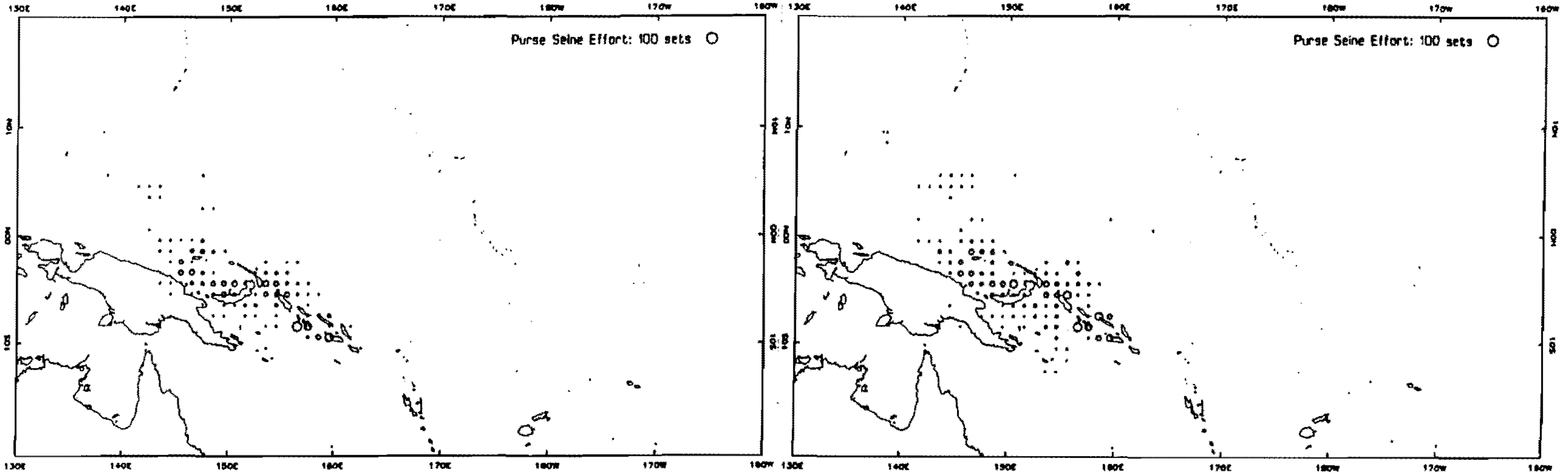
Figure 19. Geographical distribution of drifting FAD purse seine sets, by quarter, 1979-1991.

Figure 20. Geographical distribution of anchored FAD purse seinesets by quarter, 1979-1991.



Anchored FAD; 1st quarter

Anchored FAD; 2nd quarter



Anchored FAD; 3rd quarter

Anchored FAD; 4th quarter

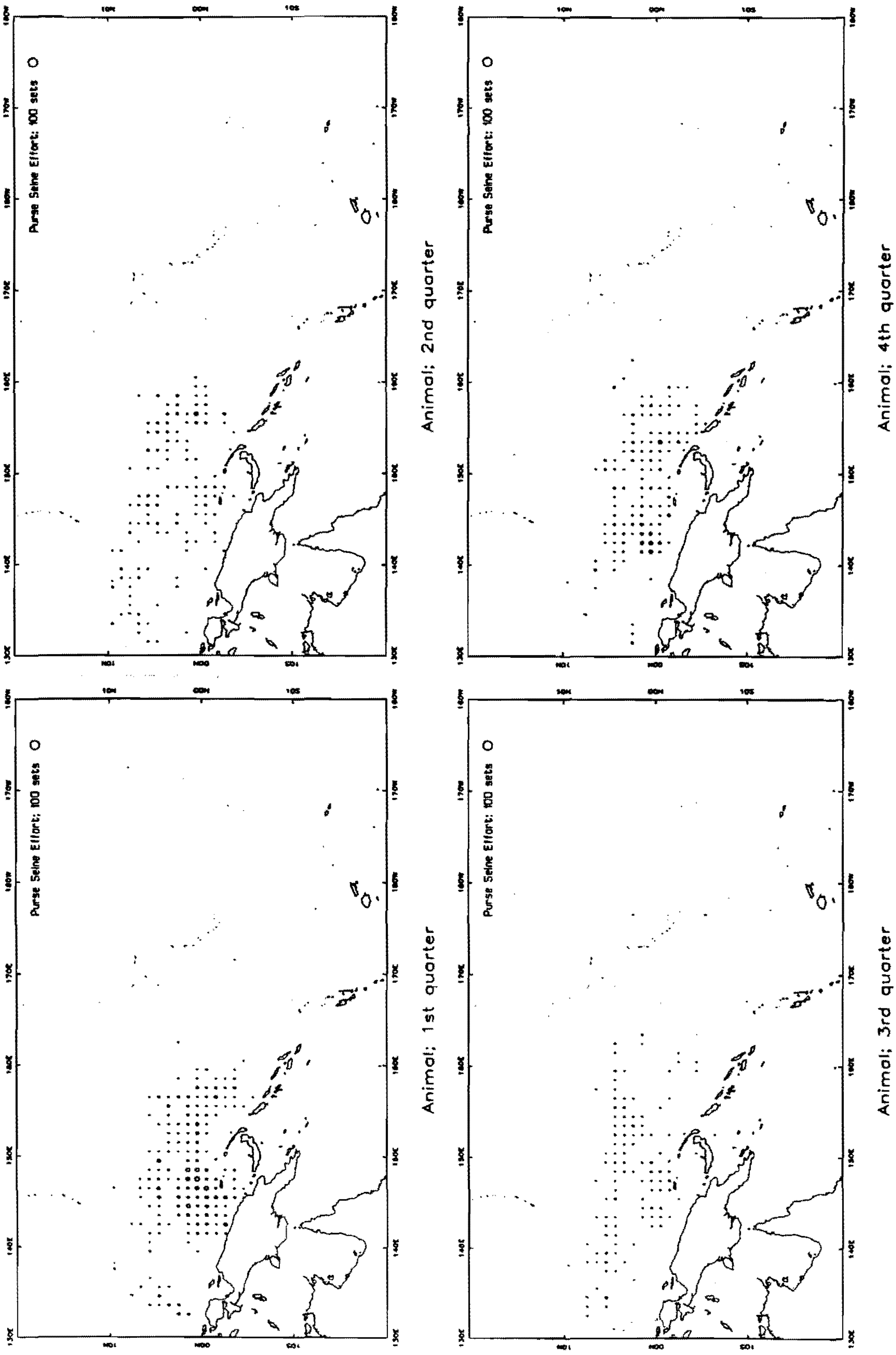


Figure 21. Geographical distribution of animal sets by purse seiners, by quarter, 1979-1991.

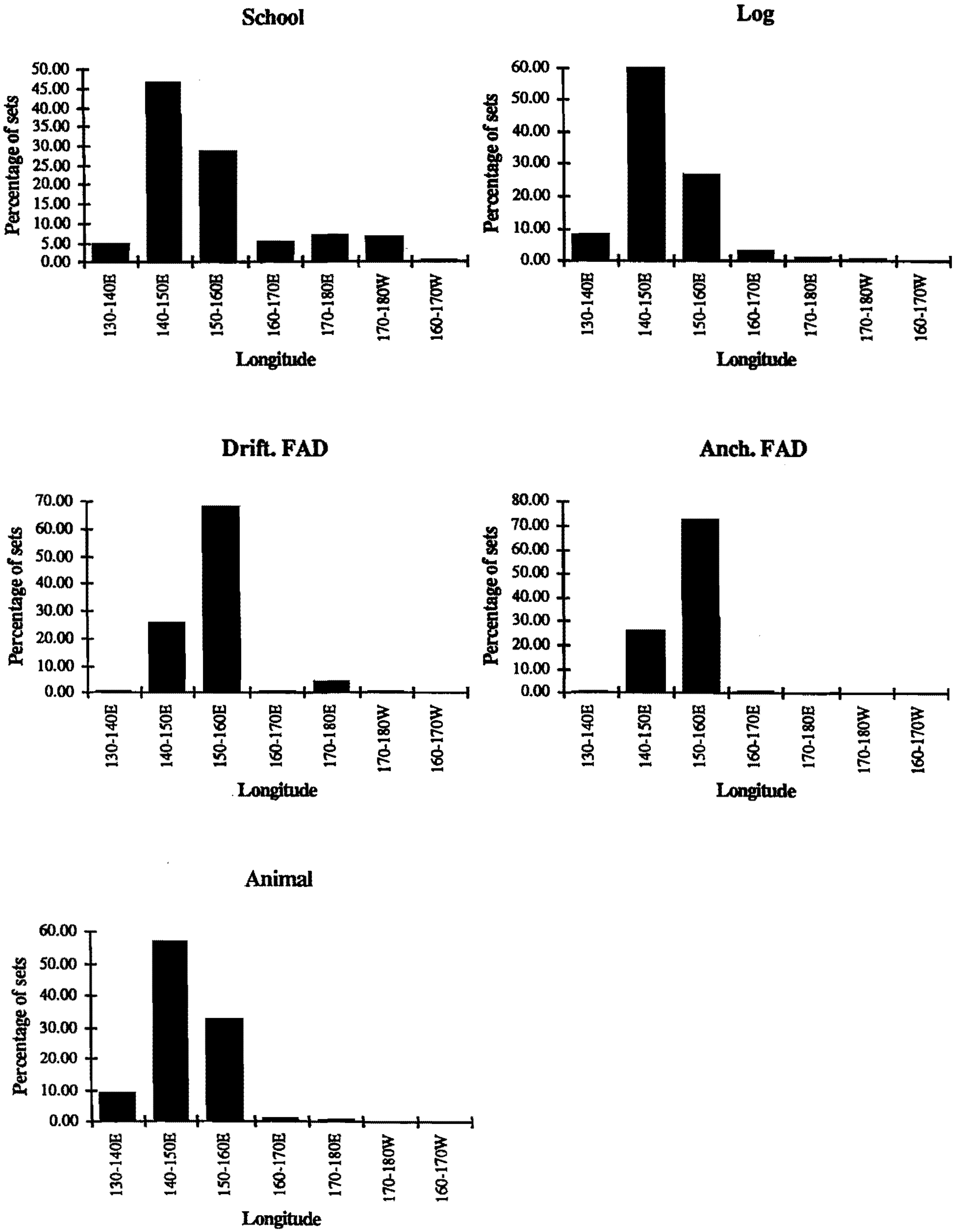


Figure 22. Distribution of purse seine sets, by longitudinal bands.

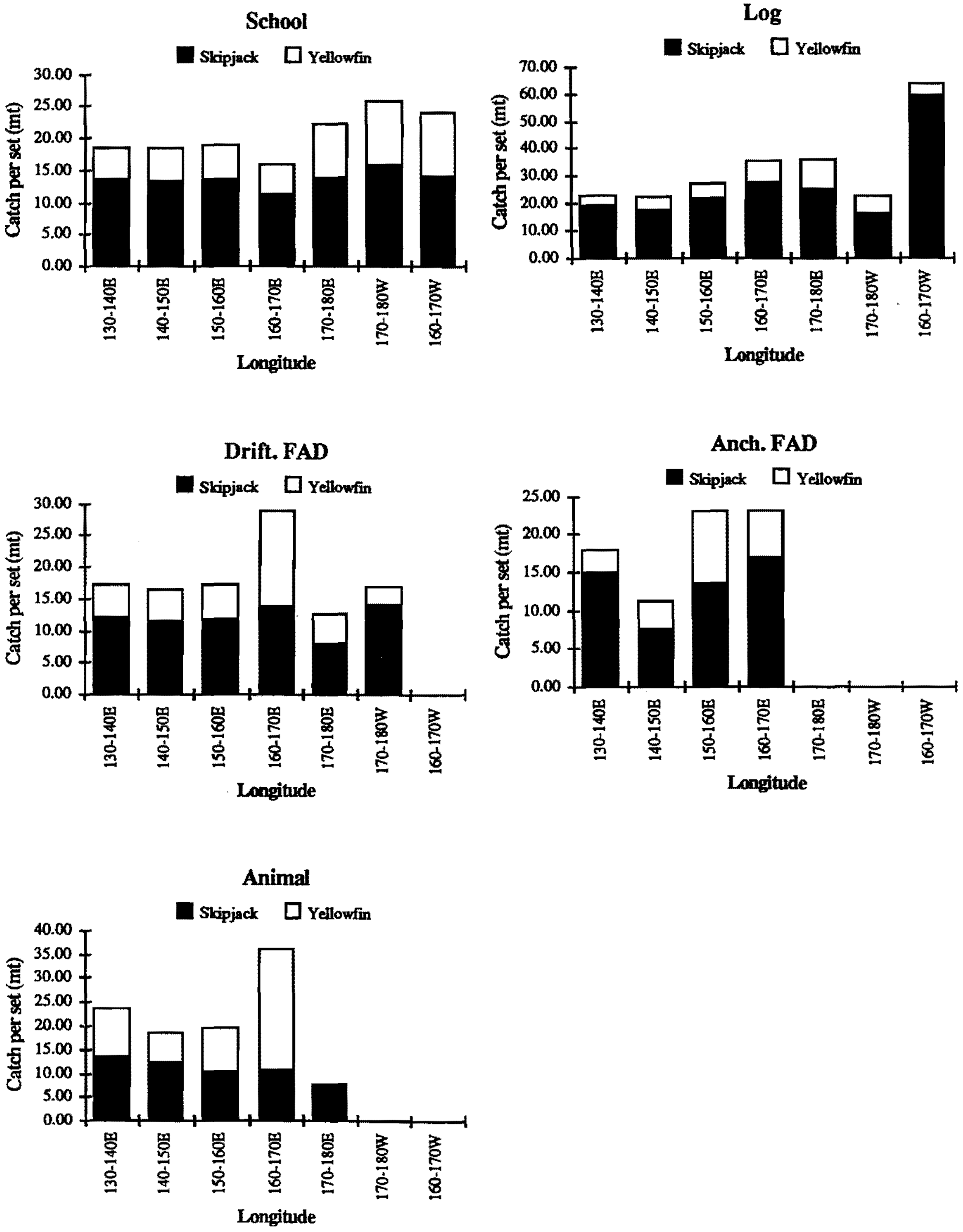


Figure 23. Distribution of purse seine catch per set, by longitudinal bands.

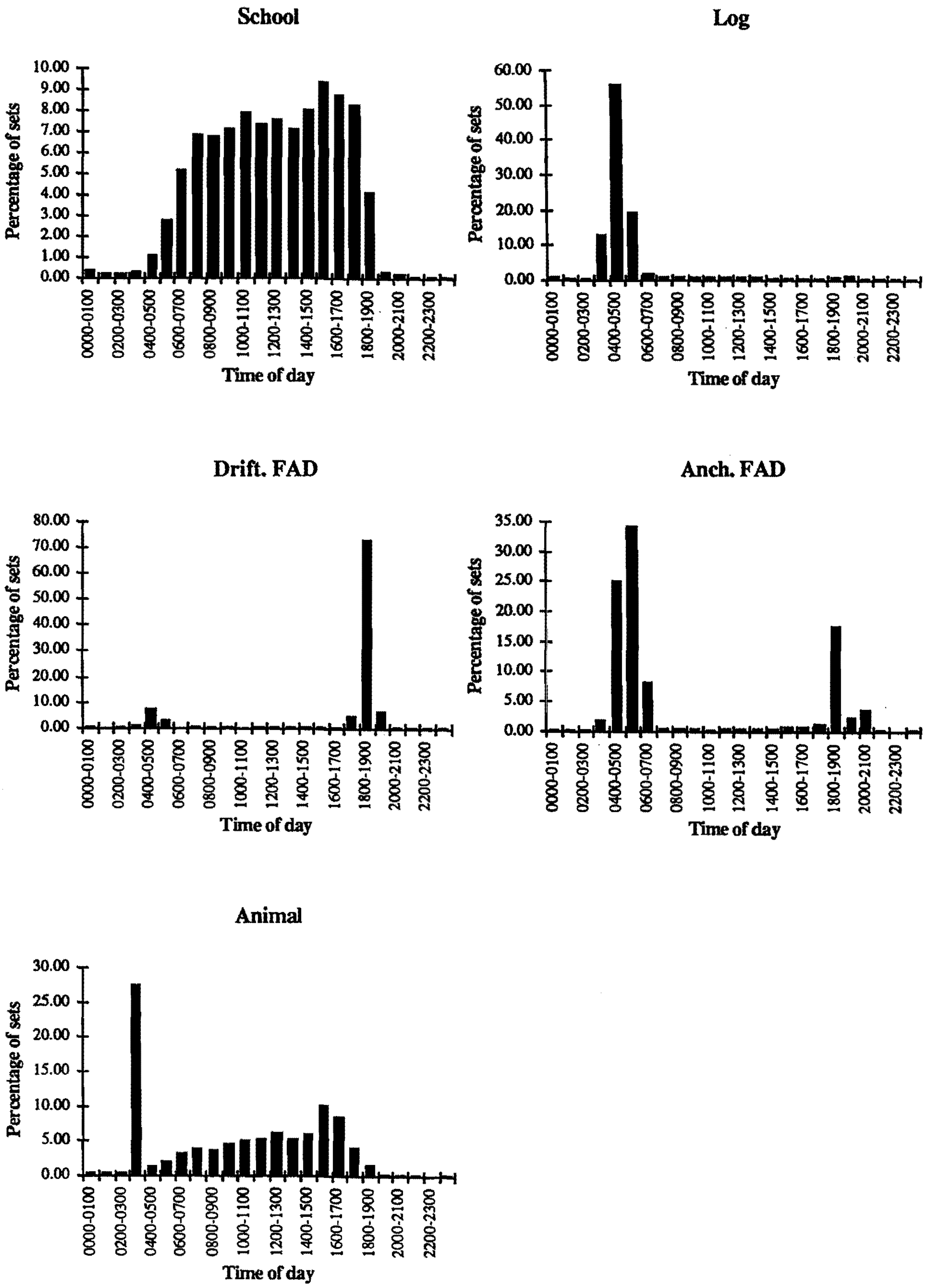


Figure 24. Distribution of purse seine sets by time of day.

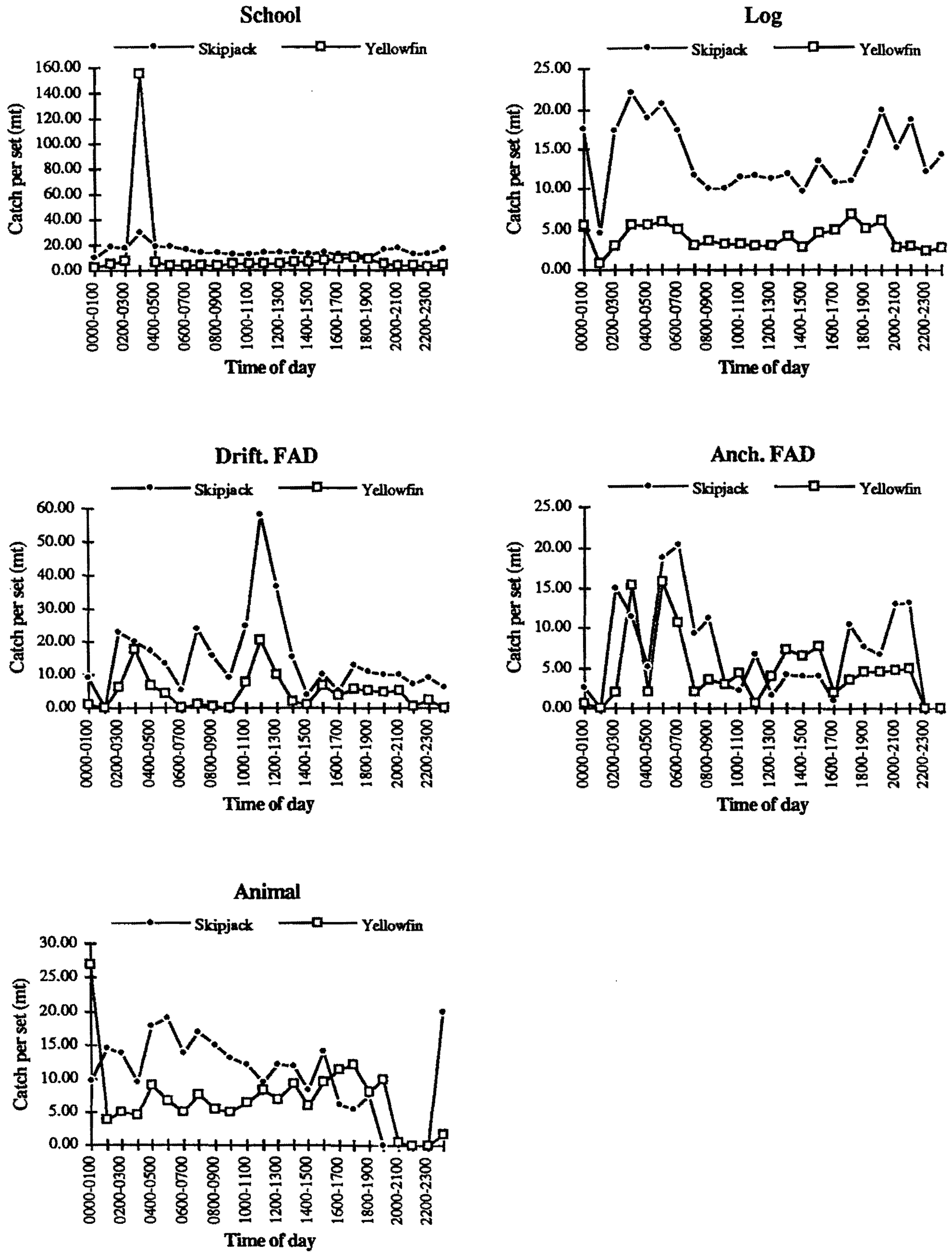


Figure 25. Distribution of purse seine catch per set by by time of day.

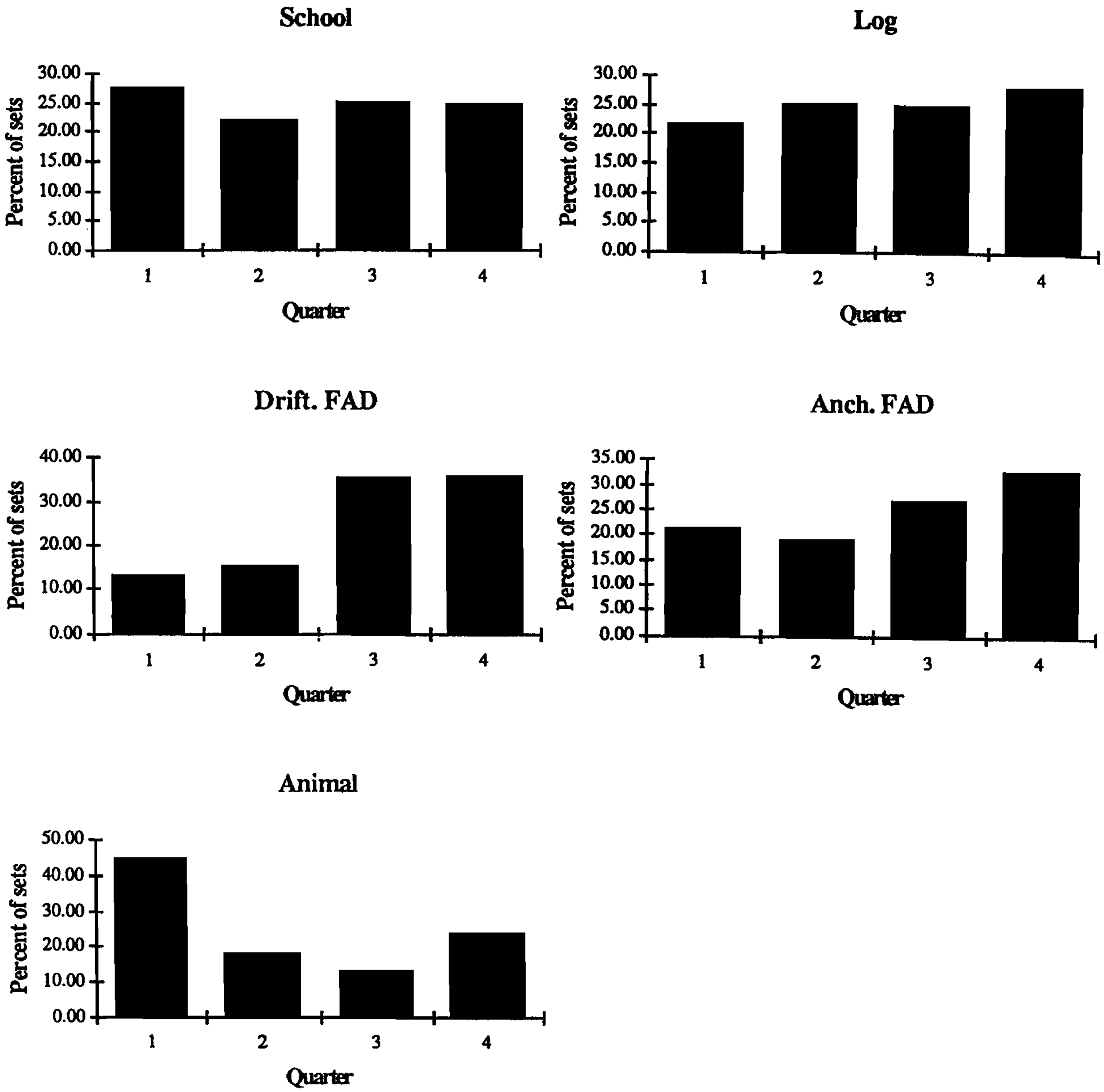


Figure 26. Distribution of purse seine sets, by quarter.

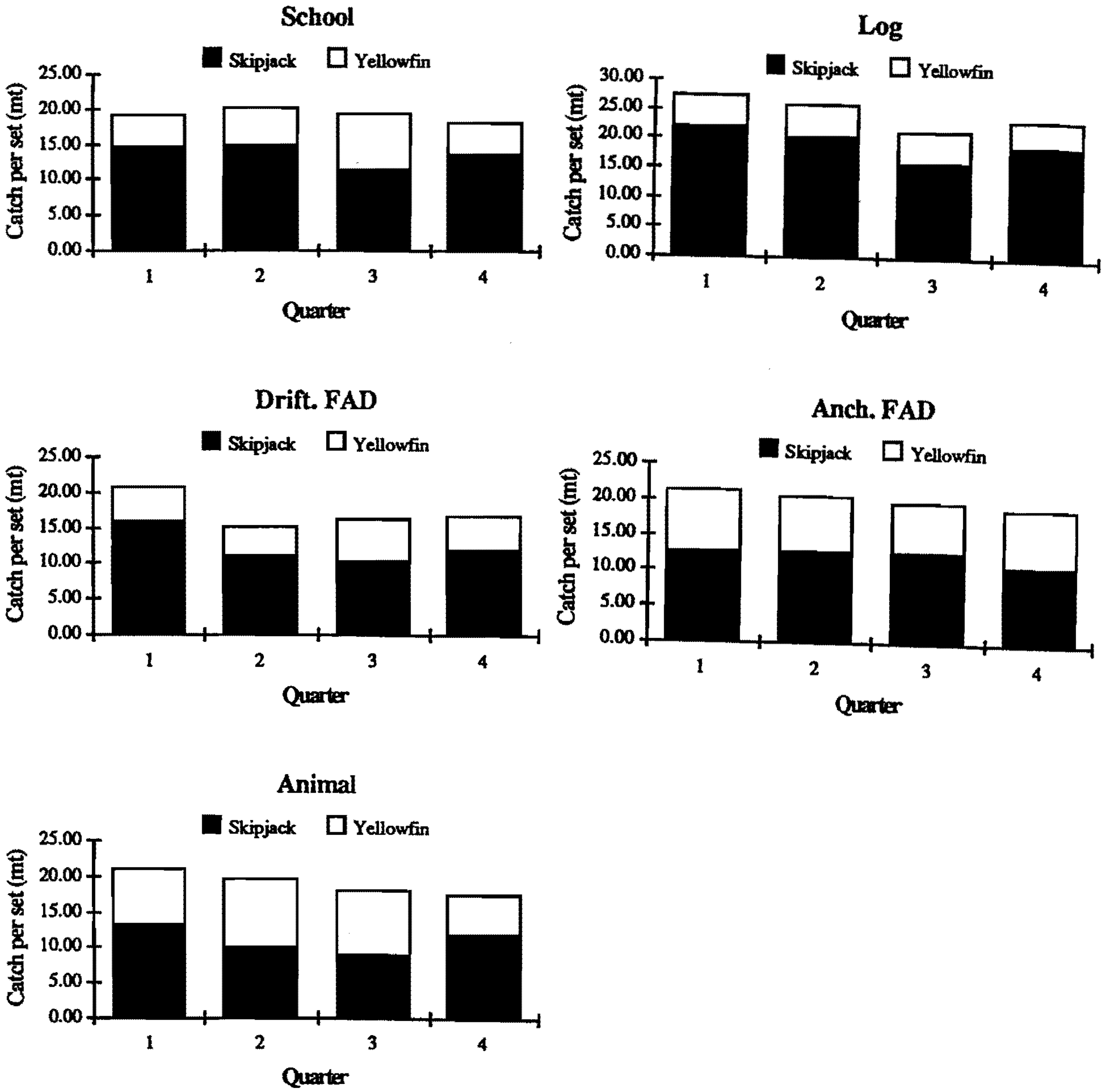


Figure 27. Distribution of purse seine catch per set, by quarter.

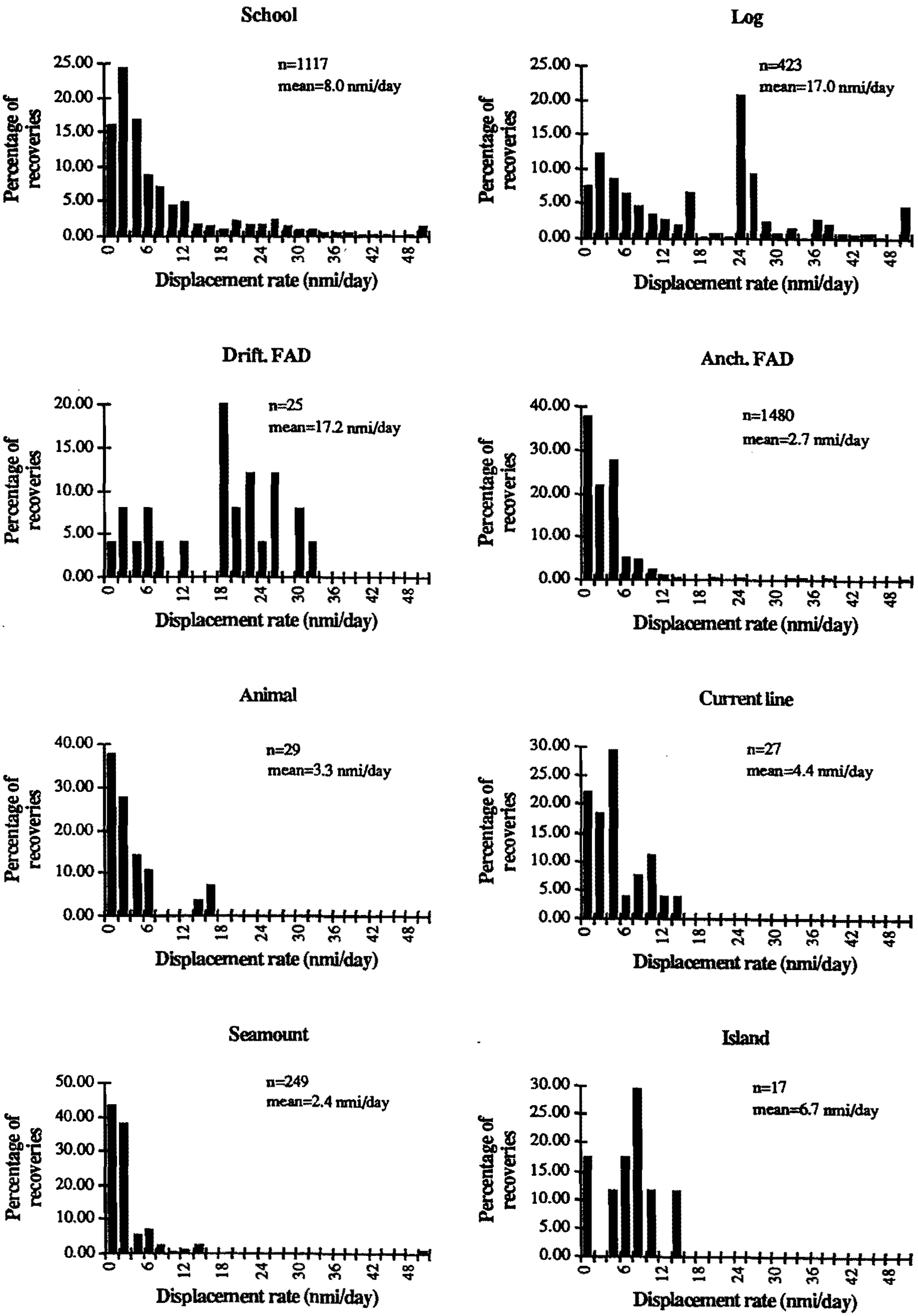


Figure 28. Displacement rate histograms for skipjack tagged from different associations.

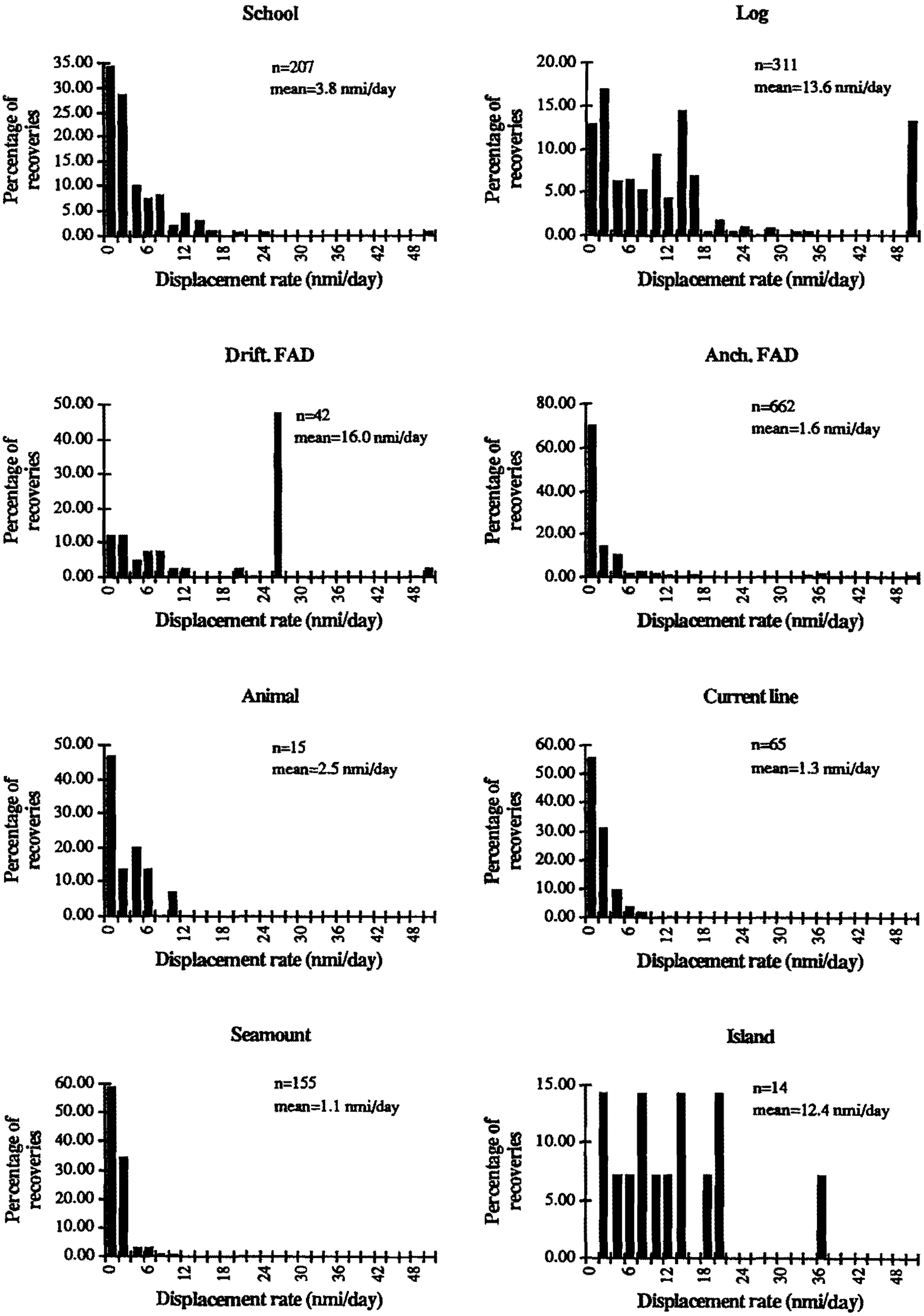


Figure 29. Displacement rate histograms for yellowfin tagged from different associations.

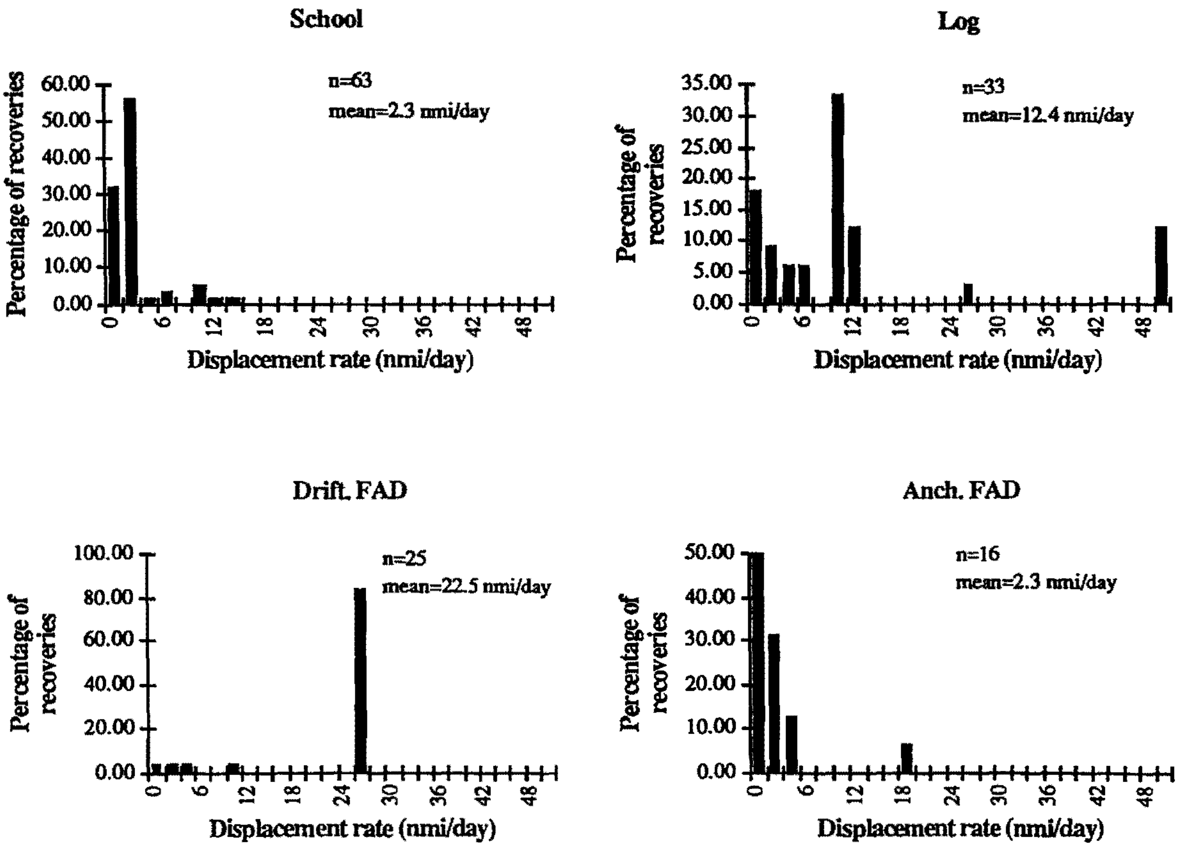


Figure 30. Displacement rate histograms for bigeye tagged from different associations.

ASSOCIATION OF FAUNA WITH FLOATING OBJECTS IN THE EASTERN PACIFIC OCEAN

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ABSTRACT

In 1987, the Inter-American Tropical Tuna Commission (IATTC) started a program to study the fauna associated with floating objects in the eastern Pacific Ocean (EPO). Observers aboard tuna vessels record the characteristics (shape, size, nature) of floating objects, and estimate the abundance (in numbers, biomass, or catch) of target and non-target species. One of the objectives of the program is to investigate the association of young yellowfin tuna and other species with floating objects in relation to possible drift patterns and migration cycles in the EPO.

An analysis of species composition data for 1987-1991 in these samples of fauna associated with floating objects was carried out. The data are limited in time and space to the range of the tuna fleet. The analyses used both presence/absence data of 39 species and/or groups and a relative index of the frequency of occurrence of schools of fish and/or individuals in 44 areas; biomass data were not included. As a first step, a number of association and covariance indices were computed by species and by sampling areas. In the second stage of the analyses, distance coefficients were calculated for sampling areas and a cluster analysis performed. The results show that overall frequency of occurrence tends to be higher, and species composition more diverse, near the upwelling coastal and nearshore waters of Central America, and in particular the Panama Bight. They also show that the species composition of epipelagic faunal groups varies by area in the EPO. Although the most commonly observed species and/or groups are found throughout the EPO, the coastal waters of Central America is the only area with the full complement of species. The patterns of faunal composition off Mexico, the Revillagigedo Islands, and the offshore region west of 120°W appear to be somewhat different, but these areas share many species. The frequency of occurrence and species composition in the areas south of the equator and around Baja California are different from those in the rest of the EPO. The species forming the nucleus of the association are dorado, yellowfin, skipjack and several shark species. They covary positively among them and with most of the other species. Sea birds covary negatively among them and with most species.

This heterogeneity in spatial distribution and species composition may reflect environmental conditions, including water masses, temperature, and coastal precipitation, as well as biological interactions. These results show that despite strong ocean circulation patterns and the consequent transport of eggs, larvae, and juveniles, some of these epipelagic populations may show incomplete mixing in the EPO. It is suggested that many species may use floating objects as links between islands and seamounts along their movement patterns. More definite

conclusions will require a better collection scheme for biomass data and an analysis of environmental information.

INTRODUCTION

The association of fish with floating objects of various kinds is a well- known phenomenon (Mortensen, 1917; Uda, 1933, Kojima, 1960a, 1960b; Besednov, 1960; Gooding and Magnuson, 1967; Hunter and Mitchell, 1967, 1968; Hunter, 1968; Dooley, 1972; Yesaki, 1977; Brock, 1985; Rountree, 1987). The species associated with floating objects in the eastern Pacific Ocean (EPO) (Figure 1) have been little studied in a systematic way (Hunter and Mitchell, 1968; Greenblatt, 1979; Au, 1991).

The area covered by this study is limited to that part of the EPO covered by the international purse-seine fleet, from approximately 30°N to 20°S and offshore to 150°W, and the term EPO as used here refers only to this area. In the EPO, small yellowfin tuna (*Thunnus albacares*), skipjack tuna (*Katsuwonus pelamis*), and other pelagic species are frequently found associated with floating objects during the course of purse-seine fishing activities (Greenblatt, 1979; Cole, 1980; Forsbergh, 1980). Most of the objects are logs of natural origin, but there are also diverse natural and man-made objects such as plastic refuse, wooden planks, fishing nets, and carcasses of whales and other large animals. Most logs in the EPO come from the tropical forests of Central America and the west coast of South America; trees are carried out to the sea by rivers, where they drift with the wind and currents until they become so waterlogged that they sink (Hall *et al.*, review article, this volume).

The purse-seine fishery in the EPO also exploits tunas associated with dolphins, and tuna schools not associated with either floating objects or dolphins. The spotted dolphin (*Stenella attenuata*), spinner dolphin (*S. longirostris*), and common dolphin (*Delphinus delphis*) are the most important species of dolphins involved in these multi-specific aggregations. Many other dolphin species are also found associated with tunas, but much less frequently (Perrin, 1968, 1969; Allen, 1985; Au and Perryman, 1985; Au and Pitman, 1988).

Faunal aggregations in the epipelagic regions of various oceans have been studied in a general way by Parin (1970), Legand *et al.* (1972), Roger and Grandperrin (1976), Vinogradov and Shushkina (1985), and Longhurst and Pauly (1987); the biogeography of pelagic ecosystems has been described by McGowan (1974). The faunal aggregations associated with the three modes of purse- seining in the EPO are diverse, and include not only dolphins but also many species of tunas and other large fish, sharks, billfish, sea turtles, and many species of seabirds and small fish (Anonymous, 1991). The purse-seine fishery for tunas in the EPO therefore affords an excellent opportunity for studying the ecology of these epipelagic aggregations, and the fishery for tunas associated with floating objects offers the additional opportunity of studying the role of these objects in the ecology of these aggregations. A systematic investigation of the spatial and temporal role of floating objects on structure, function, and patterns of these multi-specific associations has not been undertaken to date. Such a study could have implications for the study of species dispersal and biogeography and for fisheries assessment of many commercially-important species.

The objectives of the present paper are to use the data on species aggregations around floating objects in the EPO to determine (1) which species are present, and examine the relationships among them, and (2) their distribution and spatial patterns. The identification and characterization of epipelagic communities in the EPO is part of the program to investigate the association of young yellowfin tuna and other species with floating objects in relation to possible drift patterns and migration cycles in the EPO.

METHODS

The Inter-American Tropical Tuna Commission (IATTC) places observers aboard tuna purse-seine vessels of the international fleet in the EPO to record data on tuna catch and the incidental mortality of dolphins. In 1987, the IATTC started a program to study the community of fauna associated with floating objects in the EPO. The observers record the characteristics (shape, size, nature) of floating objects, and estimate the abundance (in numbers, biomass, or catch) and size ranges of target and non-target species involved in sets on or sightings of such objects.

Data for this study were gathered in the course of 497 fishing trips made from 1987 to 1990. Of the total of 5,518 individual records of observations of floating objects, 2,793 (50.6%) were sets and 2,725 (49.4%) were sightings that did not lead to sets. The following analyses were carried out on this data set:

1. Many sighting records were not considered valid observations and were omitted from further analyses. All remaining records in the area under study (Figure 1) were pooled (n=5349; 2793 sets, 2556 sightings), and the area was divided in 44 5°-squares. Each square was considered a basic sampling unit (SU); for most analyses, only squares containing more than 10 records were used.

2. The community associated with floating objects was reduced to 39 taxa (species/groups, or SP) by pooling individual species with low sample sizes (n <20) and/or of doubtful identification.

3. Two matrices (SU by SP) were built with these data: a) a presence/absence (P/A) ecological matrix, and b) a matrix based on the relative frequency of occurrence (RFO). For each area and SP, the RFO was calculated as the proportion of the number of records of a particular SP to the total number of records in the area (sets and sightings combined). These matrices were the basic units of analysis.

4. To look at the spatial distribution of the relative frequency of occurrence, the RFO matrix was used to prepare distribution maps for each SP considered.

5. To study interspecific relationships, Jaccard and Ochai indices of association (Janson and Vegelius, 1981; Hubalek, 1982), a pairwise chi-square test, and an overall test for association (Schluter, 1984) were calculated for the P/A matrix. A plexus diagram (McIntosh,

1978) was prepared for selected groups. The RFO matrix was also used to look at interspecific covariation: both Pearson's r and Spearman's rank correlation coefficients were calculated, excluding all areas in which both species were absent.

6. To study faunal resemblance between areas, Jaccard and Ochai indices were calculated for all the SU, and two distance coefficients were also computed from the RFO matrix: the percent-dissimilarity (PD) and chord distance (CRD) indices (Ludwig and Reynolds, 1988).

7. A cluster analysis was performed on the areas of the RFO matrix, using the CRD coefficients. A linear combinatorial equation (Lance and Williams, 1967) and group-average, centroid (weighted and unweighted), and flexible techniques were used for the cluster analysis.

RESULTS

The location of sightings and sets on floating objects is shown in Figure 2. Sightings are evenly distributed throughout the area, with a large concentration along the Central American coast and in the Panama Bight in particular. Sets are also concentrated along the coast of Central America, particularly near Costa Rica and in the Panama Bight; they are less common in the rest of the region. Sightings are more common than sets in the areas off Mexico and along the Baja California peninsula.

The sample size and areas included in the analysis after pooling both data sets by 5° squares are shown in Figure 3. Most log fishing is coastal, so sample sizes tend to decrease with distance offshore. Most observations of floating objects took place near the coast of Central America and the Pacific coast of Colombia, but there were also many observations northwest of the Galapagos Islands and off Central America west of 100°W. The number of records is relatively low off the coast of Mexico. Observations of floating objects were recorded as far offshore as 140°W, mostly along 10°N.

The species/groups most frequently found associated with floating objects are listed in Table 1. Some of the categories include several species or groups, and not all species recorded are included, but rather those groups of greatest importance in the purse-seine fishery. Figure 4 shows the proportions of the major groups relative to the total number of records. The most frequent species in these groups is the dorado, but sea birds and sharks (as a group), yellowfin and skipjack tunas, baitfish (usually small forage fish), and triggerfish are also important. Observations of black skipjack, frigate tunas, billfish, wahoo, and sea turtles associated with floating objects are less frequent. Records of marine mammal are extremely rare: only 24 cases were reported, many of them involving small groups of rough-toothed dolphins, *Steno bredanensis*.

Species patterns

Frequency of occurrence

Figures 5 to 11 show the distribution of each species/group, by 5° square, and the proportion of records that included a particular SP in a given SU. In general, of the 39 SP considered, only a few show consistently high values for all the areas. Dorado and unidentified sharks appear in all areas with at least 10 records, and yellowfin and skipjack are present in most of these areas. However, a proportion of 0.3 or more for a particular SP in an area is relatively rare, especially for non-target species.

Figure 5 shows the distribution of tunas. The RFO of both yellowfin and skipjack is high everywhere, with the exception of an area off Mexico where fishing on dolphins predominates (Hall *et al.*, review article, this volume). The smaller tunas (black skipjack and frigate tunas) also show a wide distribution, but their highest RFOs are found mostly in coastal areas along Central America. Bigeye tuna is found predominantly south of the equator, due probably to the influence of the cold Peru Current. The distribution of bonito is coastal, but the number of samples is very low.

Figure 6 shows the distribution of other large fish. Dorado, wahoo, and rainbow runners/yellowtail are widely distributed. Dorado is the species most frequently found in these multi-specific assemblages, and its RFO is high throughout the tropical EPO; it is particularly frequent in the area east of 105°W and south of 5°N, although it is also found offshore. The lowest RFO indices for dorado are in the dolphin-fishing area of Mexico. The distribution of RFO for wahoo is similar to that for dorado, but the values are lower. Rainbow runners/yellowtail were reported everywhere except two areas north of 15°N and five south of 0°. Other large fish are present mostly in the nearshore and coastal areas of Central America. Marlin are evenly distributed, with no clear areas of high values. This distribution contrasts with that of other billfish, which is clearly coastal, almost exclusively east of 100°W.

The distribution of unidentified sharks (Figure 7) is similar to that of dorado. It is widespread, but most important south of 15°N, with low RFO values in the coastal area of Mexico; some of the southern areas also have high RFO values. Blacktip and whitetip sharks are also widely distributed, although the latter seem to be more frequent in the nearshore and offshore areas. Hammerhead sharks and rays are found almost exclusively east of 110°W.

RFO values for seabirds are shown in Figures 8 and 9. Boobies are found mostly in the nearshore and coastal areas; masked boobies are also frequent south of 5°S, while red-footed boobies are typically coastal. Frigate birds are frequent south of the equator, and were not reported west of 120°W. Sample sizes for other birds are smaller. Shearwaters are frequent offshore and along the coast of Central America, but are not present in the nearshore regions.

RFO values for triggerfish, baitfish, and other small fish are very similar (Figure 10). Triggerfish show high values between the equator and 15°N and as far offshore as 140°W. Small baitfish are more frequent in the coastal areas, but there are some high rates in offshore areas. The RFO of sea turtles is fairly even throughout the region, except for some high values near the Galapagos Islands and around the tip of Baja California. This distribution pattern was not observed for any other SP. The association of marine mammals with floating objects are rare; the few observations reported were made mostly near the coast and in the area off Mexico.

As might be expected from the circulation patterns in the EPO, floating objects with acorn barnacles attached, and which have therefore been in the water for some time, are concentrated in the nearshore and offshore areas (Figure 11), although they are present almost everywhere. Objects with gooseneck barnacles and algae are more frequent in the southern areas and the peripheral areas south of 10°N, suggesting a relationship with the Peru Current. RFO values for crabs on logs are very low, but crustaceans are found associated with floating objects everywhere except in the Baja California area.

Interspecific association

The overall association among the 39 SP is positive. The value for Schluter's variance ratio is 335.7, so the null hypothesis of no association among the 39 SP is rejected at a = 0.001; as expected, it is highly unlikely that the species/groups are independent.

SP by SP matrices were prepared for values of chi-square, and the Jaccard, Ochai, and Dice indices, and for Pearson and Spearman correlation coefficients on all 741 possible pairwise combinations (N = SP(SP-1)/2). Table 2 shows the number and percentage of significant pairs or high values for each matrix. Only pairs of SP significant at a = 0.001 or a = 0.01 were considered further.

Chi-square tests of independence of occurrence performed on the presence/absence data show several significant relationships for most species/groups. The exceptions are the SP with very low sample sizes, such as bonito and marine mammals. Some relationships are evident: small baitfish, triggerfish, and other small fish tend to be found together; marlin tend to be found with small baitfish and some species of sharks; other billfish are associated with large fish and sharks; and the joint occurrence of skipjack and yellowfin is significant ($\alpha = 0.01$). The distribution pattern of sea turtles does not seem to match those of other species, as none of its values is significant.

The Jaccard Index (JI), which measures the strength of the associations between species, is high for most pairs of SP. Again, the exceptions are the SP with the smallest sample sizes. Many SP, including most sea birds, show neither high nor low JI values. The relationship among triggerfish, baitfish, and other small fish is again important; dorado and unidentified sharks show high values between themselves and with most SP, and especially with yellowfin, skipjack, and wahoo; the relationship between yellowfin and skipjack is strong, as is their relationship with acorn barnacles, seaweed, and gooseneck barnacles.

The results of the covariation of the RFO index between pairwise combinations were similar for both Pearson and Spearman's correlation coefficients; most of the significant coefficients are positive. However, many sea birds show a negative covariation with dorado, billfish, and sharks. The target species, yellowfin and skipjack, show a strong tendency to covary positively. However, the coefficient between dorado and skipjack is highly significant, whereas that between dorado and yellowfin is not. The coefficients among triggerfish, small baitfish, and other small fish are low and not significant, despite their overall association.

The SP pairs considered most important are summarized in Tables 3-5. Table 3 includes those pairs considered more important because of high chi- square or JI values and significant correlation coefficients. Yellowfin, skipjack, dorado, and unidentified sharks form the nucleus of the multi-specific aggregations found associated with floating objects. Dorado shows also significant relationships with bigeye, wahoo, rays, and acorn barnacles. Bigeye tuna and frigate birds share the southern areas and covary positively. Many important pairs of SP with negative covariation include seabirds, invertebrates, and sharks with other large fish and billfish.

Table 4 shows the pairs of SP with high chi-square or JI values but non-significant correlations. Many of these SP have similar spatial distributions, but apparently their biological interaction is low, because their correlation coefficients are not significant. The most notable pair is dorado and unidentified sharks, which occur together in all areas studied, but their RFO is not related. The same is true of the group of triggerfish, baitfish, and other small fish and of marlin, small baitfish, and whitetip sharks. It is possible that these species occur together around floating objects only because they are drawn to the same stimulus, and are thus aggregated by the presence of the floating object or the physical and biological characteristics it may signal (cf. Fedoryako, 1982; Hall *et al.*, this volume). This has been hypothesized for the association of yellowfin and skipjack (Yuen, 1963). However, the coefficients used in this study are only testing for linear relationships; it is possible that many biological interactions are non-linear and would remain undetected by this analysis.

Table 5 shows pairs with low chi-square or JI values and high covariance. The spatial distribution of many of these pairs is often dissimilar, but they probably interact when found together. Important pairs include yellowfin with black skipjack and marlin; skipjack and bigeye; wahoo and whitetip sharks with triggerfish and rainbow runners/yellowtail. As before, RFO values for seabirds tends to covary negatively with those for sharks and large fish. Due to the low sample sizes, the pairs involving marine mammals and bonito are considered less important. The most important relationships are depicted in the plexus diagram in Figure 12. Dorado, yellowfin, skipjack, and sharks form the nucleus of the aggregation; sea birds tend to covary negatively with many species.

Spatial patterns

Area resemblance indices

Jaccard and Ochai indices yielded similar results for area resemblance. The Jaccard Index was calculated using the P/A matrix, and determines the proportion of shared SP among SU. The value of the index varies from 0 (no resemblance) to 1 (exact resemblance). A summary of results from the JI is shown in Figure 13.

At a JI value of 1.0, a "core" or central area east of 95°W north of the equator (Areas A and B) is clearly defined. This is the only region in which all species/groups recorded were present. The two areas which form this core area are slightly different: Area A is more coastal, and encompasses the Panama Bight, while Area B is a more nearshore zone just north of the Galapagos Islands. At a JI value of 0.9, the core area (Area A) encompasses all the Central America coast west of 100°W; at this index level no areas north of 15°N or south of the equator are included. A JI value of 0.8 adds a small area south of the equator to the core area, and another area around the Revillagigedo Islands (Area C), centered at 15°N and 112°W. A small area west of 120°W shares more than 80% of species with both Areas A and C. At a JI level of 0.7, most of the SU are included in one homogeneous group; the exceptions are the peripheral areas (SU 24, 25, 33, 39, 41, and 43 in Figure 3), which also have low sample sizes. The Baja California region seems to have a different faunal component, as the proportion of species it shares with the rest of the EPO is relatively small. The areas south of the equator share more species with the core area than with the rest of the region. Faunal assemblages in the offshore area east of 120°W appear to be a mixture of those in the core and the Revillagigedo Islands areas, as contiguous SU in the region share more species with one or other of these two areas.

Distance indices

The percent-dissimilarity (PD) and chord distance (CRD) indices, computed using the RFO matrix, show similar patterns to those obtained from presence/absence data. Both indices show strong agreement, despite the fact that they emphasize different aspects. Since the CRD index was used for cluster analysis, the results obtained with this index will be further reviewed below. The core area identified with JI is well defined, as all the 5° squares in the area show low (<0.2) values. The southern, Revillagigedo Islands, and offshore areas are also well distinguished by these indices, which also show (1) that some of the 5° areas in the southern region are more similar to the core area than to the rest of the EPO; (2) an apparent relationship between the offshore area and the core area; and (3) that the RFO values in the Baja California area are most dissimilar to the rest of the region.

Cluster Analysis

The cluster analysis performed with the CRD index and the centroid (unweighted) technique did not reveal clear spatial patterns. The centroid (weighted) technique proved more useful in identifying such patterns, and the flexible (b = -0.25) and group-average strategies resulted in similar clusters. All the main areas described below are clearly identified using these three techniques.

The dendrogram resulting from the group-average strategy and the CRD index (Figure 14) shows the grouping of many SU into homogeneous clusters at levels below 0.5. The core, Revillagigedo Islands, and offshore areas identified with Jaccard's Index are clearly distinguished. The RFO values in some SU (9, 24, 1, 2, 8 in Figure 3) are so different that those areas do not enter into a cluster pair until very late in the analysis.

The results of the cluster analysis based on RFO values are consistent with those obtained with Jaccard's Index on presence/absence data, but are more detailed. Figure 15 shows the maps corresponding to several cluster levels.

At a cluster level of 0.25, several groups are evident: Clusters A (east of 95°W and north of the equator) and B (the Panama Bight coastal area) are similar to the core area identified with Jaccard's Index. Clusters C and D (off Nicaragua and off the Gulf of Tehuantepec, respectively) are also separated at this level. Cluster E suggests a linkage between the core area and the offshore region west of 115°W. A cluster level of 0.35 expands the core (A) and Revillagigedo Islands (E) areas; the latter now includes more transition areas between the core and the offshore areas. Cluster D remains the same, but two new areas appear, one off Mexico and the other south of the equator. The map for the previous cluster level (0.34) is included to show the coastal and nearshore components of the core region. A cluster level of 0.45 distinguishes the main areas in the region: the core area now includes the Revillagigedo Islands area, but the area between them (F) is clearly different. Most of the areas south of the equator now form one cluster (G), as does the important offshore fishing area west of 120°W (I). Peripheral areas begin to integrate (H). Cluster J suggests a linkage between the nearshore and the offshore regions. The map corresponding to cluster level 0.65 shows that the core and offshore areas (A) are more strongly related to each other than to the area off Mexico (F). The southern area is also different and influences some of the peripheral areas. The area off Mexico joins the rest of the EPO at a cluster level of 0.71 (A). At this level the southern area (G) is still different, and the California Current area (K) appears for the first time.

DISCUSSION AND CONCLUSION

The effects of the shape and size of the sampling units may have considerable influence over these results. The 5° squares used are not natural units and the techniques employed may not be detecting real patterns in the distribution or frequency of occurrence of the SP considered. However, it was judged that a 5° square is large enough to allow for large sample sizes, and yet also reflect accurately some of the underlying current patterns, distribution of water masses, and biological properties of the region (Hall *et al.*, review article, this volume). Nevertheless, many of the relationships revealed, especially with presence/absence data, are probably spurious. This is probably the result of both the effects of shape and size of sampling units and of the fact that circulation and transport (of eggs, larvae, juveniles and, in some cases, adults) tend to produce a complete mixing of species over the area. Thus, given enough time, all species would probably appear in all areas. This is a common problem with presence/absence data, but it probably has little effect on the frequency of occurrence, particularly in those areas with large sample sizes. This is likely the reason why Jaccard and Ochai indices show high values for most pairwise combinations.

The use of inappropriate chi-square values and the comparison of multiple pairwise values presents another problem: many of the tests in a large matrix will be significant just by chance (Ludwig and Reynolds, 1988). However, the multiple test performed (Schluter, 1984) was highly significant, so the overall positive significant relationship is probably true. This does not imply that all the species are part of a community or even part of a species assemblage. Some of these SP, such as dorado, yellowfin, skipjack, and sharks, are almost always present, but some are probably occasional visitors or associate with floating objects only in the areas in which they are very abundant.

The effect of pooling sets and sightings data should also be taken into account. Both data sets may be fundamentally different: for example, most sets on floating objects are made very early in the morning, while the distribution of sightings is evenly distributed during the hours of daylight (Hall *et al.*, review article, this volume). The spatial distribution of the two types of record is slightly different; off Mexico there are many sightings of floating objects but few sets are made. Thus, it is highly likely that the sampling of some species has not been adequate. For example, the relationship between yellowfin, skipjack, and small baitfish is not highly significant. One possible explanation for this is that yellowfin are seldom reported in sightings, and only when the fish are of small size or the school tonnage too low to be worth setting on, whereas small baitfish are frequent in this data set.

Relying on fisheries data means that there are no samples from outside the fishing areas. It is impossible to tell from this analysis whether floating objects and fauna occur together outside the fishing areas. However, the analysis of coastal vegetation, precipitation patterns, and oceanic circulation (Hall *et al.*, review article, this volume) indicates that most of the floating objects entering the EPO tend to concentrate and remain along the coast of Central America, the historical fishing grounds for the log fishery (Greenblatt, 1979).

In spite of all these factors, some of the spatial patterns and species relationships are highly significant. In a broad sense, the chi-square test indicates the possibility and the degree of spatial relationships, in other words, whether the species are found together more frequently than would be expected from random distribution. The correlation coefficients based on the RFO index may indicate biological interactions such as feeding and interspecific competition. However, from these data set it is not possible to distinguish between two species biologically associated to each other and a floating object, or just drawn to the same stimulus.

Studies of fish-aggregating devices indicate that the first species to appear in the aggregations are usually planktivores and/or juveniles of carnivorous species. Those species arriving later are mostly obligate predators (Hunter and Mitchell, 1968; Leontiev, unpub. ms.). In the EPO, the primary species/groups in the aggregations (Figure 12) are small yellowfin, skipjack, dorado, and sharks (probably silky sharks, *Carcharhinus falciformis*). These species are widely distributed, have high RFO values, and are important components of the epipelagic fauna. Samples of these species are probably also adequate for the RFO study, because they are important to fishermen. Dorado, small yellowfin, and skipjack are also the main species associated with floating objects in other oceans (Kojima, 1960a, 1960b; Besednov, 1960; Parin, 1970); this indicates the importance of these objects in the ecology of these key species. For example, yellowfin spawns within the EPO (Cole, 1980), and it is very likely that the association of young yellowfin tunas with floating objects is important in determining recruitment success. Skipjack, on the other hand, only infrequently spawns in the EPO (Forsbergh, 1980), and is caught relatively rarely in school sets and almost never in dolphin sets; its tendency to associate with floating objects is very strong. The association of some of these key species with "old" floating objects with barnacles and algae attached may also indicate a degree of "maturity" in the association.

A second faunal component, probably not as important as the first, but sometimes very common (especially in the sightings data, in which yellowfin and skipjack are nearly absent) is formed by triggerfish and small to medium fish such as rainbow runners, yellowtail, and wahoo. Triggerfish are also associated with other small fish and baitfish. These smaller species are probably a constant component in these associations, but they are not usually reported. They seem to be present in approximately the same areas, but since their correlation coefficients are low, apparently their biological interaction is not important.

Bigeye tuna are also important. The species shows some relationship with skipjack and dorado, but its biology is different to that of yellowfin and skipjack (Calkins, 1980), and its distribution is more southerly. It is probably taken incidentally only in association with floating objects in the EPO, but it may be more important in other areas. The smaller tunas, such as frigate tunas and black skipjack, seem to form a separate group, with close interactions only with small fish and brown boobies. This is probably a feeding relationship, although little is known of the food of these small tunas (Muhlia- Melo, 1980). The results suggest that these tunas are associated with the floating object, but perhaps not necessarily with the other key species in the association. The relationships between marlin, other billfish (mostly sailfish and swordfish), and other large fish are less clear. Marlins show a strong affinity with yellowfin and with sharks, particularly blacktip sharks, with which they share the offshore areas. Other billfish show a more coastal distribution, especially in the core area. They also show negative correlations with many other large fish, sharks, and seabirds: this may indicate some form of competition and resource partitioning among these predators. Many billfish caught on floating objects are juveniles; again, this shows the ecological importance of floating debris for many species.

Sample sizes for many bird species are small, due to the difficulty of identifying species and to undersampling, so it is difficult to identify clear patterns. However, most species show strong negative correlations among themselves, and also with several sharks and invertebrates. Since most of these birds forage in the surface and subsurface waters, this may indicate some type of interspecific competition among bird species and between sharks and sea birds.

The distribution of boobies is coastal; that of frigate birds is also coastal, but more southerly. In the inshore areas of the Panama Bight these two species are common near floating objects, and show strong negative covariation. Shearwaters are common offshore, where they associate with yellowfin, and probably with dolphins, in a complex interaction (Au and Pitman 1986, 1988). Negative correlation coefficients indicate that there are probably competitive interactions with boobies and other birds in this region.

The distribution and RFO patterns for sea turtles are quite different from those for the other groups. They show little affinity for most species, and seem to be found primarily near the large archipelagoes of the region, the Galapagos and Revillagigedo Islands. However, they occur relatively frequently even in the offshore region. Positive correlations are found with bigeye, due probably to the latter's southern distribution, where sea turtles are more frequent, and with invertebrates in the core area, perhaps due to trophic interactions. The lack of records of floating objects associated with marine mammals is the important result for this group. It is somewhat unexpected, given the importance of dolphins in the epipelagic zone in the EPO; the adaptive advantage other groups find in the association with floating debris is apparently minimal for dolphins. However, due to small sample sizes, little can be said about the relationships of marine mammals with other species in the association. Their distribution is coastal, and they are more frequent in the area off Mexico, where sets on floating objects are uncommon.

A number of other species are not recorded, due to purse-seine selectivity or because they are not conspicuous. Besednov (1960) and Hunter and Mitchell (1967, 1968) report many small species at different life stages associated with floating objects. Our sampling scheme is unsuitable for small fish. However, they are important as forage for other species, and in some cases they may be the only permanent residents around the floating objects.

Some of the spatial patterns in the distribution of species/groups are also clear: the presence/absence of taxa and their frequency of occurrence indicate three well-defined areas within the EPO:

1) The area around the Baja California peninsula is very different from the rest of the EPO. It is considered a different biogeographic region (McGowan, 1974; Ware and McFarlane, 1989) and its cold water usually does not mix with the eastern tropical Pacific (ETP) water (Figure 16), so this is not surprising (Wyrtki, 1966, 1967). Also, the generally dry weather along the coast past which the California Current flows in the EPO does not lead to many floating objects entering these areas. Most of the floating objects there are relatively short-lived kelp patties, typical of the California Current system.

2) The area south of the equator, which is influenced by the cold Peru Current. This result is also consistent with oceanography: this cold water seldom mixes with the warm ETP water, due to prevalent circulation patterns (Wyrtki, 1967), and this constitutes a biogeographic barrier for the distribution of many species from the southern areas. Some peripheral areas north of the equator and west of 110°W share species with the southern areas, because the current turns west along 5°N. In these areas there is probably some mixing of species from the ETP and the southern region, but most of the floating objects probably come from the ETP.

3) The warm-water tropical area, which probably consists of several subunits, as indicated by the association indices and cluster analysis. The core area is the only area in which all species are present; the number of species present in other areas decreases with distance from the core area (Figure 17). This result is consistent with the distribution of plankton and other pelagic fauna and of biologically-productive areas, (McGowan, 1974; Hall *et al.*, review article, this volume). As the floating objects are transported by water circulation from the Central American coast to the nearshore and offshore regions, the number of species/groups associated with them tends to become progressively smaller. These results may be related to density-dependent habitat selection: it is likely that the fitness of the most important species is higher in the core area, as this is probably the most favorable area for the survival of young and juveniles (MacCall, 1990). Such a mechanism has been shown to regulate not only population density and size but also community structure (Morris, 1988). This core area, which is also biologically rich, could thus be a generation and/or nursery region, and is probably crucial to the recruitment and population regulation of many of these populations.

The Revillagigedo Islands area is apparently another center of distribution for some species, and its biology and oceanography are different from those of the core area. For example, for models of yellowfin recruitment (Anonymous, 1991) it has been assumed that there is a cohort associated with the area that is independent of another cohort recruited in the core area. This could perhaps also be true of other species that reproduce in the area. The environment in the area shows a mixture of characteristics associated with the North Equatorial Current but also with the California Current (Hall *et al.*, review article, this volume). In addition, there are many islands and seamounts, where some fish species are very abundant. Historically, the area has provided good fishing grounds for many tuna species; large yellowfin are frequently caught there by sport fishermen.

The importance of the offshore area to the purse-seine fishery is seasonal, and most of the sets made in the area are dolphin sets (Hall *et al.*, review article, this volume). However, faunal associations suggest a link with the core area, since about 60% of the species in the core area are also present in the offshore region (Figure 17). The faunal composition in the offshore area is also similar to that of the Revillagigedo Islands area: in some cases the resemblance between SUs is almost exact. This is probably the result of transport of floating objects from the coast to the island area, and thence to the offshore region, by the North Equatorial Current flowing east to west.

The area off Mexico identified by cluster analysis matches the areas where dolphin fishing is most important (Hall *et al.*, review article, this volume). This could be due to the fact that the number of sets on floating objects in the area is relatively low, and thus most of the records are sightings, which tend to include less yellowfin and skipjack. The low number of sets may indicate a lesser availability of floating objects to the tunas, due to the relatively dry weather along the coast of Mexico. Alternatively, there may be a difference in habitat or in tuna behavior in this area, because most of the tuna caught in the region are associated with dolphins rather than with floating objects. Little is known of the associations of dolphins with species other than yellowfin in the EPO, although sharks and billfish are common in dolphin sets, as are seabirds (Au, 1991). Even less is known of the communities associated with floating objects, so it is hard to assess whether a particular species has the physiological and behavioral ability to switch between floating objects and dolphins. Some species, such as seabirds, could probably do this with relatively little effort, but others, such as triggerfish and sea turtles, may find it nearly impossible. Thus, the composition of the species associated with floating objects and with dolphins is probably quite different. Both types of floating objects (*i.e.*, "true" floating objects and dolphins) may be competing to attract the full complement of species available in the area.

These results show that floating objects probably play an important role in the ecology of many species in the EPO. They attract the epipelagic fauna in the region, in some cases probably most of the available species, although our sampling does not cover areas without floating debris. Some major characteristics of the epipelagic fauna associated with floating objects can be distinguished:

1) There is probably a greater diversity and abundance of fauna in association with floating objects (inanimate or alive) and the physical characteristics they may signal (*e.g.*, drift lines (Fedoryako, 1982)) than in the rest of the open ocean environment. Floating objects aggregate species otherwise dispersed in the pelagic environment. This phenomenon is probably similar to the aggregation of pelagic fauna around islands and seamounts (Parin *et al.*, 1985; Boehlert and Genin, 1987), as many of the same species are present near floating objects and around seamounts and islands (Klimley and Butler, 1988). It is also probably analogous to the aggregation of fauna around reefs and seagrasses in the coastal environment (Bell and Pollard, 1989).

2) Epipelagic fauna associate with floating objects for different lengths of time and/or at different stages of their life history (Kojima, 1960a). The abundance of juveniles of many species suggests that floating objects are important in the recruitment of many populations.

3) The species composition and relative frequency of occurrence of aggregations found associated with floating objects in the EPO probably depend on the proximity of the core area, islands and seamounts.

4) Aggregations of fauna in different areas (*e.g.*, the 5° squares used in this study) often vary in species composition, even when the areas are adjacent. This is probably related to circulation patterns and water masses (*e.g.*, the adjacent California Current and warm-water tropical area, or this latter area and the southern area).

It could be considered that floating objects behave essentially as free-drifting islands or reefs. The ecological role played by these "floating reefs" is probably different for different species, but the assemblage is dynamic, changing in space and time, and it shows some degree of organization. The aggregation may show different stages of development (characterized perhaps by different species composition or different size of the primary species), separated by weeks or months and by hundreds of miles (Vinogradov and Shushkina, 1985). Thus, we believe that the use of floating debris is adaptive for most species. Some may find shelter or food, but for most of the major components, floating objects signal areas of high productivity, because they originate at the mouths of tropical rivers, travel through biologically-rich coastal areas, and tend to accumulate in rich oceanic areas (Hall *et al.*, review article, this volume). In this way, floating objects could be used as "stepping stones" in movements by tunas, dorado, and other large fish. These "stepping stones" could link the major circulation features and migration paths with the numerous islands and seamounts in the region (Figure 18). For example, it is known that yellowfin and other large fish stop and spend some time at these highly-productive places during their movements (Parin *et al.*, 1985; Bohelert and Genin, 1987); Klimley and Butler (1988) and Klimley *et al.* (1988) have proposed such a model for the movements of hammerhead sharks and other pelagic species between seamounts in the Gulf of California. Pelagic assemblages around seamounts and islands separated by expanses of deep water are analogous to the associations between birds and mammals on oceanic islands. In this biogeographic sense, floating objects may be acting as free drifting islands, carrying a subset of epipelagic fauna between productive regions. Such an idea would be important from the point of view of dispersal and biogeography, and would also provide a unified approach for the study of the ecology of these assemblages.

LITERATURE CITED

Allen, R.L. 1985. Dolphins and the purse-seine fishery for yellowfin tuna. In: Beddington, J.R., R.J.H. Beverton, and D.M. Lavigne (eds). Marine mammals and fisheries. Allen and Unwin, Inc., Winchester, MD. Pp. 236-252.

Anonymous. 1991. Annual report of the Inter-American Tropical Tuna Commission, 1989. 270 p.

Au, D.W.K. 1991. Polyspecific nature of tuna schools: shark, dolphin and seabird associates. Fish. Bull. 89:343-354.

Au, D.W.K. and W.L. Perryman. 1985. Dolphin habitats in the eastern tropical Pacific Ocean. Fish. Bull. 83:623-643.

Au, D.W.K. and R.L. Pitman. 1986. Seabird interactions with dolphins and tuna in the eastern tropical Pacific Ocean. Condor 88:304-317.

Au, D.W.K. and R.L. Pitman. 1988. Seabird relationships with tropical tunas and dolphins. In: Burger, J. (ed) Seabirds and other marine vertebrates. Columbia University Press. New York. Pp. 174-212.

Bell, J.D., and D.A. Pollard. 1989. Ecology of fish assemblages and fisheries associated with seagrasses. In: Larkun, A.W., McComb, A.J., and S.A. Sheperd (eds). Biology of seagrasses. Elsevier, Amsterdam. Pp. 565-609.

Besednov, L.N. 1960. Some data on the ichtyofauna of Pacific Ocean flotsam. From "Works of the Institute of Oceanology [Trudy Instituta Okeanologii]. 41: 192-197.

Boehlert, G.W. and A. Genin. 1987. A review of the effects of seamounts on biological processes. In: Keating, B.H., Fryer, P., Batiza, R., and G.W. Boehlert (eds). Seamounts, islands and atolls. Geophysical Monograph 43: 319-334.

Brock, R.E. 1985. Fish aggregation devices: how they work and their place in fisheries enhancement. In: Stroud, R.H. (ed) Proceedings of The First World Angling Conference. Cap d'Agde, France. Sep 12 to 18, 1984. International Game Fish Association, Fort Lauderdale. Pp. 193-202.

Calkins, T.P. 1980 Synopsis of biological data on the bigeye tuna, *Thunnus obesus* (Lowe, 1839), in the Pacific Ocean. Inter-Am.Trop. Tuna Commn. Spec. Rep., 2: 213-260.

Cole, J.S. 1980. Synopsis of biological data on the yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788), in the Pacific Ocean. Inter-Am.Trop. Tuna Commn. Spec. Rep., 2: 71-212.

Dooley, J.K. 1972. Fishes associated with the pelgic sargassum complex, with a discussion of the sargassum communnity. Contributions in Marine Science, Texas University 16: 1-32.

Fedoryako, B.I. 1982. Langmuir circulations and a possible mechanism of formation of fish associations around a floating object. Oceanology 22: 228-232.

Forsbergh, E.D. 1980. Synopsis of biological data on the skipjack tuna *Katsuwonus pelamis* (Linnaeus, 1758), in the Pacific Ocean. Inter-Am. Trop. Tun. Comm., Spec. Rep., 2: 295-360.

Gooding, R.M. and J.J. Magnuson. 1967. Ecological significance of a drifting object to pelagic fishes. Pac. Sci. 21: 486-497.

Greenblatt, P.R. 1979. Associations of tuna with flotsam in the eastern tropical Pacific. Fish. Bull. 77: 147-155.

Hunter, J.R. and C.T. Mitchell. 1967. Association of fishes with flotsam in the offshore waters of Central America. Fish. Bull. 66: 13-28.

Hunter, J.R. and C.T. Mitchell. 1968. Field experiments on the attraction of pelagic fish to floating objects. J. Cons. 31: 427-434.

Hunter, J.R. 1968. Fishes beneath flotsam. Sea Frontiers 14: 280-288.

Hubalek, Z. 1982. Coefficients of association and similarity based on binary (presence-absence) data: an evaluation. Biol. Rev. 57: 669-689.

Janson, S., and J. Vegelius. 1981. Measures of ecological association. Oecologia 49: 371-376.

Klimley, A.P., and S.B. Butler. 1988. Immigration and emigration of pelagic fish assemblages to seamounts in the Gulf of California related to water mass movements using satellite imagery. Mar. Ecol. Progr. Ser. 49: 11-22.

Klimley, A.P., S.B. Butler, A. Stull, and D.R. Nelson. 1988. Diurnal movements of scalloped hammerhead sharks (*Sphyrna lewini* Griffith and Smith) to and from a seamount in the Gulf of California. J. Fish. Biol. 33: 751-761.

Kojima, S. 1960a. Studies of dolphin fishing conditions in the western Sea of Japan--V. On the species of fishes attracted to bamboo rafts. Bull. Jap. Soc. of Scient. Fish. 26: 379-382.

Kojima, S. 1960b. Studies of dolphin fishing conditions in the western Sea of Japan--VI. On the ecology of the groups of fish congregating around bamboo rafts. Bull. Jap. Soc. of Scient. Fish. 26: 383-388.

Lance, G.N., and W.T. Williams. 1967. A general theory for classificatory sorting strategies. 1. Hierachical systems. Computer J. 9: 373-380

Legand, M., Bourret, P., Fourmanoir, P., Grandperrin, R., Gueredrat, J.A., Michel, A., Rancurel, P., Repelin, R., and C. Roger. 1972. Relations trophiques et distributions verticales en milieu pélagiques dans l'océan Pacifique inter-tropicale. Cah. ORSTOM, Ser. Océanogr. 10: 303-393.

Longhurst, A.R., and D. Pauly. 1987. Ecology of Tropical Oceans. Academic Press, San Diego. 407 p.

Ludwig, J.A., and J.F. Reynolds. 1988. Statistical Ecology. John Wiley & Sons. 337p.

MacCall, A.D. 1990. Dynamic geography of marine fish populations. U. of Washington Press, Seattle. 153 p.

McGowan, J.A. 1974. The nature of oceanic ecosystems. In: C. B. Miller (ed) The biology of the oceanic Pacific. Oregon State Univ. Press. Pp. 9-28.

McIntosh, R.P. 1978. Matrix and Plexus techniques. In: Whittaker, R. H. (ed) Ordination of plant communities. W. Junk, The Hague. Pp. 151-184.

Morris, D.W. 1988. Habitat-dependent population regulation and community structure. Evol. Ecol. 2: 253-269.

Mortensen, T. 1917. Observations on protective adaptation and habits, mainly in marine animals. In: Papers from Dr. Th. Mortensen's Pacific Expedition 1914-1916. Vidensk. Medd. Dansk Naturchist. Forem. 69: 57-96.

Muhlia-Melo, A.F. 1980. Synopsis of biological data on the black skipjack tuna, *Euthynnus lineatus* Kishinouye, 1920. Inter-Am. Trop. Tuna Commn. Spec. Rep., 2: 361-394.

Parin, N.V. 1970. Ichtyofauna of the epipelagic zone. Nauka, Moscow (Isr. Program Sci. Transl., Jerusalem). 206 p.

Parin, N.V., Neiman, V.G., and Yu.A. Rudyakov. 1985. To the question of the biological productivity of waters in areas of submerged elevations of the open ocean. In: Vinigradov, M.E., and M.V. Flint (eds). Biological basis of the commercial exploitation of the open areas of the ocean. Academy Of Sciences of the U.S.S.R., Commision on problems of the world ocean. Nauka Pub. Moscow: 192-193.

Perrin, W.F. 1968. The porpoise and the tuna. Sea Frontiers 14 : 166-174.

Perrin, W.F. 1969. Using porpoise to catch tuna. World Fish. 18 (6): 42-45.

Roger, C., and R. Grandperrin. 1976. Pelagic food webs in the tropical Pacific. Limnol. and Oceanogr. 21: 731-735.

Rountree, R. 1987. Ecology of the association of fishes with fish aggregation devices (FAD's); importance of structure complexity, with a discussion of the association of fishes with drift materials. Ms Thesis, College of Charleston, Charleston, South Carolina. 176 p.

Schluter, D. 1984. A variance test for detecting species associations, with some example applications. Ecology 65: 998-1005.

Uda, M. 1933 . The shoals of "Katuwo" and their angling. Bull. Jap. Soc. Scient. Fish. 2: 107-111.

Vinogradov, M.E. and E.A. Shushkina. 1985. Some aspects of the study of ecosystems of the epipelagial of the ocean. In: Vinigradov, M.E., and M.V. Flint (eds). Biological basis of the commercial exploitation of the open areas of the ocean. Academy Of Sciences of the U.S.S.R., Commision on problems of the world ocean. Nauka Pub. Moscow. Pp. 8-20.

Ware, D.M. and G.A. Mcfarlane. 1989. Fisheries production domains in the Northeast Pacific Ocean. In: R.J. Beamish and G.A. McFarlane (eds). Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Can. Spec. Publ. Fish. Aquat. Sci 108: 359-379.

Wyrtki, K. 1965. Surface currents of the eastern tropical Pacific Ocean. Bull. Inter-Am. Trop. Tun. Comm. 9: 207-304.

Wyrtki, K. 1966. Oceanography of the eastern equatorial Pacific Ocean. Oceanogr. Mar. Biol. Ann. Rev. 4: 33-68.

Wyrtki, K. 1967. Circulation and water masses in the eastern equatorial Pacific Ocean. Int. J. Oceanol. Limnol. 1(2): 117-147.

Yesaki, M. 1977. Innovations in harvest of pelagic resources. Mar. Fish. Rev. 39(9): 14-23.

Yuen, H.S.H. 1963. Schooling behavior within aggregations composed of yellowfin and skipjack tuna. FAO, Fish. Rep., 6(3): 1419-1429.

Table 1. Biota associated with floating objects in the ETP, and species/groups included in the analysis.

Group No.	Code			Number of Observations
Tuna				
1.	YF	Yellowfin	*Thunnus albacares*	2,422
2.	SJ	Skipjack	*Katsuwonus pelamis*	2,310
3.	BE	Bigeye	*Thunnus obesus*	146
4.	BSJ	Black skipjack	*Euthynnus lineatus*	1,092
5.	BUL	Bullets	*Auxis* spp.	907
6.	BON	Bonito	*Sarda* spp.	37
Billfish				
7.	MARL	Marlin	*Makaira* spp., *Tetrapterus* spp.	654
8.	OTBF	Other billfish[1]	Istiophoridae, Xiphiidae	170
Other Fish				
9.	DORA	Dorado	*Coryphaena* spp.	3,099
10.	WAHO	Wahoo	*Acanthocybium solandri*	916
11.	RRYT	Rainbow runner/ Yellowtail	*Elagatis bipinulatus*/ *Seriola* spp.	672
12.	OTLF	Other large fish[2]		290
13.	TRGF	Triggerfish	Balistidae	1,638
14.	SMBF	Small baitfish[3]		1,687
15.	OTSF	Other small fish[4]		587
Sharks and Rays				
16.	BTSH	Blacktip shark	*Carcharhinus limbatus*	487
17.	WTSH	Whitetip shark	*Carcharhinus longimanus*	170
18.	HHSH	Hammerhead	*Sphyrna* spp.	141
19.	OTSH	Other Shark	*Carcharhinus* spp.	260
20.	UNSH	Unidentified shark[5]	*Carcharhinus* spp.	1,672
21.	RAYS	Manta ray/ Sting ray	Mobulidae, Rajidae/ Dasyatidae	140
Other Fauna				
22.	TURT	Sea turtles[6]	Chelonidae, Dermochelydae	745
23.	MMAM	Marine mammals	*Stenella* spp., *Delphinus* spp.	24
24.	INVB	Invertebrates[7]		73

Sea Birds				
25.	RFBO	Red-footed boobies	*Sula sula*	113
26.	MABO	Masked boobies	*Sula dactylatra*	502
27.	BRBO	Brown boobies	*Sula leucogaster*	433
28.	UNBO	Unidentified booby	*Sula* spp.	351
29.	SHWA	Shearwaters	*Puffinus* spp.	279
30.	TERN	Terns	*Sterna* spp., *Chlidonias* spp.	189
31.	MOW	Frigate bird	*Fregata* spp.	675
32.	PETR	Petrels	*Pterodroma* spp.	66
33.	OBRD	Other birds[8]		93
34.	UNBD	Unidentified bird		325
Epibiota				
35.	ACBR	Acorn barnacles	Balanomorpha	1,120
36.	GNBR	Gooseneck barnacles	Lepadomorpha	1,312
37.	CRAB	Crabs	Decapoda	544
38.	WEED	Seaweed		837
39.	OEPI	Other epibiota		475

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[1] Mostly sailfish (*Istiophorus platypterus*) and swordfish (*Xiphias gladius*).

[2] Includes sea bass and cabrilla (Serranidae), and jacks (Carangidae).

[3] Small fishes, usually very abundant. Several families, including: Engraulidae, Clupeidae, Kyphosidae, Haemulidae.

[4] Other small fishes not considered baitfish by fishermen such as flyingfish (Excocoetidae), small cabrillas (Serranidae) and small scombrids.

[5] The most common shark in the tuna fishing grounds is the silky shark (*Carcharhinus falciformis*), but it is difficult to identify.

[6] The most common sea turtle in the ETP is the olive ridley (*Lepidochelyis olivacea*).

[7] Usually squids (Cephalopada), and jellyfish (Scyphozoa).

[8] Mostly coastal birds such as gulls (Laridae), pelicans (Pelecanidae), and cormorants (Phalacrocoracidae).

Table 2. Number of significant pairwise combinations.

α	χ^2	r_s	r
0.05	74 (10.8%)	90 (12.1%)	79 (10.7%)
0.01	43 (6.3%)	47 (6.3%)	59 (8.0%)
0.001	20 (2.9%)	43 (5.8%)	30 (4.0%)

Index Value	**JI**
0.7-0.8	105 (14.2%)
0.8-0.9	101 (13.6%)
>-0.9	49 (6.6%)

Note: Number of total pairwise comparisons is 741.

Table 3. Association of pairs of species/group.

Group A = Highly significant

PAIR	χ^2	**JI**	r_s	**r**
YF – SJ	**	1.00	***	***
YF – DORA	-	0.98	*	**
YF – UNSH	-	0.98	***	***
SJ – DORA	-	0.98	***	***
SJ – UNSH	-	0.98	***	***
SJ –ACBR	**	0.96	*	*
BE –DORA	-	0.48	***	**
BE – MOW	*	0.55	**	***
BSJ-SMBF	**	0.88	**	**
DORA-WAHO	-	0.96	**	***
DORA-GNBR	-	0.93	**	***
DORA-RAYS	-	0.45	***	**
DORA- MOW	-	0.68	***	***
DORA-UNBD	-	0.82	*** (-)	*** (-)
UNSH-TRGF	-	0.89	***	***
TRGF-RRYT	*	0.85	***	***
UNSH-WAHO	-	0.96	**	n.s.
MARL-UNSH	-	0.82	***	***
UNSH-ACBR	-	0.98	***	***
HHSH-OTLF	***	0.66	** (-)	* (-)
BTSH-CRAB	***	0.90	*	n.s.
BTSH-MARL	***	0.90	**	n.s.
OTSH-OBRD	-	0.45	*** (-)	** (-)
OTBF-OTLF	**	0.57	* (-)	* (-)
OTBF-RFBO	**	0.54	* (-)	* (-)
SMBF-BRBO	*	0.81	**	**
INVB-RAYS	**	0.54	** (-)	** (-)
INVB-PETR	*	0.44	*** (-)	* (-)
RFBO-PETR	*	0.50	*** (-)	** (-)
MABO-GNBR	**	0.83	**	***

Note: (χ^2) Chi square; (JI) Jaccard Index; (r_s, r) Spearman's and Pearson's correlation coefficients; (-) Undetermined; n.s. (Not significant); (*,**,***, significant at α = 0.05, 0,01, 0,001).

Table 4. Association of pairs of species/groups.

Group B = Significant χ2, high JI and low covariance

PAIR	**χ2**	**JI**	**r_s**	**r**
YF -ACBR	**	0.96	n.s.	n.s.
YF -WEED	**	0.96	n.s.	n.s.
SJ -WEED	**	0.96	n.s.	n.s.
DORA-SMBF	-	0.91	n.s. (-)	n.s. (-)
DORA-ACBR	-	0.98	n.s. (-)	n.s. (-)
DORA-UNSH	-	1.00	n.s.	n.s.
DORA-TURT	-	0.93	*	n.s.
DORA-WEED	-	0.98	n.s.	n.s.
UNSH-SMBF	-	0.91	n.s.	n.s.
UNSH-TURT	-	0.93	n.s.	n.s.
UNSH-GNBR	-	0.93	n.s. (-)	n.s. (-)
UNSH-WEED	-	0.98	n.s.	n.s.
BTSH-SMBF	***	0.95	n.s.	n.s.
WTSH-MARL	***	0.78	n.s.	n.s.
OTSH-MABO	***	0.79	n.s.	n.s.
MARL -SMBF	***	0.90	n.s.	n.s.
MARL -CRAB	***	0.90	n.s.	n.s.
TRGF-SMBF	***	0.93	n.s.	n.s.
TRGF-OTSF	***	0.95	n.s.	*
OTSF-SMBF	***	0.93	n.s.	n.s.
OTSF-CRAB	***	0.93	n.s.	n.s.

Note: (χ^2) Chi square; (JI) Jaccard Index; (r_s, r) Spearman's and Pearson's correlation coefficients; (-) Undetermined; n.s. (Not significant); (*,**,***, significant at α = 0.05, 0,01, 0,001).

Table 5. Association of pairs of species/groups.

Group C = Significant covariance, low $\chi2$

PAIR	$\chi2$	JI	r_s	r
YF - BSJ	n.s.	0.82	***	***
YF -MARL	n.s.	0.84	***	***
SJ - BE	n.s.	0.49	***	*
BE -TURT	n.s.	0.48	***	***
BE -UNBO	n.s.	0.34	*** (-)	*** (-)
BSJ - BUL	n.s.	0.78	***	***
BUL -SMBF	n.s.	0.81	***	**
WAHO-WTSH	n.s.	0.71	***	**
WAHO-TRGF	n.s.	0.84	***	***
WAHO-RRYT	n.s.	0.84	***	***
WTSH-TRGF	n.s.	0.72	**	**
WTSH-OTBF	n.s.	0.47	*** (-)	** (-)
WTSH-INVB	n.s.	0.34	*** (-)	* (-)
WTSH-MABO	n.s.	0.60	*** (-)	* (-)
WTSH-BRBO	n.s.	0.60	*** (-)	** (-)
WTSH-OBRD	n.s.	0.50	*** (-)	* (-)
WTSH-RRYT	n.s.	0.67	**	**
BTSH-GNBR	n.s.	0.88	***	***
RRYT-OBRD	n.s.	0.45	*** (-)	** (-)
OTLF-OBRD	n.s.	0.50	*** (-)	*** (-)
SMBF-UNBO	n.s.	0.71	**	***
TURT-INVB	n.s.	0.41	***	*
INVB-OBRD	n.s.	0.37	*** (-)	* (-)
BON -PETR	n.s.	0.27	*** (-)	* (-)
BON -MMAM	n.s.	0.29	*** (-)	** (-)
MMAM-RAYS	n.s.	0.18	*** (-)	** (-)
MMAM-TERN	n.s.	0.23	*** (-)	** (-)

Note: (χ^2) Chi square; (JI) Jaccard Index; (r_s, r) Spearman's and Pearson's correlation coefficients; (-) Undetermined; n.s. (Not significant); (*,**,***, significant at $\alpha = 0.05, 0{,}01, 0{,}001$).

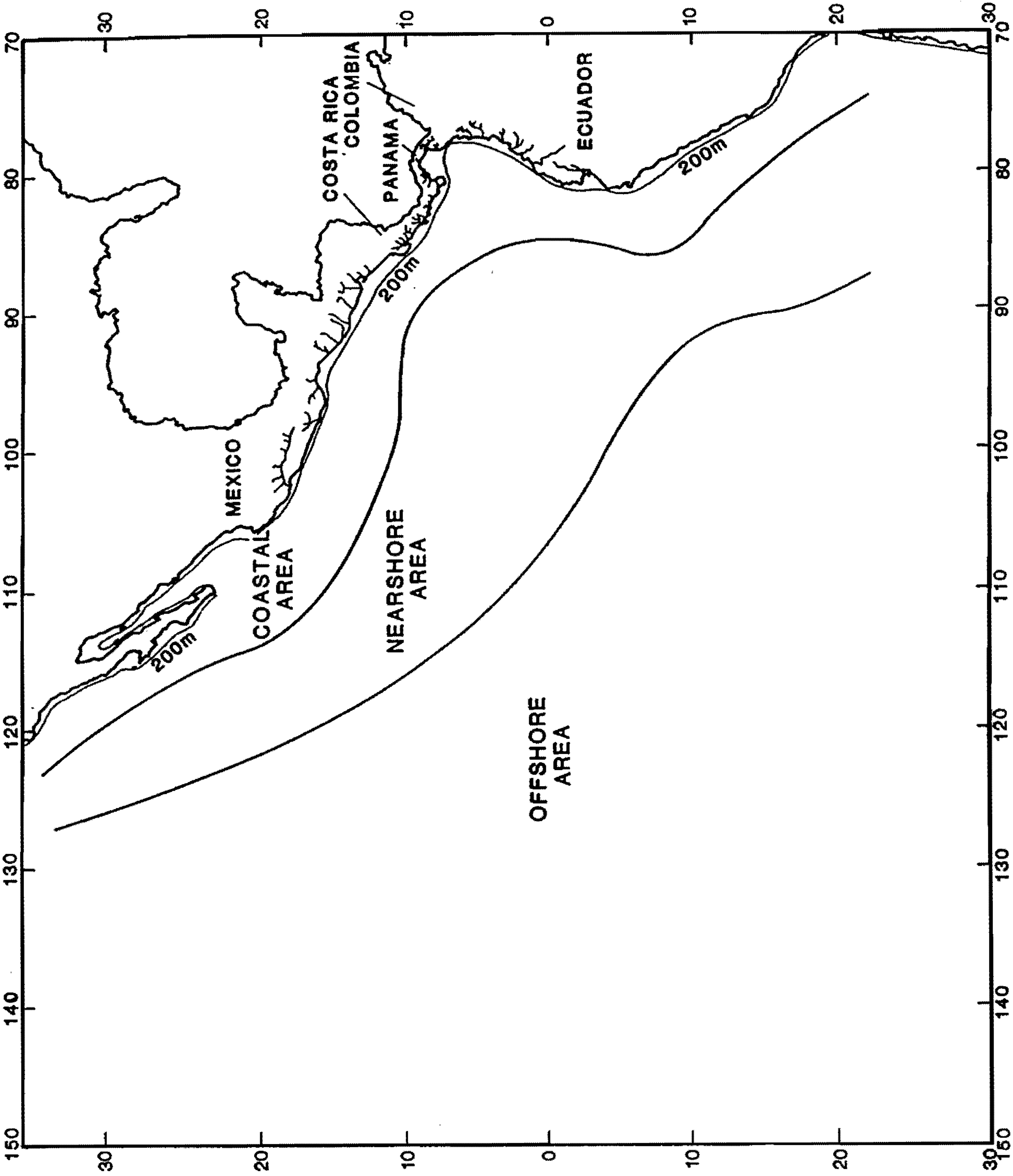

Figure 1. The eastern Pacific Ocean (EPO). The coastal area corresponds with the area of high biological productivity; the offshore region corresponds roughly with the IATTC's yellowfin regulatory area (CYRA).

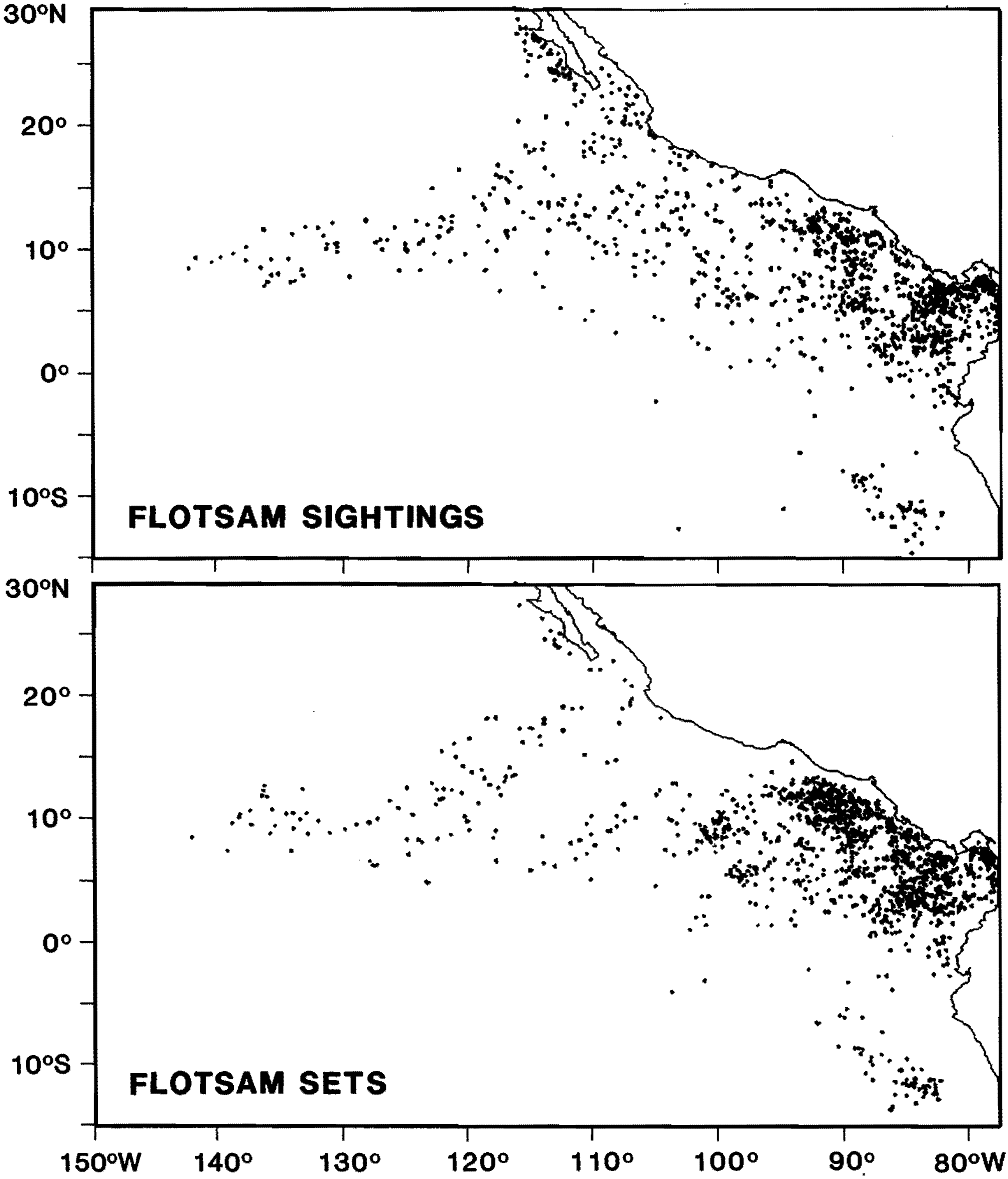

Figure 2. Distribution of sightings and sets on floating objects in the EPO; 1987-1991.

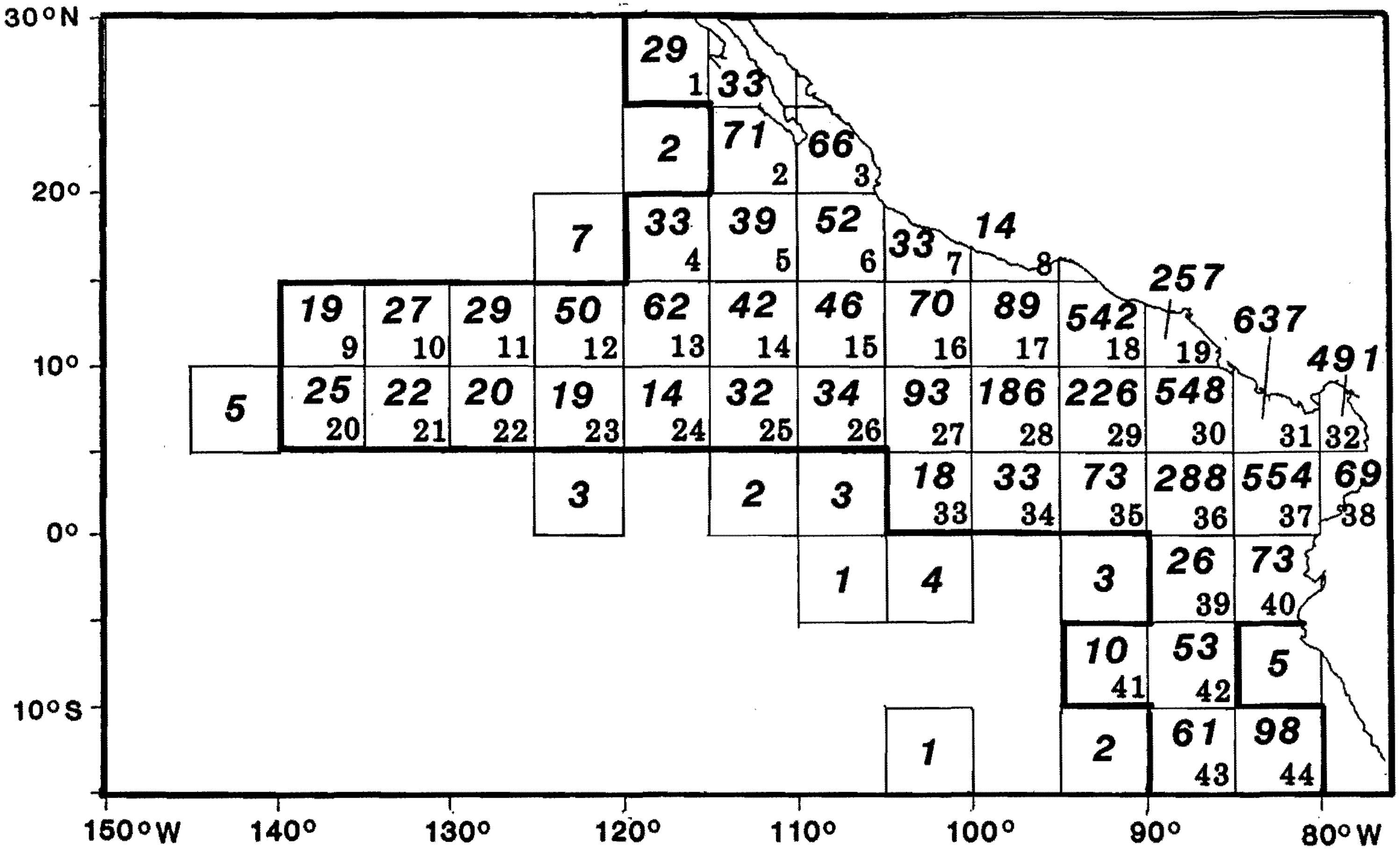

Figure 3. Areas selected and sample size. Each 5°-square represents a sampling unit, numbered in the corner. The numbers in the center of the squares are sample sizes.

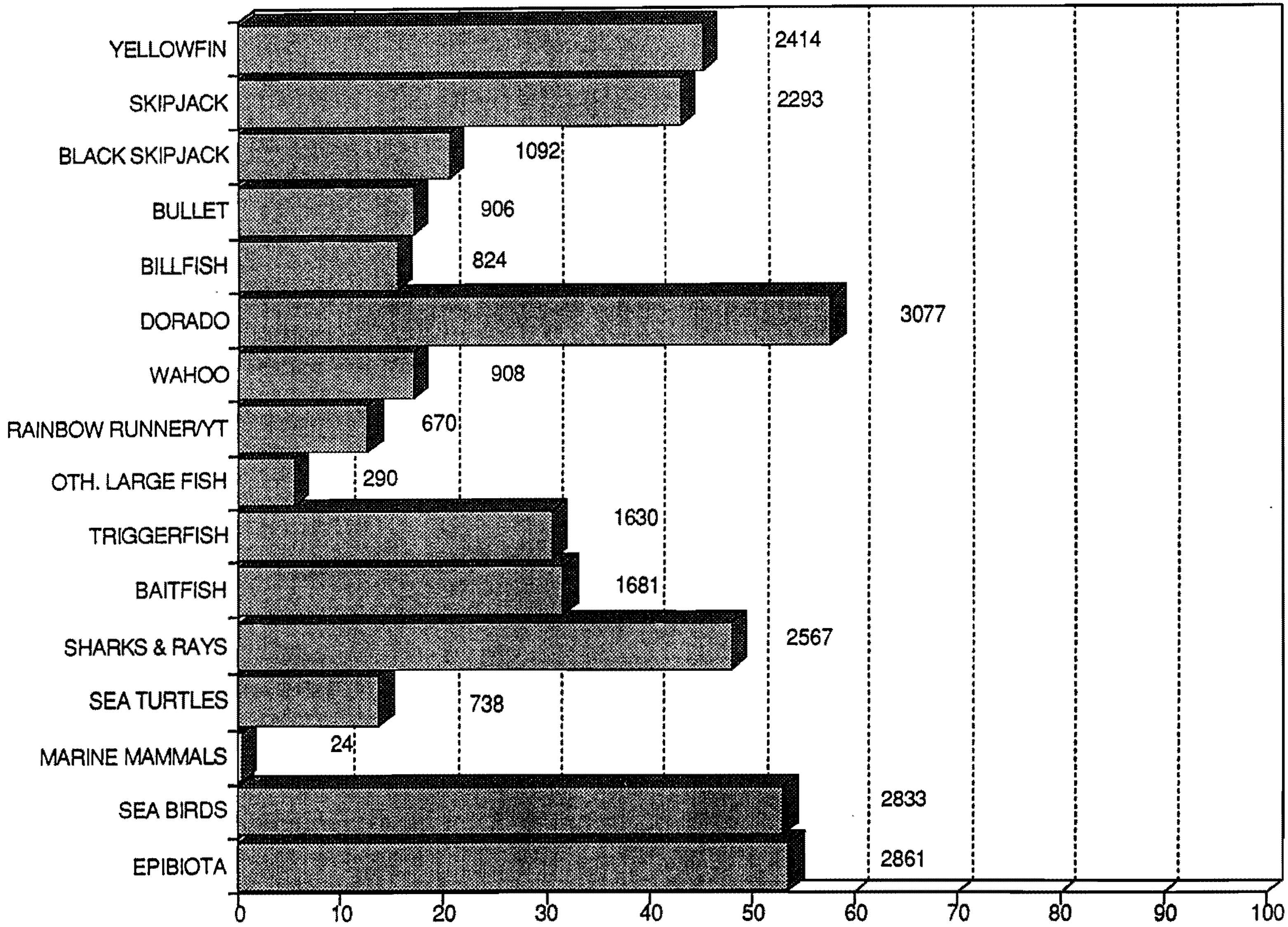

Figure 4. Frequency of records (sets and sightings combined) for selected species and/or groups.

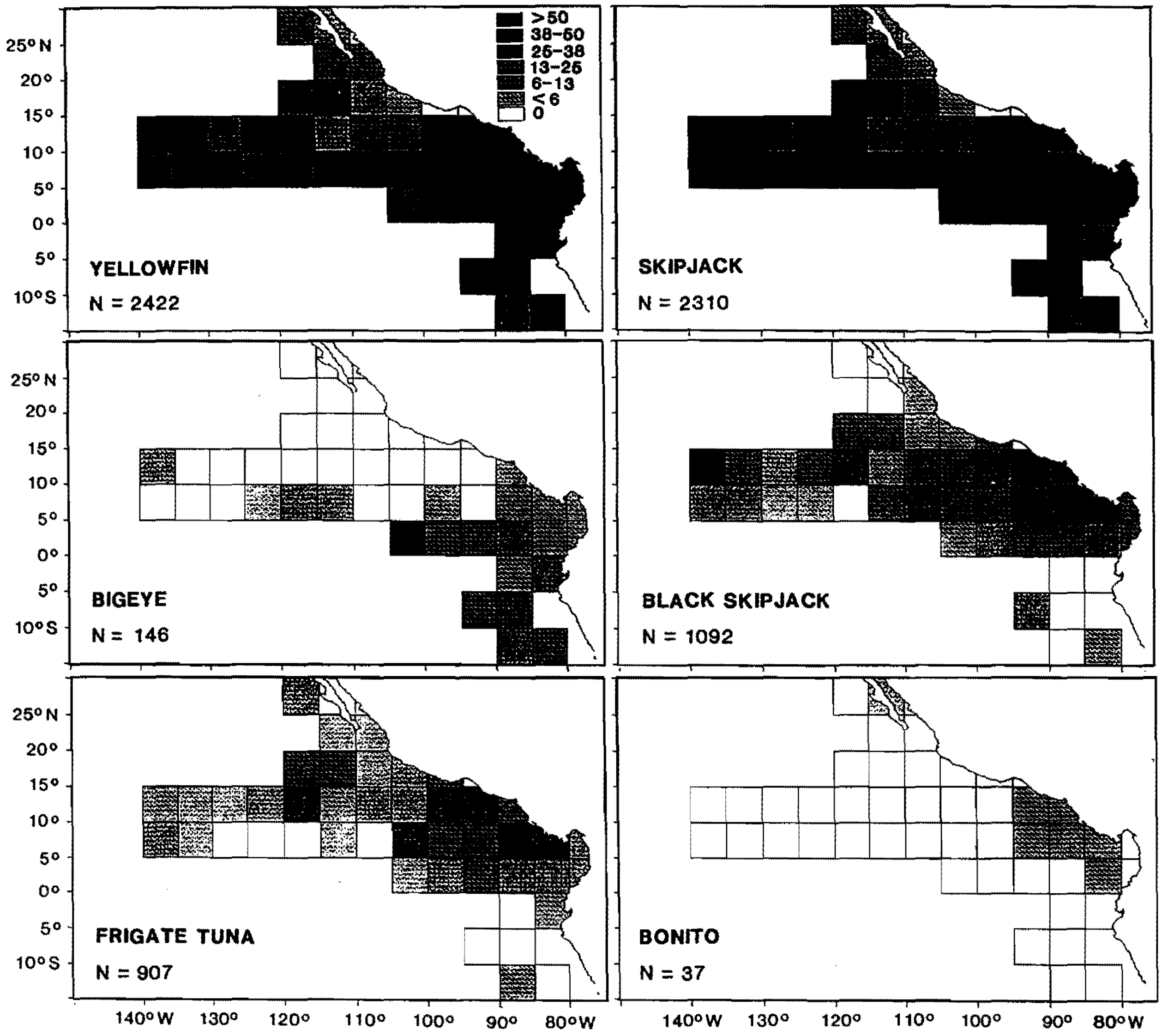

Figure 5. Proportion of records containing tuna species, by 5° square.

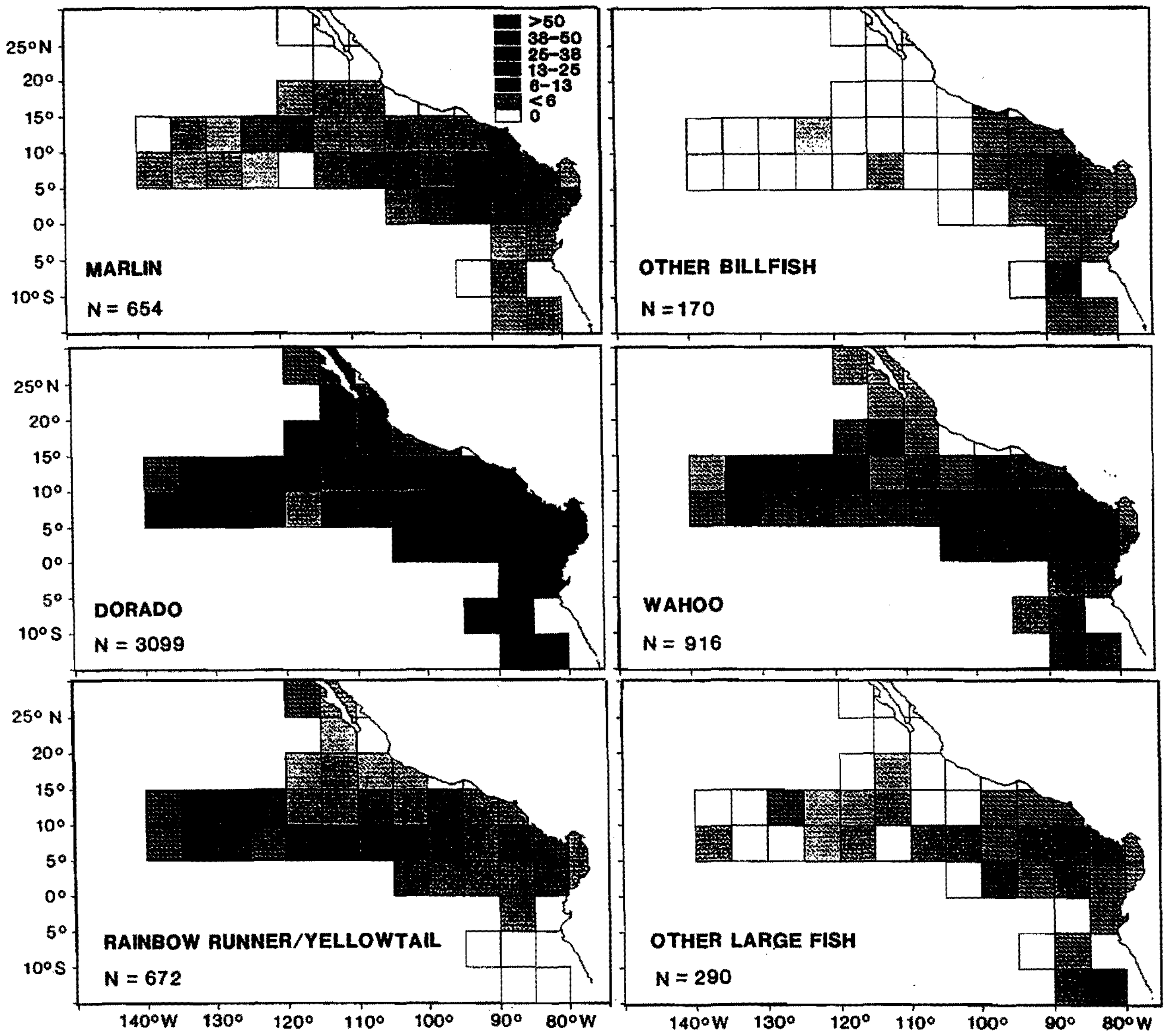

Figure 6. Proportion of records containing other large fish groups, by 5° square.

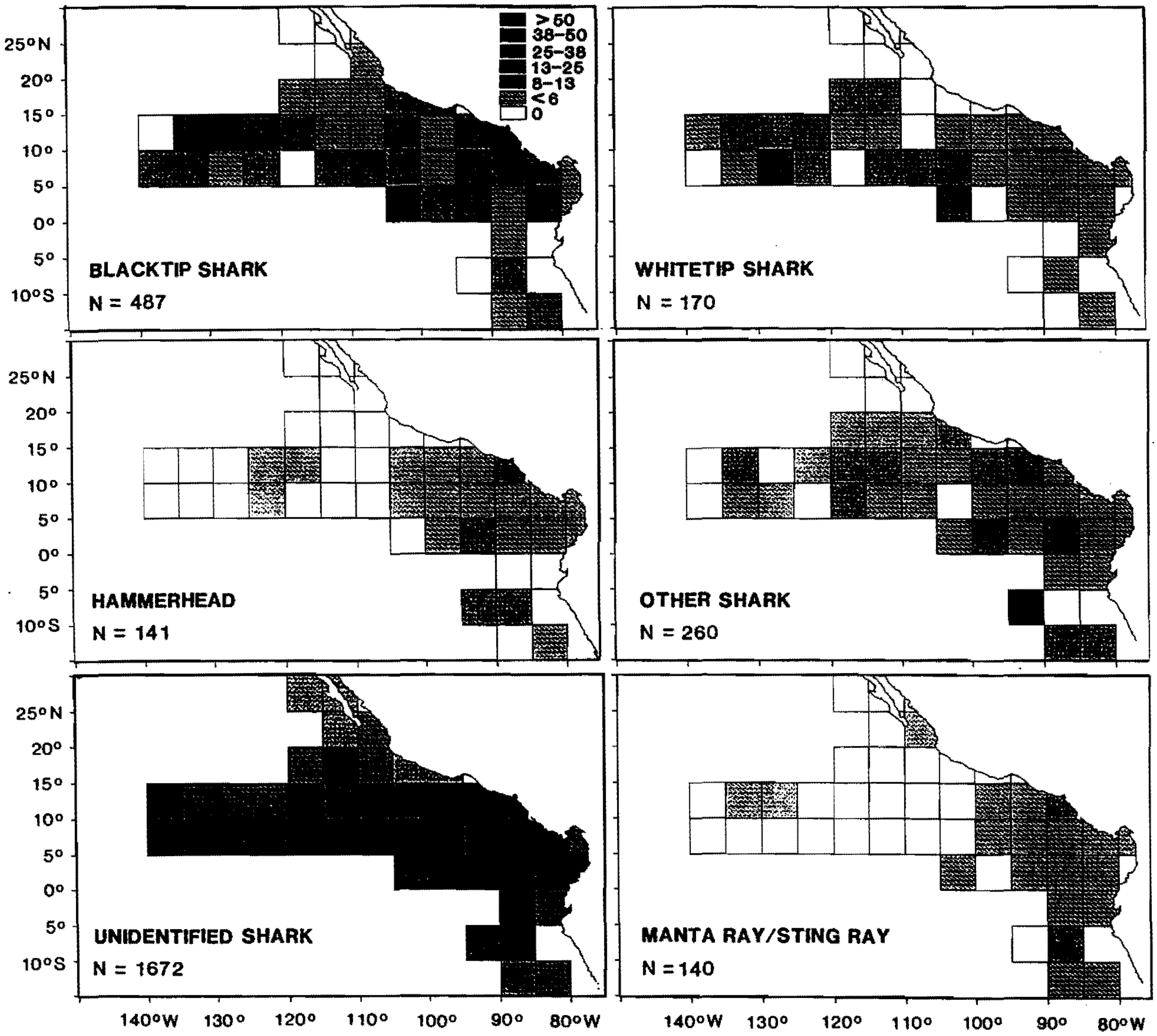

Figure 7. Proportion of records containing sharks and rays, by 5° square.

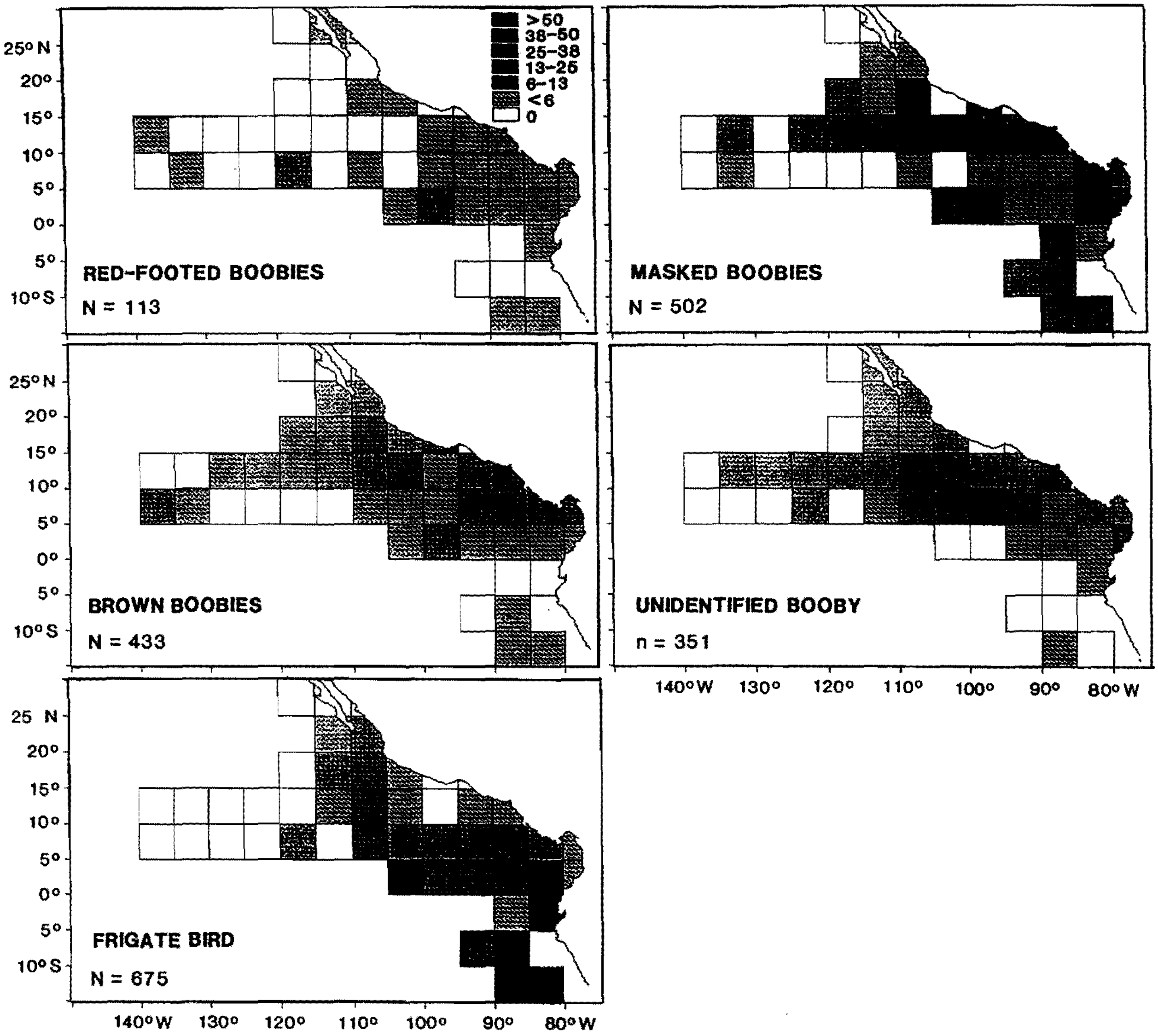

Figure 8. Proportion of records containing boobies and frigate birds, by 5° square.

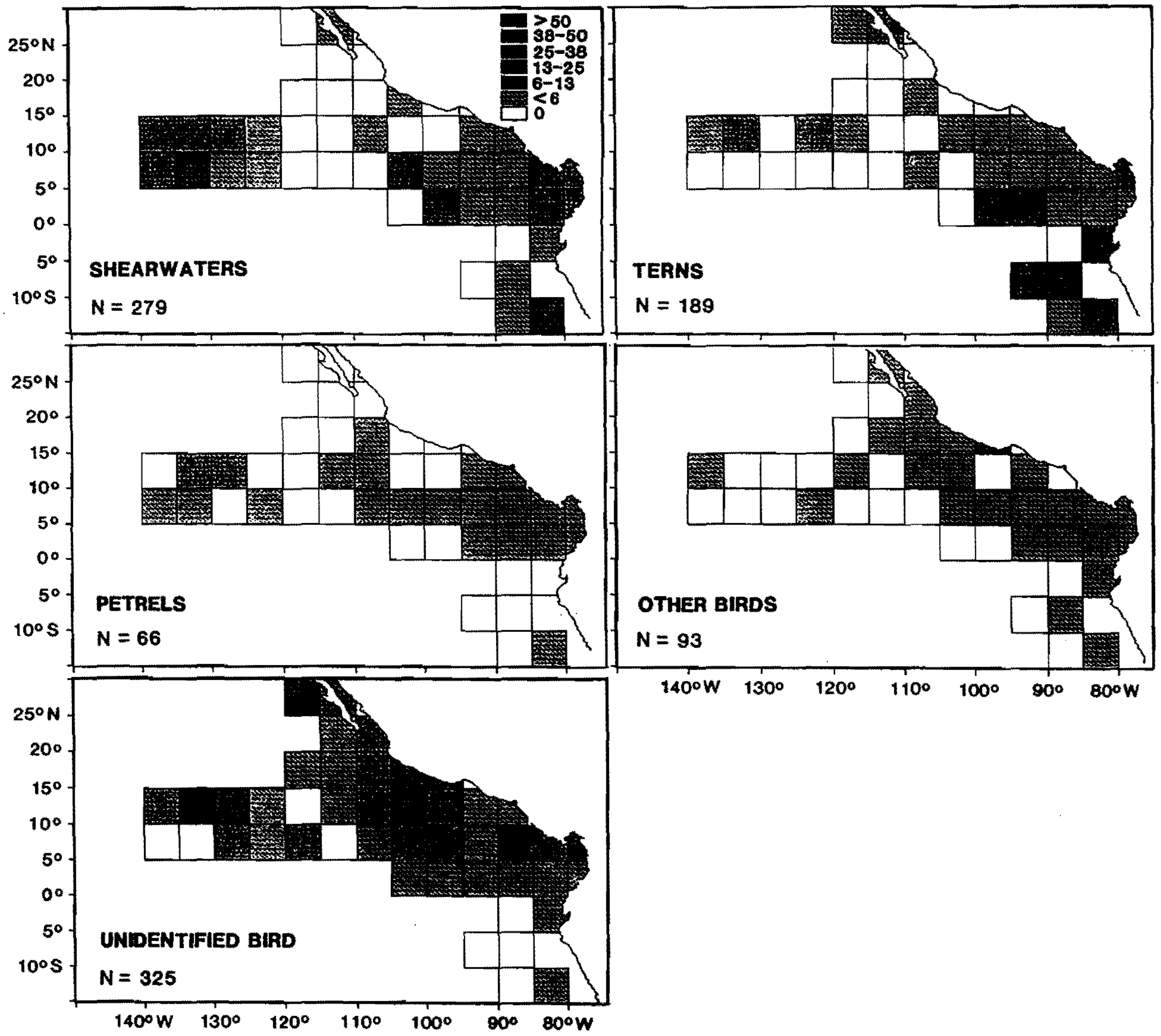

Figure 9. Proportion of records containing other sea birds, by 5° square.

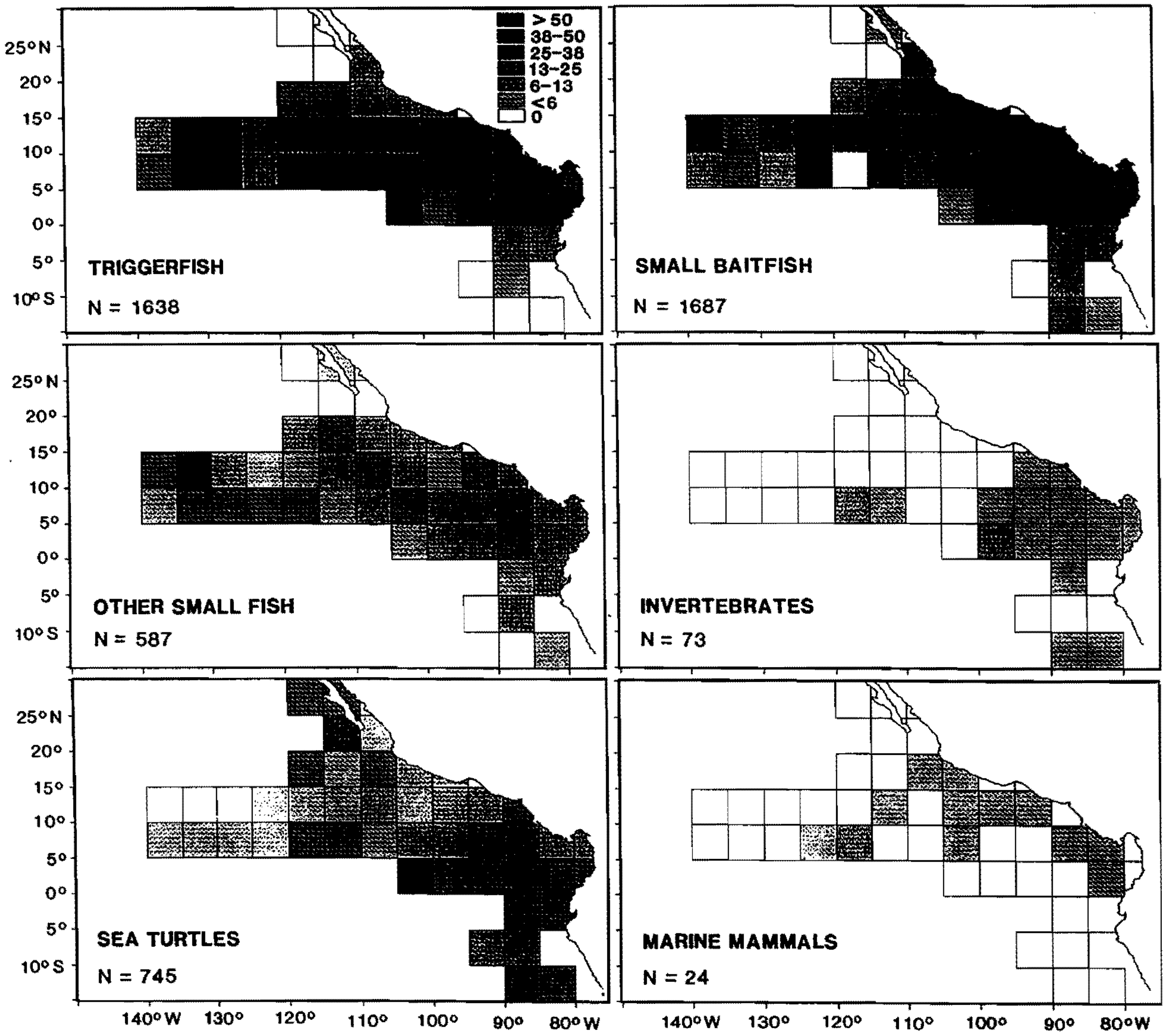

Figure 10. Proportion of records containing small fish, invertebrates, turtles, and marine mammals, by 5° square.

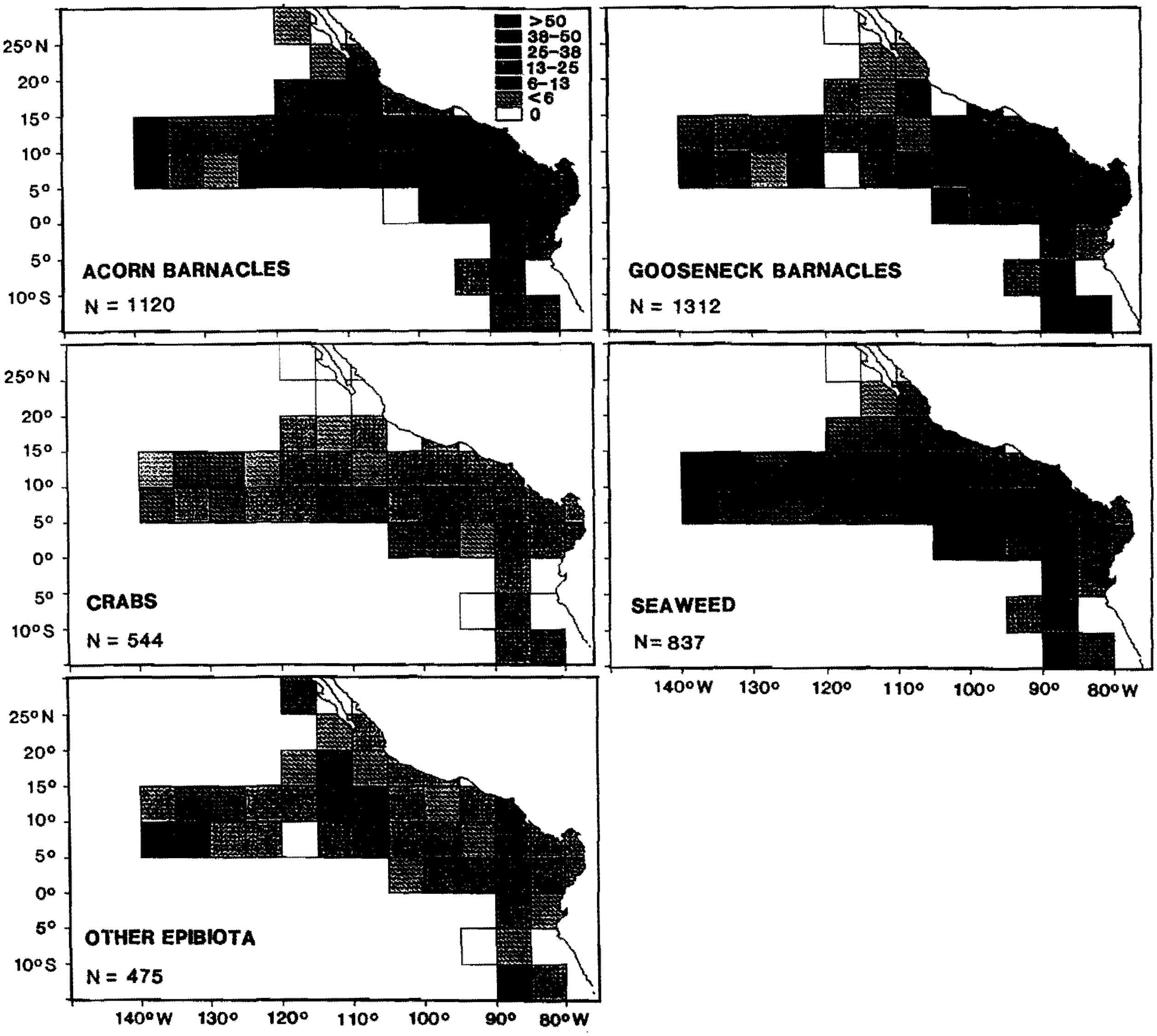

Figure 11. Proportion of records containing floating objects with diverse epibiota, by 5° square.

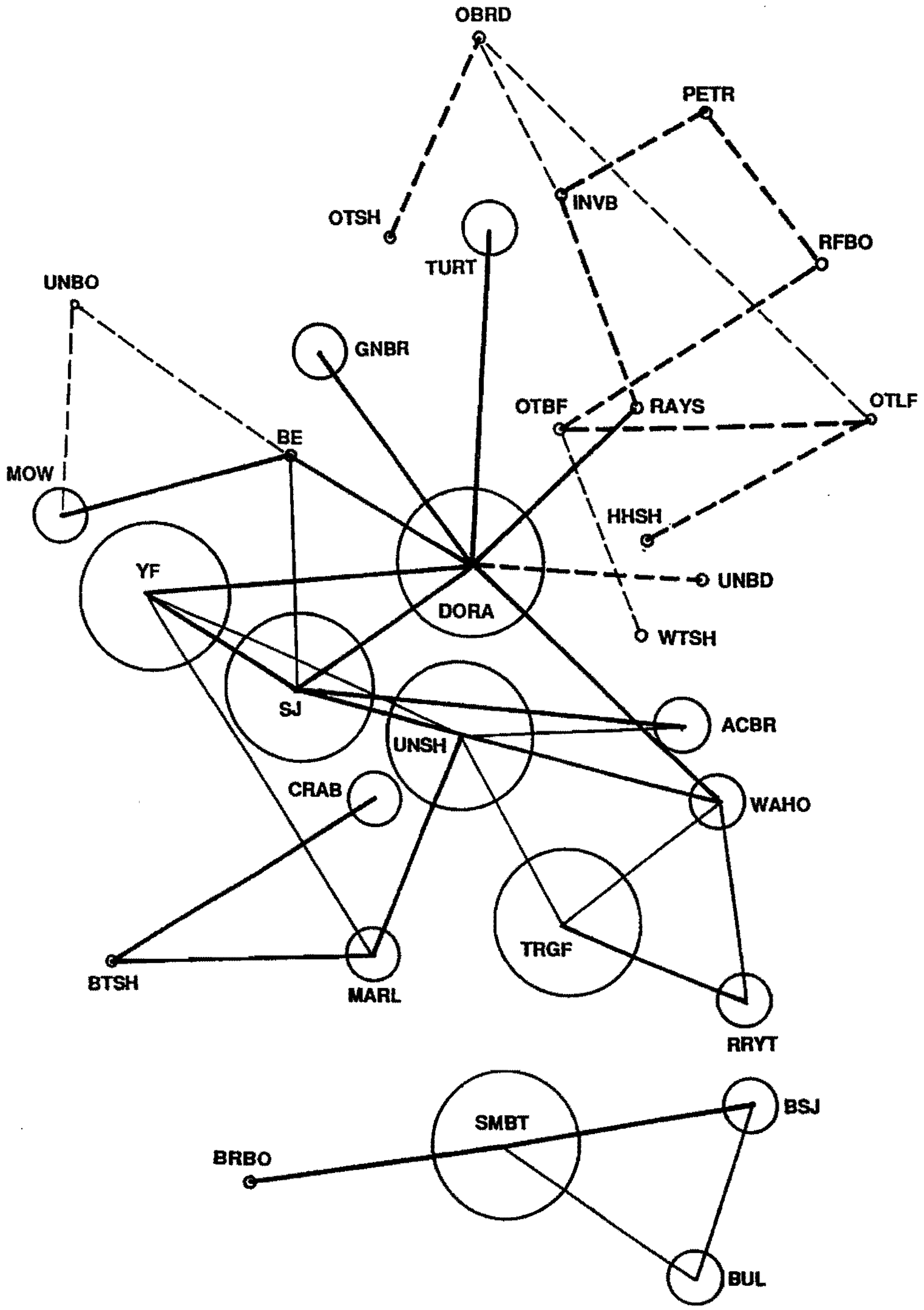

Figure 12. Plexus diagram of the most important relationships among species and/or groups. The circles represent sample sizes of <500, 500-1500, and >1500. Line length is proportional to the Spearman's correlation coefficient; solid lines represent positive covariation, broken lines represent negative covariation. Heavy lines also had significant chi-square and high Jaccard's Index (JI) values.

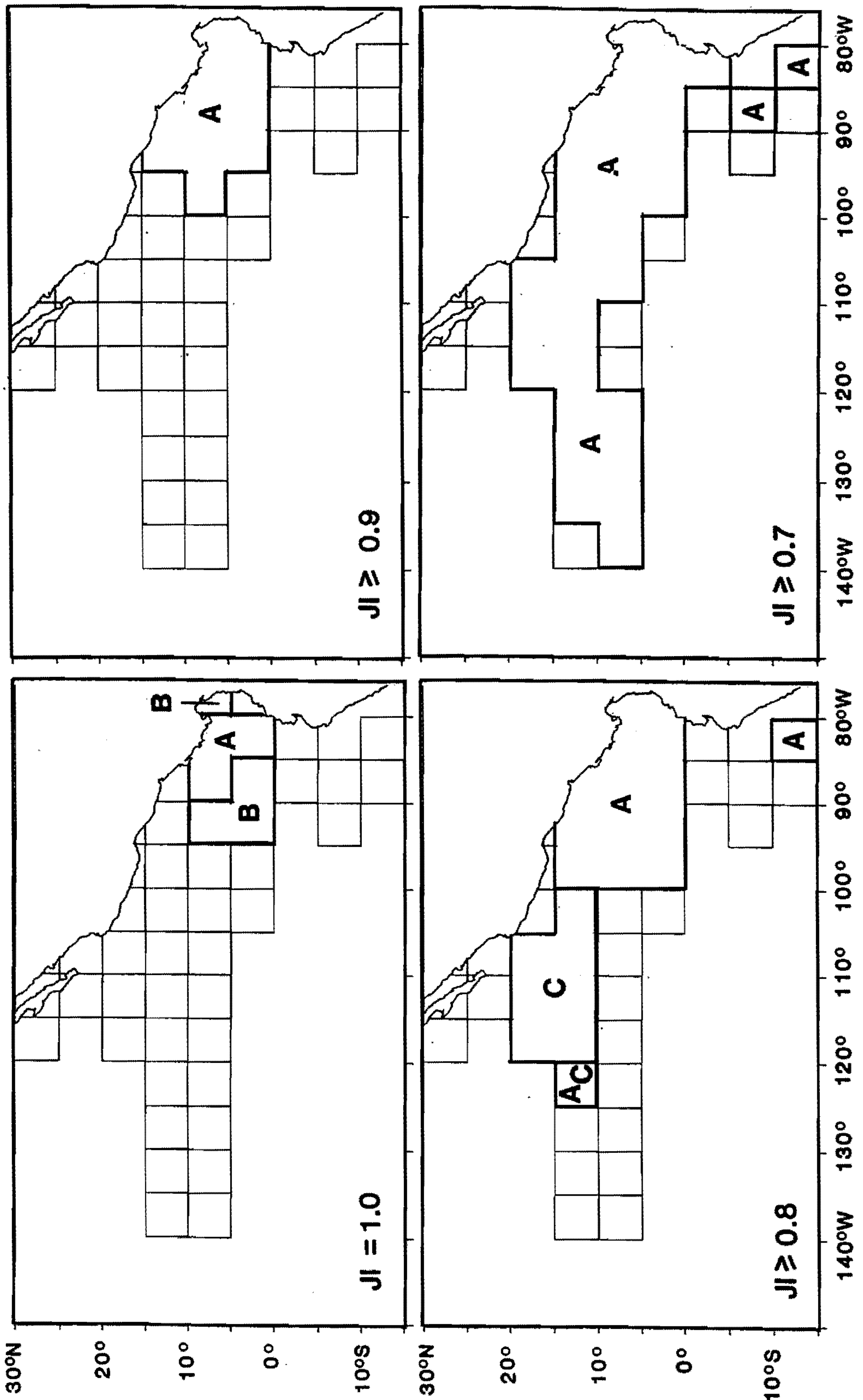

Figure 13. Jaccard's Index of similarity among areas, based on presence or absence of species and/or groups. Values for the index are arbitrary.

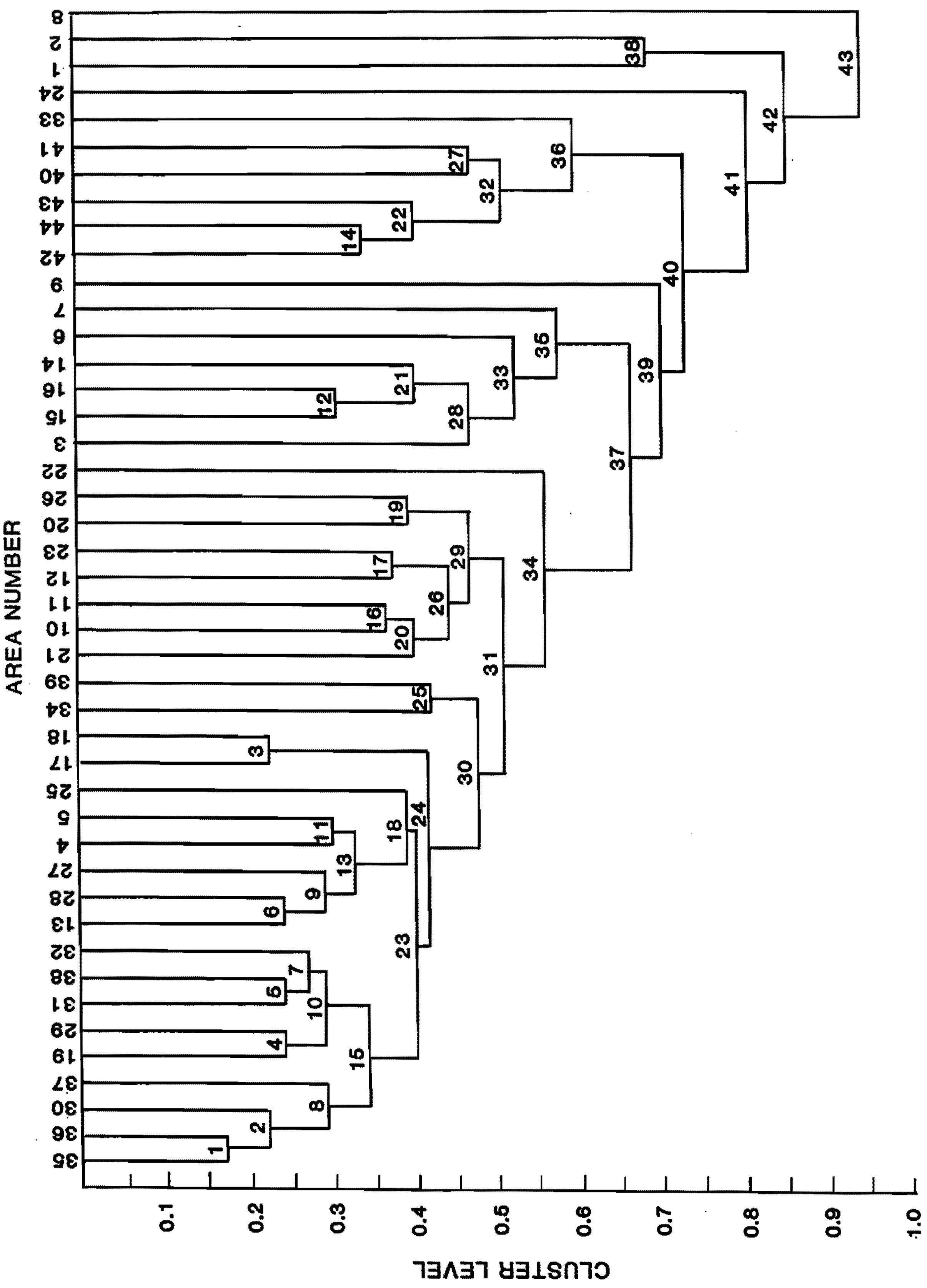

Figure 14. Dendrogram for cluster analysis, using the group-average strategy.

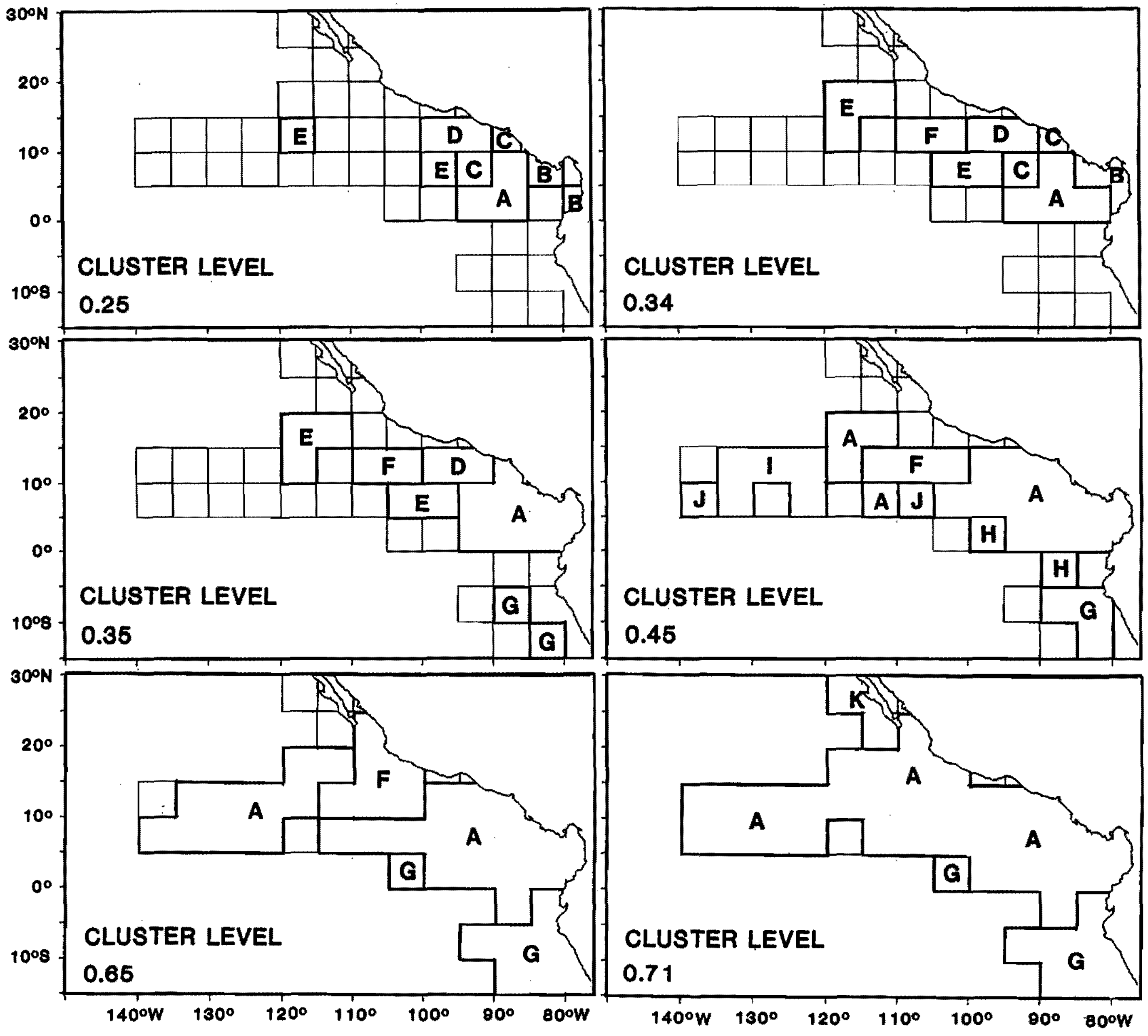

Figure 15. The relative-frequency-of-ocurrence (RFO) index and similarity among areas for several cluster levels. The levels selected are arbitrary.

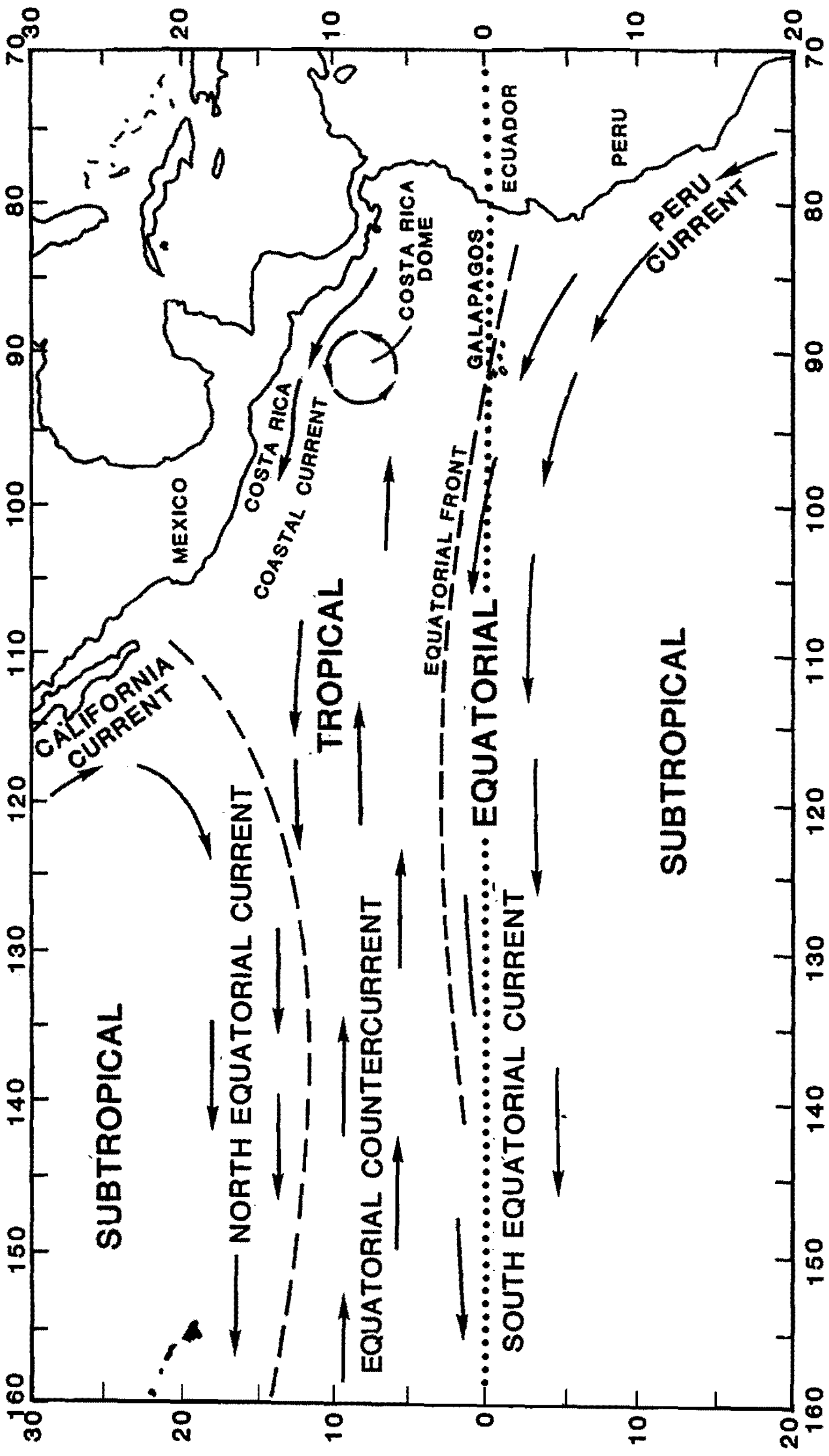

Figure 16. Schematic representation of the surface water masses and surface circulation of the eastern tropical Pacific, adapted from Wyrtki (1966, 1967).

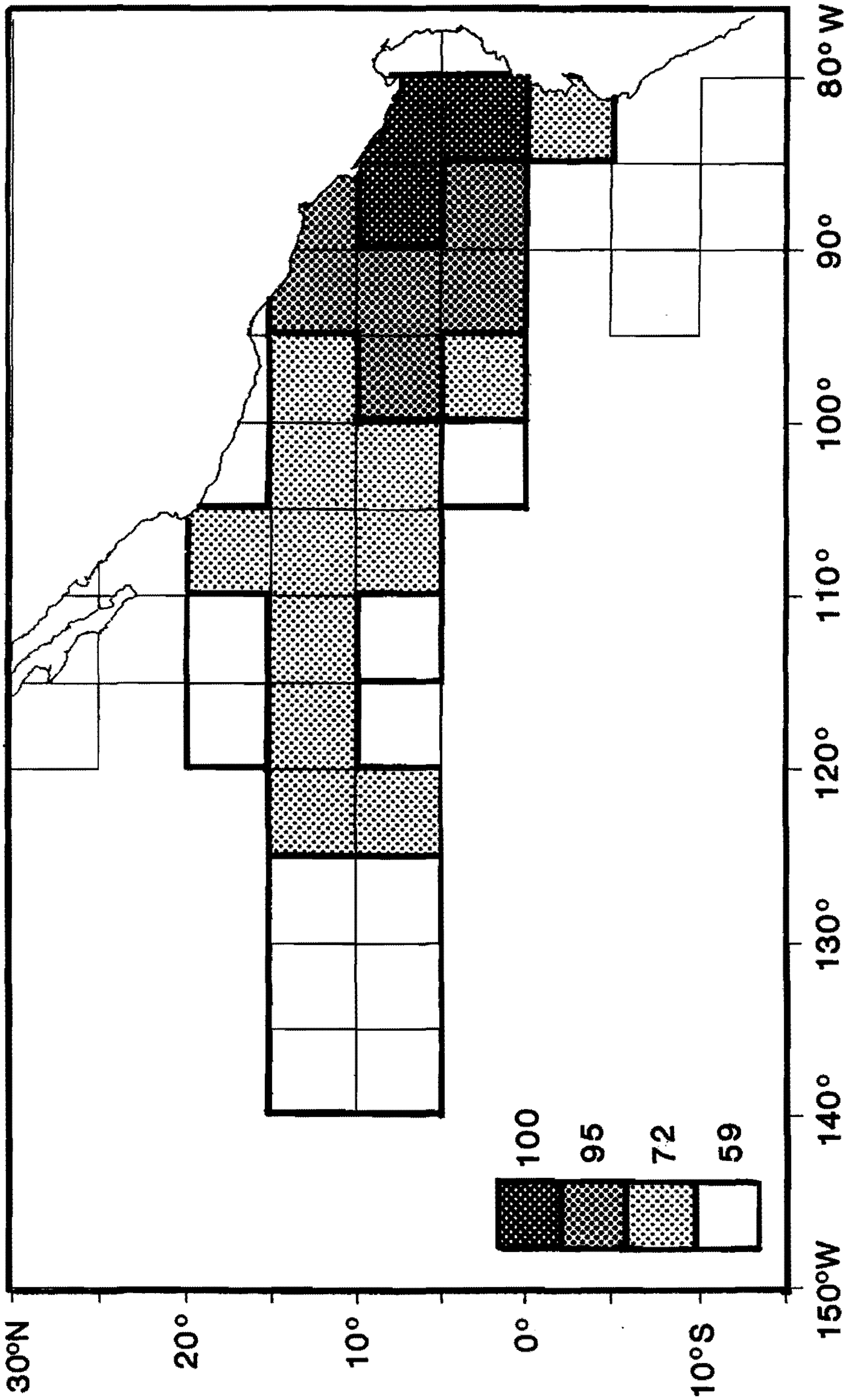

Figure 17. Proportions of shared species, by 5° square.

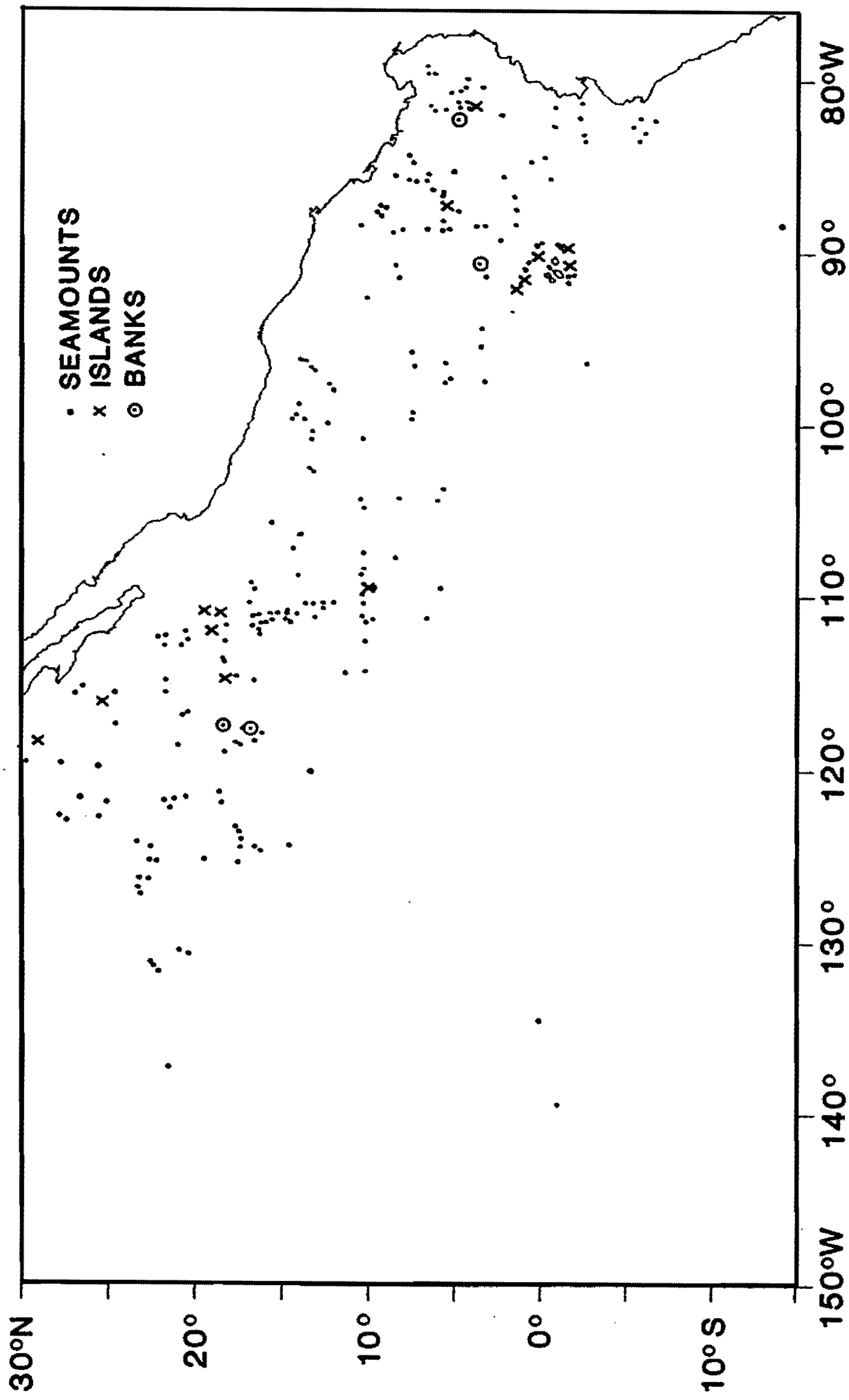

Figure 18. Islands, seamounts, and banks in the eastern Pacific Ocean.

YELLOWFIN TUNA ASSOCIATIONS WITH SEABIRDS AND SUBSURFACE PREDATORS

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ABSTRACT

Yellowfin tuna (*Thunnus albacares*) in the eastern tropical Pacific often co-occur with certain species of seabirds, predatory fishes, and dolphins (Cetacea) as multi-species foraging aggregations or associations. The species involved include the sharks and other pelagic fishes that are commonly caught with the yellowfin tuna. All are nomadic foragers that search out productive and apparently large food patches. The bird-flock observations indicate that most tuna schools forage as free schools and are not usually with cetaceans when feeding at the surface. When they are, however, it is mainly with spotted (*Stenella attenuata*) or spotted and spinner (*S. longirostris*) dolphins. Other cetacean species are infrequently if ever involved. The birds, primarily boobies (*Sula* spp.), Wedge-tailed Shearwaters (*Puffinus pacificus*), Juan Fernandez Petrels (*Pterodroma externa*), and Sooty Terns (*Sterna fuscata*), are strongly associated with the tuna, which drive prey to the surface. Intense daytime feeding interactions are seen between the birds and tuna, but not between the birds and dolphins. A direct tuna-dolphin feeding link was not apparent. These observations are consistent with studies by other researchers that indicate the dolphins may often feed at night. On the other hand, tuna will break from feeding and flee with the dolphins from danger, showing that their relationship is at least sometimes direct.

INTRODUCTION

In the eastern tropical Pacific (ETP), seabirds, sharks, and dolphins (Cetacea) are characteristically associated with yellowfin tuna (*Thunnus albacares*) (*e.g.*, Au 1991, Arenas *et al.*, this vol.), and from this, certain behaviors of the tuna can be inferred. For example, certain sharks and other predatory fishes are captured with the tuna at rates differing according to the tuna's size and schooling behavior, a reflection of differences in the foraging behavior of these different predators as well as in the habits of their prey. The species composition of seabirds in feeding flocks varies by area (Ballance 1993, Pitman 1986) and type of associated subsurface predator (Seki and Harrison 1989, Harrison and Seki 1987, Au and Pitman 1986), which relates to the kinds and behaviors of the prey that tunas drive to the surface. The association between the tuna and dolphins in the ETP tends to be very species-specific, and this suggests that the underlying behaviors are also very species-specific.

The purpose of this paper is to report upon and discuss observations of yellowfin tuna (YFT) interactions with seabirds and other (subsurface) species in the ETP. The latter are nektonic predators, generally larger than 50 cm as adults, that occur with YFT. They are caught by purse-seine vessels as bycatch from tuna schools that may be associated with flotsam or that may be freely swimming. The latter type tuna schools are often also associated with dolphins, and that behavior will also be discussed. A basic premise of this paper is that seabirds can provide insight into the nature of feeding aggregations involving tuna.

DATA AND METHODS

The information we present is derived from two sources: our observations of birds and other predators taken while aboard research vessels censusing dolphin populations, and records from other observers who sailed aboard tuna purse-seine vessels.

Research vessel observations

We utilized a set of research cruises of the Southwest Fisheries Science Center (SWFSC) that were designed to assess the status of dolphin stocks in the ETP. Two vessels conducted surveys during July to December from 1986 through 1988, following pre-determined tracks but with diversions made toward dolphin schools to identify species, estimate school sizes, and count associated birds. Two observers scanned the ocean with 25X binoculars during most daylight hours to census mammals by line-transect methods (see Holt and Sexton 1989 for details). We (Pitman and Ballance) recorded sightings of all birds seen, regardless of their distance from the ship, and noted any other associated animals and all distinguishable behaviors. Most areas of the ETP east of 160°W were surveyed (see Figure 1; also Wade and Gerrodette 1993). Similar bird data from SWFSC surveys of 1979 through 1985 (Pitman 1986) are also used in this paper.

We defined a flock as five or more birds, and for this analysis used only flocks in which all seabirds were identified to at least the generic level and from which all individuals were counted. All bird flocks were observed carefully for associated cetaceans and schooling fishes. Very likely, few associated cetacean schools were missed, because the mammals must surface to breathe. But any fish schools that remained below the surface were undetected; therefore, the number of times fishes were recorded with the seabirds constitutes only a minimum estimate of their true rate of co-occurrence.

For this paper, we regarded all feeding flocks as flocks likely to have been with tunas, even when those fishes were not seen. We made this assumption for the following reasons:

1) The only predatory fishes we saw beneath feeding birds were tuna species.

2) Pelagic seabirds have been found previously to depend upon tunas to drive their mutual prey to the surface (Ashmole and Ashmole 1967, Au and Pitman 1988); tunas are, moreover, the most widespread of large, schooling predators in all tropical seas.

3) Universally, tuna fishermen use bird flocks as their primary cue to the presence of these fish, regardless of any association with other animals.

The research vessel data provided fishery-independent information on seabird flocks and their behaviors, especially with respect to the interactions with the different species of the cetacean community. Information on the bird associations with other subsurface predators, such as tuna, was sometimes direct, but often inferred as described above.

Purse-seine vessel observations

The SWFSC also placed observers aboard tuna purse-seine vessels to monitor fishing operations and incidental dolphin kill, and this provided us with a second set of information about the pelagic predator community, a set linked to YFT directly. We used species data from purse-seine "sets" (*i.e.*, net encirclements and haulbacks) categorized according to how the YFT schools were caught: as log-associated (captured around flotsam), as non-associated (captured as free schools), or as dolphin-associated (captured with dolphins). Our sample was from the years 1974-1975 when observers had much freedom in what they could record (after 1975 certain species incidentally caught with tuna were not recorded, and a rigid, formatted procedure of data recording was emphasized; since the late 1980s, however, Inter-American Tropical Tuna Commission observers have been instructed to collect such data on forms designed to quantify the bycatch). The data were the records from 33 fishing trips monitored by 22 observers who had consistently taken careful notes. These notes on species caught or seen with tuna (*i.e.*, "associated" with tuna) were mostly in addition to the catch and fishing operation data specifically requested and represented the observers' interests in bycatch species. Still, many of the taxonomic identifications they recorded were to family level only.

The purse-seine set data were stratified into two areas: (1) from 17°N latitude off central Mexico to 7°S latitude off Ecuador and westward to longitude 100°W (the southerly "Off Central America" sample) and (2) from more oceanic waters between longitudes 100°W and 135°W, *i.e.*, areas to the southwest of southern Mexico (the northerly "Off Mexico" sample). The Off Central America sample consisted of 1364 set records from 18% log-associated, 37% non-associated, and 45% dolphin-associated tuna schools, all similarly distributed in the area. The smaller Off Mexico sample (n = 398 set records) was from 1% log-associated, 26% non-associated, and 73% dolphin-associated schools. Overall, these purse-seine data represented sets located primarily north of the equator and east of 115°W (see Au, 1991, for details). Ninety percent of this information was collected between January and mid-June.

These data from the purse-seine vessels provided information on seabirds and subsurface species that were captured with YFT. The YFT were mainly found by searching for seabird flocks in areas where the fishermen had anticipated successful fishing. These data complemented the research-cruise observations that usually could not directly detect tuna or other subsurface predators.

RESULTS

The nature of the seabird flocks and of the associated, subsurface predators as seen from the research and from the purse-seine vessels are described in turn.

Research Vessel Observations

Species composition of seabird flocks

The data from 813 flocks and 30 bird taxa seen from the research vessels showed that 4 to 5 species or species groups predominated (Table 1). Considering all the flocks, the most abundant seabirds were terns, especially the Sooty Tern (scientific names are listed in Table 1), followed by Wedge-tailed Shearwaters, Juan Fernandez Petrels, and Red-footed, Masked, and Brown boobies.

These species often occur together in flocks feeding upon squids and small fishes that are driven to the surface by tunas or other subsurface predators, and they define, in large part, a characteristic feeding guild (Ballance 1993). Their mean numbers in the flocks ranged from 1.3 for the Brown Booby to 8.1 for the Sooty Tern (Table 1). Overall, each flock contained an average of 43.6 (SE = 4.06) individuals and 2.7 (SE = .07) different species. Micronekton-feeding storm-petrels (*e.g.*, Pitman and Ballance 1990) were also abundant, but generally did not join the flocks of the above birds.

The relative abundances of the species in the flocks differed according to the habitat preferences of the component species (Figure 1). West of 125°W, along the equator, and southwest of the Galapagos Islands, flocks were numerically dominated by Sooty Terns. North of the equator from 125°W to 160°W, and also off the coast of Peru, Juan Fernandez Petrels and Wedge-tailed Shearwaters were the most common species in the flocks. East of 115°W and north of the equator, flocks were comprised largely of Masked and Red-footed Boobies. This latter area can be considered the main purse-seine fishing "grounds" for YFT (see Hall *et al.*, this vol.).

Seabird flocks and associated subsurface predators

The majority, or 608 of the 813 total flocks (74.8%), were sighted without associated subsurface predators other than tuna (tuna were seen under 46 of these 608 flocks, and no subsurface predators could be seen under the remaining 562 flocks). Many of the tuna seen were large-sized, and therefore probably YFT. Although not commonly seen, tuna were still likely present in most cases, since seabirds aggregate in flocks to feed, and many of the flocks were actively feeding. There were no cetaceans seen with these 608 flocks.

The remaining 25.2% of the flocks (n = 205) were associated with cetaceans. Again, the flocks were usually feeding, so tuna were likely present, and in fact were seen under 76 of these flocks. The majority, 160 (78.0%) of these flocks, were with the relatively abundant spotted (*Stenella attenuata*), spinner (*S. longirostris*), or common (*Delphinus* spp.) dolphin species, while 33 (16.1%) were with other species. Most, 140 (68.3%), were with spotted dolphins, either in pure schools or schools mixed with spinner dolphins. Only a few were with common dolphins (8 or 3.9% of the 205 flocks). The prevalence and relative importance of the spotted dolphin-seabird association can be judged from Figure 2, which shows percentages relative to the total 813 flocks to accommodate also showing the percent for total flocks actually seen with tuna (15%).

The size and species diversity of flocks varied with the species of dolphin or tuna (Table 2). Flocks seen with spotted dolphin schools and mixed spotted and spinner dolphin schools were larger and more diverse (in terms of number of species) than those with spinner dolphins only (Table 2). The relatively few flocks with the presence of tuna confirmed but with no dolphins present were also large, but had the lowest diversity (Table 2). Considering the standard errors, only this latter regarding diversity constituted a difference that was significant, however.

Differences in flock diversity stem from the characteristic species that comprise the different types of flocks. Those flocks that were with spotted or spinner dolphins tended to be dominated by Wedge-tailed Shearwaters, Juan Fernandez Petrels, and boobies (Table 3). Those flocks without dolphins but with confirmed sightings of tuna were often dominated by Sooty Terns and/or the more nearshore Black Terns, in more monospecific flocks.

Purse-Seine Vessel Observations

Seabirds associated with YFT

Birds were recorded with most of the YFT schools caught, a consequence of fishermen locating such schools by searching for flocks. Mixed-species flocks accompanied approximately 80% of the log-associated and non-associated YFT schools and nearly all dolphin-associated schools (see Figures 3 and 5). Most of the latter involved spotted dolphins, as described below.

Different species of seabirds co-occurred frequently in all three types of YFT schools, but the frequencies of occurrence by species varied. Overall, the most-often-recorded species groups in the January-June purse-seine vessel data were boobies, shearwaters, terns, and frigatebirds and, less frequently, jaegers and petrels (Figure 3). Species-composition patterns differed somewhat from, but were not inconsistent with, that of the July-December research vessel observations. Boobies were commonly reported in the flocks with log-associated and dolphin-associated YFT, significantly more often than in flocks with non-associated YFT (as indicated by the depicted confidence limits). And terns occurred more frequently with non-associated YFT, similar to results from the research vessels. Frigatebirds (not numerous, but especially watched for by fishermen) were reported frequently with all school types, but significantly more often with dolphin-associated YFT. Shearwaters were common in flocks with all three types of tuna schools.

Flock size was a function of the flocks' species composition and the type of YFT school (Figure 4)(a similar graphic for a smaller sample was given by Au, 1991). Boobies, shearwaters, and terns occurred in relatively large groups or "subflocks" (birds of a taxon within a flock), while other taxa usually numbered less than ten. As with the research vessel observations, boobies and shearwaters were often abundant, particularly within the flocks with dolphin-associated YFT in the Central America sample; their means (geometric) were 65.2 and 108.4 birds per flock (SE = mean x/÷ 1.06 and 1.10) respectively. There were more large groups of boobies and shearwaters with dolphin-associated YFT than with the log-associated and non-associated tuna (Kolgomorov-Smirnov tests with $\alpha = .01$), suggesting that the dolphin-associated schools were at more productive feeding sites. The subflock sizes of terns, which though more frequent with the non-associated YFT schools, were similar among school types.

Subsurface predators associated with YFT

The predatory fishes and other species caught as bycatch with tuna constituted a sample of the subsurface predator community of which YFT are a part. Figure 5 shows the percent of purse-seine sets in which different species or species groups were caught in association with YFT. Details of these catches were given by Au (1991).

The dolphins associated with the YFT were mostly spotted dolphins, as already mentioned. Of the total 908 dolphin-associated schools encircled, 81.4% were with spotted or spotted plus spinner dolphins, 2.4% were with spinner dolphins only, and 15.6% were with common dolphins.

Sharks were commonly associated with the YFT, occurring in 40% of the sets upon log-associated schools overall, though up to 90% of such sets on some fishing trips. Most were 2 m or longer in length. The percentage of co-occurrence declined significantly (95% CIs not overlapping (not shown)) to 21% and to 13% in the non-associated and the dolphin-associated YFT schools respectively from off Central America. The silky shark (*Carcharhinus falciformis*) was commonly reported, especially in the log-associated schools; their numbers when present averaged 29, though 500 were recorded from one particular set. In the sets upon dolphin-associated YFT, the oceanic white-tip shark (*C. longimanus*) was the more commonly caught species.

Billfishes (Istiophoridae) were caught with YFT in 9% of all sets. The mean occurrence rate was similar among all types of tuna schools, although on some trips billfishes were caught in up to 43% of the sets upon log-associated schools. Billfishes, especially the sailfish (*Istiophorus platypterus*), occurred with YFT more frequently off Central America.

A relatively high percentage of the purse-seine sets took YFT together with skipjack tuna (*Katsuwonus pelamis*) or other small tunas (generally <50 cm FL). Sixty-six percent of log-associated YFT schools that were caught included both YFT and skipjack. This rate declined significantly to 40% with non-associated and to 3% with dolphin-associated schools. The smaller "bullet" tuna (*Auxis spp.*) and black skipjack tuna (*Euthynnus lineatus*) were also found associated with YFT. Their occurrence rates averaged 11% in sets on log-associated YFT, though some trips recorded bullet tuna in up to 41% of such sets. These small tunas were rare with the dolphin-associated schools.

Rays, especially mantas (Mobulidae), and turtles (mainly the olive ridley (*Lepidochelys olivacea*) (see Pitman 1993)) were each caught with YFT in 10% or less of the sets, the former mainly with non-associated and seldom with the log-associated schools. Dolphinfish (*Coryphaena spp.*) were caught especially with log-associated YFT, as they themselves are often log-associated.

The above subsurface predators are not normally seen with YFT unless the tuna are captured. Some species are caught more frequently than others, and the species' frequencies change with the type of tuna school, but all are regularly taken. Like seabirds and dolphins, they appear to be associated with YFT schools, at least in so far as being attracted to the same feeding places.

DISCUSSION

The research vessel and purse-seine vessel observations, considered together, reveal some important association patterns among YFT, seabirds, cetaceans, and other pelagic predators. In particular, the data indicated that seabird flocks are comprised of a certain few, numerically important species; that most surface-feeding tuna schools in the ETP are not usually with cetaceans; and that when they are, only a few of many possible cetacean species are involved.

The tuna birds

The research vessel observations showed that seabird flocks, especially those associated with dolphins, were comprised largely of Wedge-tailed Shearwaters, Juan Fernandez Petrels, Red-footed and Masked boobies, and Sooty Terns (see also Au and Pitman 1986, 1988). These species characterize a widespread, "subsurface predator-dependent (seabird feeding) guild" in the ETP (Ballance 1993). The purse-seine vessel data from the area of the main purse-seine fishing grounds (ETP areas north of the equator and east of 115°W) likewise linked an abundance of shearwaters, boobies, and, less commonly, terns to YFT, dolphins, and other subsurface predators actually caught.

The above seabird species are thus characteristic of the flocks found over surface-feeding YFT in the ETP. All are highly mobile predators that specialize in gathering quickly over surface-feeding tuna (Ballance 1993). The minor differences between the research and purse-seine vessels' lists of frequently occurring and numerically important species in the flocks stemmed from the larger area surveyed by the research vessels, the special interests of fishermen (*e.g.*, the importance of frigatebirds), and especially from differences in season of observation. For example, breeding jaegers return northward from the tropics by the northern summer and Juan Fernandez Petrels southward by the northern winter, so the jaegers were more often reported from the purse-seine vessels (winter-spring observations) and the petrels more often from the research vessels (summer-fall observations).

Bird flocks and subsurface predators

Seabird flocks occur wherever tunas feed frequently near the sea surface, with the relative abundances of different species in the flocks varying as the seabirds' habitats change. These habitats differentially overlap the habitat of surface-feeding YFT that delineates the grounds of the purse-seine fishery, a vast triangular area from Mexico to Peru and westward to about 145°W (see Hall *et al.*, this vol.). Thus while the highest-density areas for Sooty Terns are excluded from these grounds, those of boobies are not, especially on the main fishing grounds east of 115°W (Figure 1; Ballance 1993). Terns, however, were found to be common with the non-associated YFT schools even in areas characterized by booby-dominated flocks, just as they dominate many flocks not with dolphins in the far offshore areas. Perhaps these terns, which are relatively small birds, were with smaller tunas (next paragraph) that were pursuing smaller, more-suitable prey.

The subsurface bycatch data suggest that YFT schools and their associated flocks are often part of multi-species feeding assemblages (Figure 5). The subsurface predators common with the smaller (mostly <70 cm FL), log-associated YFT, are mainly sharks, other species of small tunas, and sometimes billfishes. These species occurred less frequently with non-associated and dolphin-associated YFT schools. There is an increase in the modal size of YFT with school type (modes at *ca.* 45 cm with log-associated and increasing to *ca.* 105 cm with dolphin-associated YFT; see Hall *et al.*, this vol.), and so it appears that as these fish grow and become more nomadic, they meet other nomadic, though more thinly-distributed, predators. These predators include many of the species that aggregate near logs, but also others that are more free-ranging, such as certain rays, turtles, and cetaceans. YFT schools in the ETP, therefore, appear to be "polyspecific," *i.e.*, they seem to forage nomadically, often with multi-species associates (Au 1991).

A significant observation concerning the behavior of the flocks associated with these schools is that their feeding bouts can be long, sometimes lasting for hours over the moving schools (Ballance 1993; pers. obs.). Apparently, the prey "patches" the tuna feed upon are often large, perhaps several km in dimension. Prey may extend well below the surface, and feeding activity may occur at depth, for catches from such tuna schools will take other predators as well, like sharks and marlins that are not seen at the surface. Thus these prey patches may be extensive and as a result attract a variety of nomadic predators, including YFT in several size modes varying from 50 to more than 150 cm FL (Calkins 1965; pers. obs.), dolphins, seabirds, and even the tuna purse-seine vessels.

Tuna and dolphins

It is curious that the YFT schools are found predominantly associated with only three dolphin species: spotted dolphins especially, but also spinner and common dolphins (*e.g.*, Allen 1985). Only the first two species, in pure or mixed schools, are commonly (>50% of schools) with bird flocks that indicate the presence of tuna. The research vessel data showed that while only 25% of flocks seen were with cetaceans, 68% of such flocks were with spotted dolphins in pure schools or schools mixed with spinner dolphins. Just as importantly, the tuna appear to not be with the 20 or so other species of dolphins and whales of the ETP, those species being rarely with flocks, even though not uncommon, at least as aggregate species (Au and Pitman 1986, 1988). This is remarkable, considering that YFT are known to swim with or near a variety of other pelagic animals as well as all kinds of flotsam. It seems that YFT either distinguish the different cetacean species and especially select spotted dolphins or that dolphin, in particular, is attracted to the YFT, the main schooling predatory fish in its environment.

As mentioned, the research vessel observations indicated that most surface-feeding tuna schools in the ETP are not usually in company with cetaceans. Au and Pitman (1986) similarly found that 57% of flocks were not with dolphins in the ETP north of 5°N and east of 125°W, with higher dolphin-free percentages occurring to the west. Tuna-indicating seabird flocks not with dolphins being common over wide areas, it does not appear that YFT find it especially advantageous to feed with dolphins.

Furthermore, in watching tuna and dolphins when they are together, it became apparent to us that only the tuna make prey available to the attendant feeding birds. Nearly all the nekton-feeding bird species in the ETP will take advantage of these tuna-feeding situations, the species showing little or no interest being exceptional (*e.g.*, Pitman and Ballance 1992). Our observations indicate that the birds focus their attention almost entirely upon the tuna, just as they do when dolphins are not present, while the associated dolphins are seen to feed casually, if at all, among the frenzied tuna. This is consistent with observations that these dolphins appear to often feed at night (Leatherwood and Ljungblad 1979, Norris and Dohl 1980, Carey and Olson 1982, Scott and Wussow 1983, Scott and Cattanach 1998). Corroboratively, samples from the purse-seine fishery show that many spotted dolphins that are caught with YFT have empty stomachs in the afternoon (Scott and Cattanach 1998). While Edwards (1992) argued, mainly from energetics considerations, that YFT should be obtaining feeding benefits from the dolphins, we have not seen evidence for that.

These various observations related to feeding tuna and birds indicate to us that the association between YFT and dolphins does not result from a simple feeding relationship, though it may be prey-based. Any benefits the day-feeding tuna may provide to the dolphins (or perhaps night-feeding dolphins to the tuna) may be only supplementary and may be indirect or delayed. During the day then, the dolphins may be mainly following or monitoring the prey resources along with other predators, perhaps also obtaining information about that prey from the tuna, as some seabirds appear to do.

Notwithstanding the above, there is also reason to suspect that the relationship between YFT and dolphins may be more, or other than, prey-based, that there is a protection aspect as well. Considering that YFT are caught under chased and encircled dolphins in the purse-seine fishery, this is an obvious possibility, and has been suggested previously (Au and Pitman 1988, Scott and Cattanach 1998). We have frequently observed that even when the tuna have been vigorously feeding at the surface for an hour or more, they would quit feeding and flee with the dolphins upon our research vessel's approach to within 1-2 km, the same kind of behavior that leads to the tuna's capture by purse-seiners. Fleeing with dolphins would be advantageous to tuna if, as a general tactic, it results in escaping most other predators most of the time. It seems that the tuna-dolphin association involves multifaceted relationships, with both direct and indirect, reciprocal benefits.

LITERATURE CITED

Allen, R. L. 1985. Dolphins and the purse-seine fishery for yellowfin tuna. *In* Beddington, J. R., R. J. H. Beverton, and D. M. Lavigne (eds.), Marine mammals and fisheries, p. 236-252. Allen and Unwin, Inc., Winchester, Maryland.

Ashmole, N. P., and M. J. Ashmole. 1967. Comparative feeding ecology of seabirds of a tropical oceanic island. Peabody Mus. Nat. Hist., Yale Univ. Bull. 24:1-131.

Au, D. W. 1991. Polyspecific nature of tuna schools: shark, dolphin, and seabird associates. Fish. Bull., U.S. 89:343-354.

Au, D. W. K., and R. L. Pitman. 1986. Seabird interactions with dolphins and tuna in the eastern tropical Pacific. Condor 88(3):304-317.

Au, D. W., and R. L. Pitman. 1988. Seabird relationships with tropical tunas and dolphins. *In* Burger, J. (ed.), Seabirds and other marine vertebrates, p. 174-112. Columbia Univ. Press, New York

Ballance, L. T. 1993. Community ecology and flight energetics in tropical seabirds of the eastern Pacific: energetic correlates of guild structure. PhD Dissertation, University of California, Los Angeles.

Calkins, T. P. 1965. Variation in size of yellowfin tuna (*Thunnus albacares*) within individual purse-seine sets. Inter-Amer. Trop. Tuna Comm. Bull. 10(8):463-524.

Carey, F. G., and R. J. Olson. 1982. Sonic tracking experiments with tunas. Int. Comm. Conserv. Atl. Tunas, Collect. Vol. Sci. Pap., 17(2):444-457.

Edwards, E. F. 1992. Energetics of associated tunas and dolphins in the eastern tropical Pacific Ocean: A basis for the bond. Fish. Bull., U.S. 90:678-690.

Harrison, C. S., and M. P. Seki. 1987. Trophic relationships among tropical seabirds at the Hawaiian Islands. *In* Croxall, J. P., (ed.), Seabirds: feeding ecology and role in marine ecosystems, p. 305-326. Cambridge Univ. Press, Cambridge.

Holt, R. S., and S. N. Sexton. 1989. Monitoring trends in dolphin abundance in the eastern tropical Pacific using research vessels over a long sampling period: analysis of 1986 data, the first year. Fish. Bull. U.S., 88:105-111.

Leatherwood, S., and D. K. Ljungblad. 1979. Nighttime swimming and diving behavior of a radio-tagged spotted dolphin, *Stenella attenuata*. Cetology 34:1-6.

Norris, K. S., and T. P. Dohl. 1980. Behavior of the Hawaiian spinner dolphin, *Stenella longirostris*. Fish. Bull., U. S. 77(4):821-849.

Pitman, R. L. 1993. Seabird associations with marine turtles in the eastern Pacific Ocean. Colonial Waterbirds 16(2):194-201.

Pitman, R. L. 1986. Atlas of seabird distribution and relative abundance in the eastern tropical Pacific. Admin. Rep. LJ-86-02, Southwest Fisheries Center, La Jolla, Calif.

Pitman, R. L., and L. T. Ballance. 1992. Parkinson's petrel distribution and foraging ecology in the eastern tropical Pacific: Aspects of an exclusive feeding relationship with dolphins. Condor 94:825-835.

Pitman, R. L., and L. T. Ballance. 1990. Daytime feeding by Leach's storm petrel on a midwater fish in the eastern tropical Pacific. Condor 92:524-527.

Scott, M. D., and K.L. Cattanach. 1998. Diel patterns in aggregations of pelagic dolphins and tunas in the eastern Pacific. Mar. Mammal Sci. 14(3):401-428

Scott, M. D., and P. C. Wussow. 1983. Movement of a Hawaiian spotted dolphin. *In* Pincock, D. (ed.), Proceedings, fourth international conference of wildlife biotelemetry, Halifax, Nova Scotia, p. 353-364.

Seki, M. P., and C. S. Harrison. 1989. Feeding ecology of two subtropical seabird species at French Frigate Shoals, Hawaii. Bull. Mar. Sci. 45(1):52-67.

Wade, P. R., and T. Gerrodette. 1993. Estimates of cetacean abundance and distribution in the eastern tropical Pacific. Rep. Int. Whal. Commn. 43:477-494.

Table 1. Species composition of seabird flocks in the eastern tropical Pacific (n = 813 flocks). Listed are the thirty most abundant taxa.

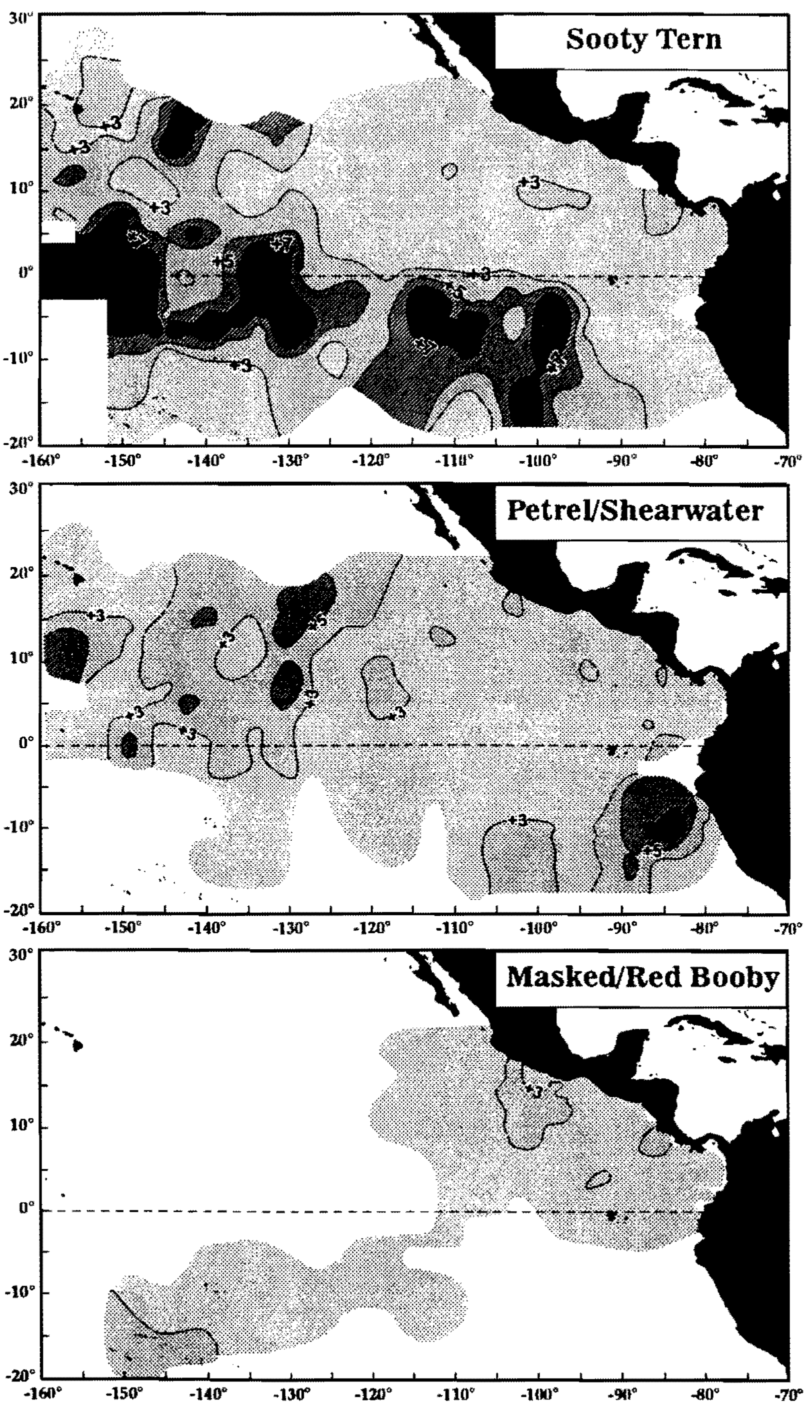
Species	**Total Number Recorded in Flocks**	**Mean Number per Flock (SE)**
Sooty Tern, *Sterna fuscata*	6,632	8.1 (0.9)
Wedge-tailed Shearwater, *Puffinus pacificus*	5,611	6.9 (1.6)
Juan Fernandez Petrel, *Pterodroma externa*	5,176	6.4 (1.1)
Red-footed Booby, *Sula sula*	3,372	4.1 (0.9)
Black Tern, *Chlidonias niger*	2,735	3.4 (2.5)
Masked Booby, *Sula dactylatra*	1,830	2.2 (0.6)
Galapagos Storm-petrel, *Oceanodroma tethys*	1,163	1.4 (0.4)
Brown Booby, *Sula leucogaster*	1,084	1.3 (0.3)
Storm-Petrel species, *Oceanodroma* spp.	999	1.2 (0.4)
Frigatebird species, *Fregata* spp.	961	1.2 (0.3)
Arctic Tern, *Sterna paradisaea*	820	1.0 (0.2)
Townsend's Shearwater, *Puffinus newelli*	640	0.8 (0.2)
Black-vented Shearwater, *Puffinus opisthomelas*	454	0.6 (0.4)
Red Phalarope, *Phalaropus fulicarius*	401	0.5 (0.3)
Dark-rumped Petrel, *Pterodroma phaeopygia*	337	0.4 (0.3)
Phalarope species, *Phalaropus* spp.	283	0.3 (0.1)
White Tern, *Gygis alba*	272	0.3 (0.1)
Pink-footed Shearwater, *Puffinus creatopus*	242	0.3 (0.05)
Unidentified non-passerine	230	0.3 (0.1)
Leach's Storm-petrel, *Oceanodroma leucorhoa*	223	0.3 (0.1)
Leach's/Harcourt's Storm-petrel, *Oceanodroma leucorhoa/castro*	174	0.2 (0.1)
Audubon's Shearwater, *Puffinus lherminieri*	147	0.2 (0.1)
Cook's Petrel, *Pterodroma cooki*	146	0.2 (0.1)
Brown Noddy, *Anous stolidus*	119	0.1 (0.04)
Tern species, *Sterna* spp.	115	0.1 (0.1)
White-winged Petrel, *Pterodroma leucoptera*	104	0.1 (0.05)
Jaeger species, *Stercorarius* spp.	99	0.1 (0.03)
Christmas Shearwater, *Puffinus nativitatus*	82	0.1 (0.02)
Black Storm-petrel, *Oceanodroma melania*	79	0.1 (0.05)
Hornby's Storm-petrel, *Oceanodroma hornbyi*	78	0.1 (0.1)

Table 2. Flock size and diversity of seabird flocks feeding over different subsurface predators.

	Identity of Subsurface Predator			
	SPOTTED DOLPHIN (no spinner)	**MIXED SPOT./SPIN.**	**SPINNER DOLPHIN (no spotted)**	**TUNA (no dolphin)**
Mean Flock Size (SE)	115.8 (28.0)	114.3 (18.0)	43.0 (19.5)	105.7 (44.0)
Mean No. Species (SE)	5.3 (0.3)	5.7 (0.3)	4.4 (0.6)	3.4 (0.3)
Total No. Species Recorded all Flocks	25	30	18	29
Number of Flocks	62	78	12	46

Table 3. The 10 most abundant seabird species (mean number) recorded in flocks feeding over three different subsurface predators. Numbers in parentheses represent mean number of individuals per flock of that seabird in flocks associated with each type of subsurface predator.

SPOTTED DOLPHIN (no Spinner) (n=62 flocks)	**SPINNER DOLPHIN (no Spotted) (n=12 flocks)**	**TUNA (no dolphin) (n=46 flocks)**
Wedge-tailed (34.7) Shearwater	Wedge-tailed (24.8) Shearwater	Black Tern (48.3)
Juan Fernandez (28.0) Petrel	Juan Fernandez (6.5) Petrel	Sooty Tern (19.0)
Red-footed (21.8) Booby	Black Storm- (2.9) Petrel	Juan Fernandez(13.0) Petrel
Brown Booby (8.0)	Townsend's (2.7) Shearwater	Wedge-tailed (6.3) Shearwater
Sooty Tern (7.1)	Red-footed (1.7) Booby	Dark-rumped (5.5) Petrel
Frigatebird (4.4) Spp.	Brown Booby (0.7)	Red-footed (2.8) Booby
Masked Booby (4.1)	Masked Booby (0.7)	Arctic Tern (2.6)
Townsend's (2.9) Shearwater	Frigatebird (0.5) spp.	White Tern (1.5)
Pink-footed (1.4) Shearwater	Sooty Tern (0.5)	Brown Booby (1.3)
Arctic Tern (1.0)	Jaeger spp. (0.4)	Frigatebird (1.2) spp.



Sooty Tern

Petrel/Shearwater

Masked/Red Booby

Figure 1. Distribution patterns of three major seabird flock types in the eastern tropical Pacific ("Sooty Tern" = seabird flocks numerically dominated by Sooty Terns; "Petrel/Shearwater" = numerically dominated by Juan Fernandez Petrels and Wedge-tailed Shearwaters; "Masked/Red Booby" = numerically dominated by Masked and Red-footed boobies). Contours indicate the total number of seabird flocks of each type sighted during the surveys (darker shading indicates greater numbers of flocks). After Ballance (1993).

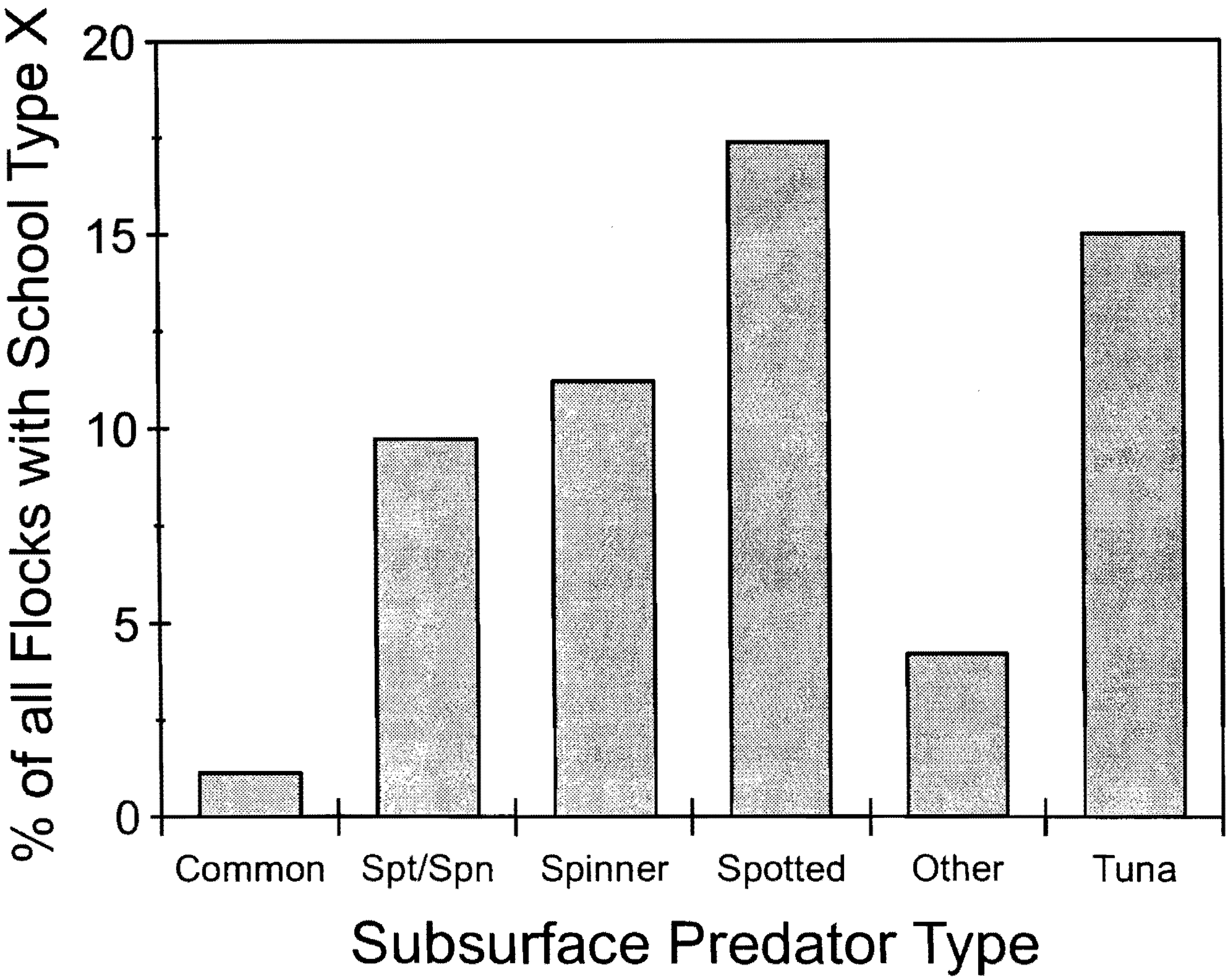


Figure 2. Percent of all seabird flocks that occurred over different school types, *i.e.*, schools of the different predators: Common dolphin, Spotted dolphin, Spinner dolphin, Spt/Spn (both Spotted and Spinner dolphins), Other cetaceans, and Tuna (tuna seen, both with and without cetaceans).

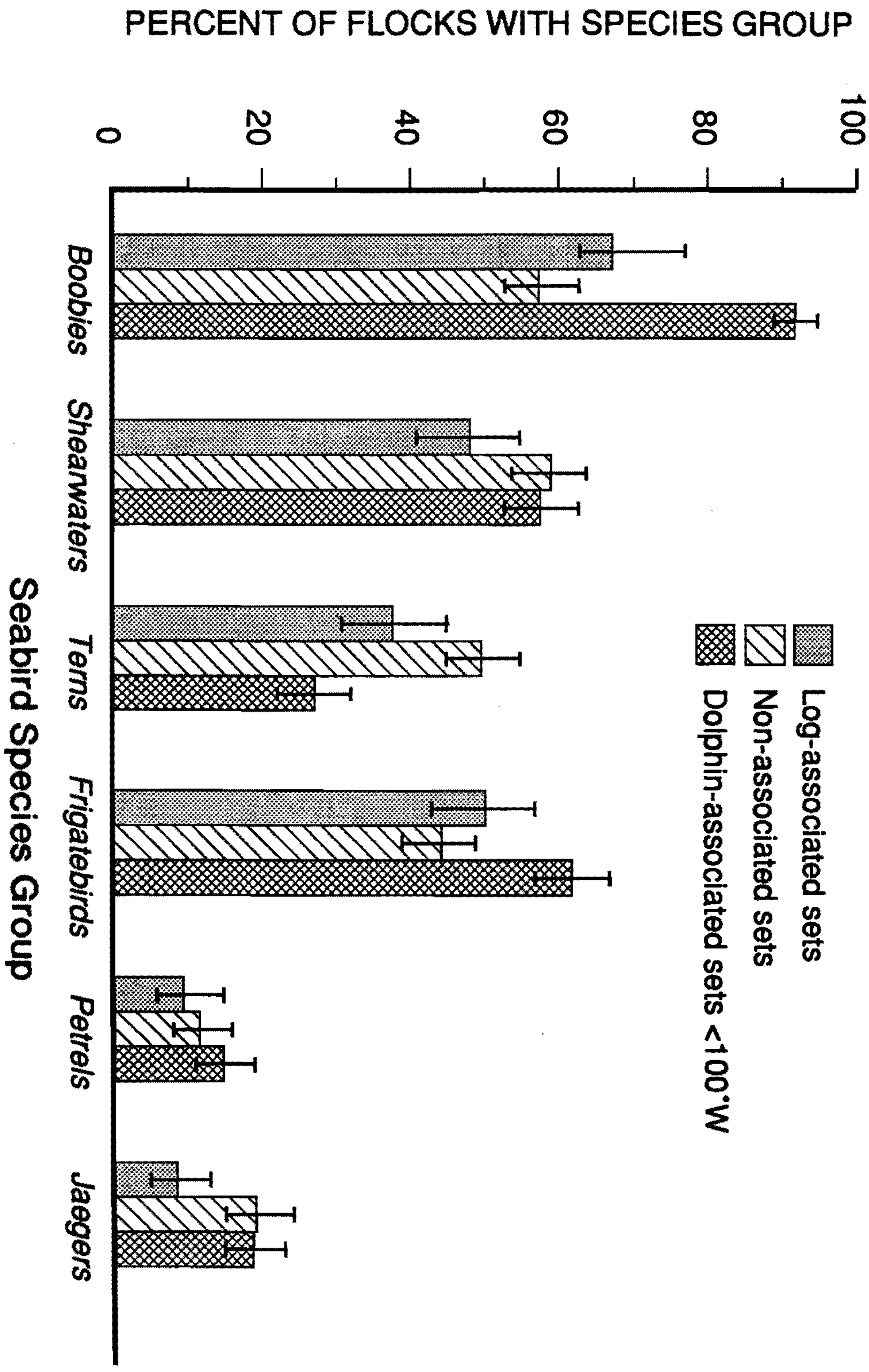


Figure 3. The percent of yellowfin-tuna-associated flocks with different species groups of seabirds present, according to the type of tuna school association or set. Data are from the "Off Central America" area. Error bars are 0.95 confidence intervals (CI) from the binomial distribution.

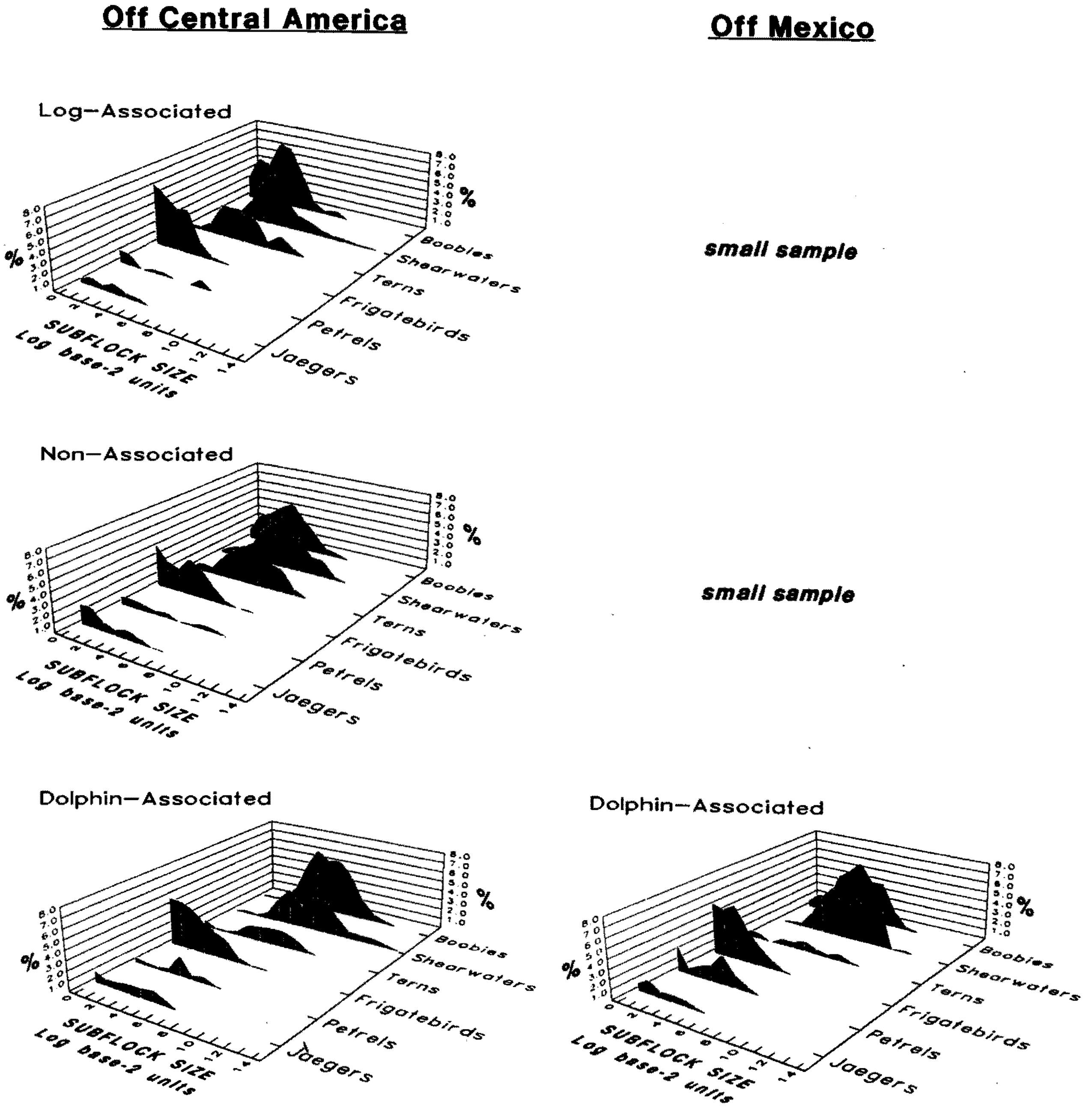


Figure 4. Size frequencies of bird species groups according to the type of tuna school association. Subflock sizes on the x-axes are the upper bounds of doubling size increments indicated by the log-base-2 scale (*e.g.*, 1 = size of $2^1 = 2$, 2 = size of $2^2 = 4$, etc.). Ordinate scales show the percentage that different species' subflocks, by size, were of all subflocks with that type of tuna school.

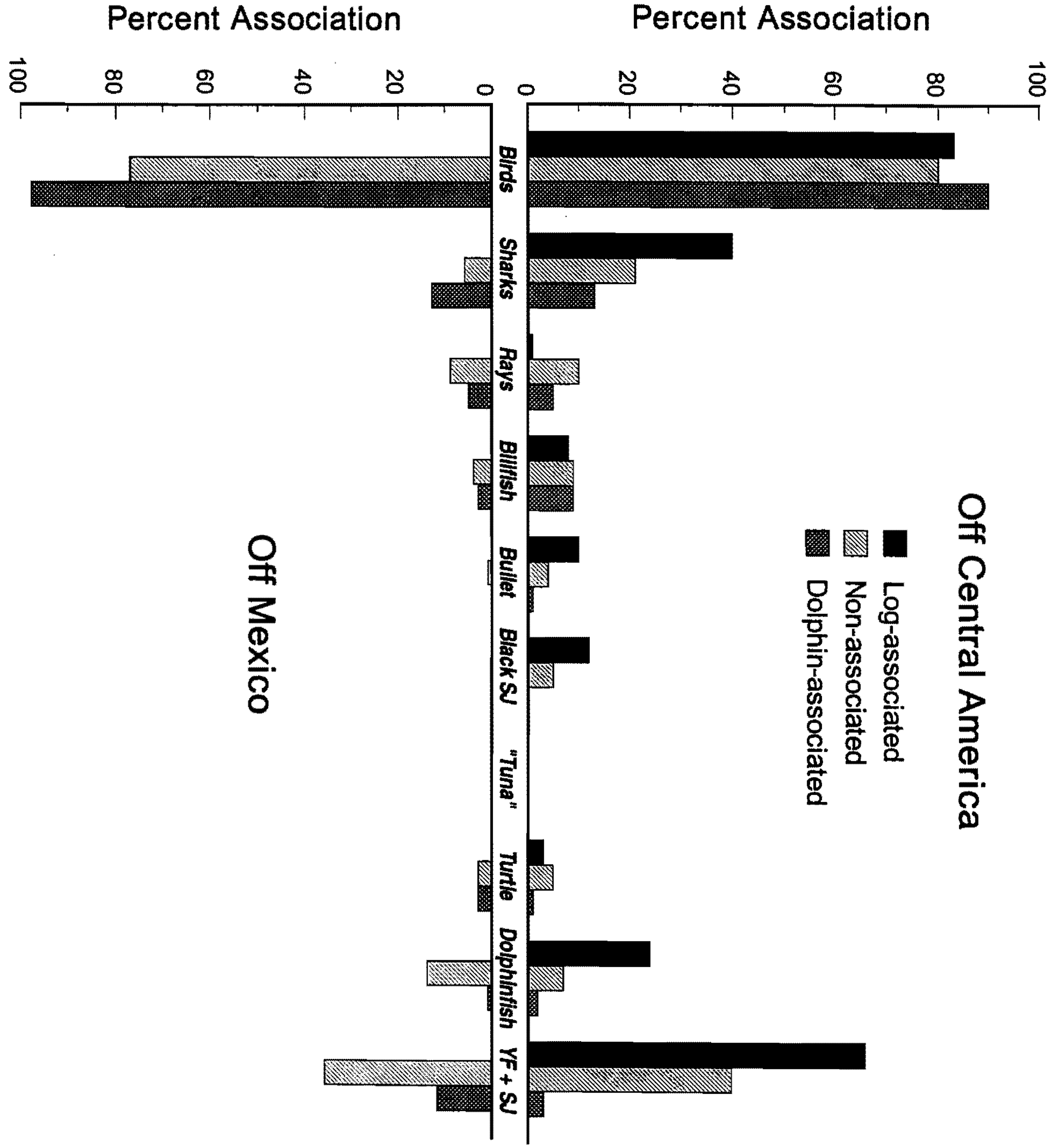


Figure 5. Species, or species group, percent association with yellowfin tuna schools ("Tuna" = unspecified tuna species, YF = yellowfin tuna, SJ = skipjack tuna). After Au (1991).

SIMULATED TRAJECTORIES OF FLOATING OBJECTS ENTERING THE EASTERN TROPICAL PACIFIC OCEAN

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ABSTRACT

A Lagrangian simulation model is used to predict and analyze the trajectories of floating objects entering the eastern Pacific Ocean through five selected locations near the mouths of major rivers of the region.

For each location, basic characteristics, seasonality (especially in relation to precipitation patterns), and annual variability (with emphasis on the impact of El Niño events) are presented and discussed.

The main conclusions are that: (1) through either cyclic current patterns or oscillating north-south movements, most objects are retained relatively close to their source for considerable periods; (2) practically all the transport offshore occurs along 10°N, which receives objects from the north and south; (3) El Niño events alter the patterns substantially, increasing the velocity of the offshore movements of the objects, but always along 10°N.

It is suggested that the association of tunas with floating objects is a retention mechanism, keeping the tunas in the rich coastal areas, and eventually carrying them west through the most productive areas of the eastern Pacific Ocean.

There are many other potential uses for the drift trajectories, among them studies of biogeochemical cycles involving the floating objects, distribution of marine debris, distribution of juveniles of marine organisms such as sea turtles, and regional and transoceanic dispersal.

INTRODUCTION

Hall *et al.* (review article, this volume) identified tropical rivers that empty into the ocean after crossing forests, jungles, and mangrove swamps were the primary sources of natural floating objects to the eastern Pacific Ocean (EPO). During the rainy season, floods and augmented river flow increase the transport of tree trunks and parts and other floating objects to the ocean. It is of ecological interest to know what happens with all this material after entering the ocean.

What kind of material enters the oceans, and in what quantities? How long do these floating objects last in the surface layers? Are they spread by diffusion or do they concentrate in some areas? How long do they remain in the coastal zone? What proportion becomes stranded on beaches? Are there areas of the ocean floor that receive large amounts of these objects? How does the decomposition process work in these areas? Do nutrients and organic matter re-enter the surface layer and, if so, how long does this take? We are interested in the population dynamics of floating objects: their "recruitment" seasons and areas, their movements, their "mortality rates," and their role as focal points for faunal communities and as dispersal agents for species. We are also interested in their role in biogeochemical cycles. The answers to many of these questions will probably be of significance to the ecology of tunas, and may help us understand why they associate with floating objects.

One of the main questions from the point of view of the association of tunas with floating objects is where do the objects go after they enter the ocean? To answer this question two limited experiments were carried out off Colombia and Ecuador, in which natural logs were tagged with numbered plastic squares (Anonymous, 1988; 1989). Cayré and Marsac (1990) conducted a similar study in the western Indian Ocean. In all cases, the number of recoveries was low or the results were limited by the number of objects studied. A different approach is described here, based in the use of a simulation model of the surface circulation in the area. The main underlying processes that affect the dynamic behavior of the oceans have been modeled by several authors. Busalacchi and O'Brien (1980, 1981) and Busalacchi *et al.* (1983) described the seasonal and interannual variability of the equatorial Pacific, using a wind-forced, reduced-gravity, linear transport model. Luther and O'Brien (1985) described the use of a non-linear reduced-gravity model to simulate the wind-driven circulation in the Indian Ocean. Parés-Sierra and O'Brien (1989) used a similar model to describe the variability of the California Current system. Seckel (1972) used a simple wind-driven circulation model to study the contribution of the currents to the migration of skipjack that enter the North Equatorial Current (NEC) in the eastern Pacific and to support the hypothesis that skipjack may travel from the eastern Pacific to Hawaii by swimming randomly and drifting with the current. Power (1986), using an advection-diffusion model, demonstrated that variations in the location and time of spawning of the northern anchovy and changes in the magnitude of Ekman transport have significant effects on the larval distribution of the species.

The main objectives of this study are to model the movement of floating objects entering the EPO from the rivers of South and Central America, and to relate these movements to the proposed migrations of yellowfin tuna. The study is focused on natural objects, mostly trees and parts of trees, the most abundant type of floating object found.

The main questions we want to explore are:

- Direction, velocity, and other characteristics of the trajectories.
- Influence of the origin of the object on its final destination.
- Seasonal and annual variation in the trajectories of objects with a common origin.
- Effects of El Niño events (Table 1) as a special case of annual variability.

MATERIALS AND METHODS

A 1½ reduced-gravity, non-linear model (Figure 1a), based on the equations described by Parés-Sierra and O'Brien (1989), was used to obtain the underlying ocean currents of the Equatorial Pacific Ocean. This equatorial model differs from that described by Busalacchi and O'Brien (1980, 1981) only in the resolution of the borders and the introduction of non-linear terms. The model was adapted by redefining in more detail the western coast of the American continent, and solved on a grid of 663 by 182 0.25-degree squares, covering the equatorial Pacific from 20°S to 25°N. The model was forced using realistic values of wind speed and direction for the area from the Comprehensive Ocean- Atmosphere Data Set (COADS). The model equations were integrated from 1971 to 1987, obtaining monthly matrices of current vectors and thickness of the upper layer. These matrices were the input for a Lagrangian simulation model to compute the trajectories of the drifting objects. The drift direction and speed of an object was calculated as the vector resulting from the linear interpolation of the current components on the four corners of the square in which the object is located (Figure 1b). The possible effects of the object's shape and depth and of direct wind-induced drag on the object were ignored. For each of five selected areas, one-year-long simulations of the trajectory of five objects were run for each month in the 1976-1986 period. The starting point of each object was a random point in a circle of radius 0.25 degrees drawn around the center of each selected area. The model was run on the CRAY-YMP supercomputer in the San Diego Supercomputer Center. For the interpretation of the current patterns, the maps of circulation vectors from Wyrtki (1965) were used (Figure 2).

RESULTS AND DISCUSSION

Location of Sources (Origins)

The origins were defined based on the location of the mouths of the main rivers of the area (Figure 3). A total of 15 entry points were selected, and from those we chose the following five for a more detailed discussion. Precipitation values are approximate.

Area 1: Centered at 16°N, 104°W. The most important river in southern Mexico, the Balsas River, is located in this area. The rainy season occurs between May and October, with peaks in June-July (>300 mm/month). The dry season takes place from November to April, with the lowest precipitation levels in February-March (25 mm/month) (Figure 4).

Area 2: Centered at 13°N, 93°W, off the Guatemalan coast, and probably influenced by the Suchiate (Mexico), Coyolate (Guatemala), and Lempa (El Salvador) rivers. Abundant rain (1200 - 3200 mm/yr). Rainy season occurs from May to October, with the peak in June (390 mm/month). The dry season takes place from November to May, with the lowest rainfall in January (<10 mm/month) (Figure 4).

Area 3: Centered at 7°N, 86°W, off Costa Rica; receives water from the Tempisque, Pirris, and General rivers. High precipitation (>3200 mm/yr). The rainy season occurs from May to November, with peaks in September and October (300 mm/month). The dry season takes place from December to April, with the lowest precipitation level in January (25 mm/month) (Figure 4).

Area 4: Centered at 4°N, 79°W, off Colombia, it receives water from many Colombian rivers, including the Bando, San Juan, San Juan Micay, and Patia. It has the highest precipitation in the entire continent (Figure 4). The extended rainy season occurs from May to November, with peaks in September and October (900 mm/month), and the lowest levels in February-March (650-700 mm/month).

Area 5: Centered at 3°S, 83°W, off the Gulf of Guayaquil. Includes the Guayas River, the main river of the west coast of South America. The rainy season occurs from January to April, with peaks in February-March (300 mm/month). The dry season takes place from May to December, with low levels of precipitation (<10 mm/month) (Figure 4).

Seasonal and Annual Variation: Area Studies

Area 1: Seasonal and annual variability is quite pronounced in this area. The current system is the result of the interaction between the Costa Rica Coastal Current (CRCC), moving northwest along the coast of Central America, and the Counter Current of Southern Mexico (CSM), flowing southeast toward the Gulf of Tehuantepec. There is an annual cycle in the intensity and location of both currents. During May to July, both are present, and the CRCC is close to the continent. During August and September, the CRCC is the dominant current. From October to April, the CSM comes closer to the continent, displacing the CRCC to the southwest. This process peaks in February-March, when the CRCC is completely replaced as the dominant force by the CSM flowing southeast. This is clearly seen in Wyrtki's (1965) charts of monthly surface circulation (Figure 2). Objects entering the ocean in the rainy season (June-July) start drifting to the southeast, eventually turning toward the continent or to the west when they reach the Gulf of Tehuantepec. Objects entering the ocean between August and October start drifting to the northwest, under the influence of the CRCC, reaching the Cape Corrientes area of Mexico. Objects reaching Cape Corrientes during May-July continue north and then turn south near the mouth of the Gulf of California to return to Cape Corrientes (Figure 7, January). Objects arriving at Cape Corrientes between December and April approach the coast and begin a return movement to the southeast (Figure 7, August and September).

For floating objects in this area, the simulations show that there is a high probability that they will eventually reach the northern end of the Gulf of Tehuantepec, where they are carried to the west by the North Equatorial Current (NEC). The current system carrying the objects from the Gulf of Tehuantepec to the west varies among seasons and years, especially when there is an El Niño event. In some seasons, the objects reach farther south, to the edge of the Costa Rica Dome, before turning west (Figure 5a), or turn west just off the Gulf of Tehuantepec (Figure 5b).

The most obvious El Niño effect in this area is a faster than normal westward movement. The objects that entered the Pacific in 1983 in this area followed the same trajectories regardless of the season: an initial drift to the southeast, a turn to the northwest, and then due west to the NEC (Figure 6). Similar trajectories can be seen in the weak El Niño event of 1976 (Figure 7).

<u>Area 2:</u> Trajectories in this area are similar, and seasonal changes are not very pronounced. Figure 2 shows the three main currents that influence this area: (1) the CRCC, flowing toward the northwest along the coast; (2) the CSM, influencing the October-April period, and flowing toward the southeast; and (3) the anticyclonic gyre of Central America, especially noticeable during February-March.

Many trajectories resulted in stranding of the objects, frequently in the northern end of the Gulf of Tehuantepec (Figure 8). Even if the model is not accurate in predicting movement close to the coast (because of local topography and tides, and other factors more detailed than the model's resolution), the trajectories are similar to surface-current vectors on the charts (Figure 2). Throughout the year, the Gulf of Tehuantepec is dominated by a coastal current, branching off from the northwest-flowing CRCC and deviating toward the southwest as a consequence of the topography in the north of the Gulf (Blackburn, 1962). This deviation and the influence of local currents may be the reason for the number of objects stranding in this area.

> Floating objects entering the ocean during the rainy season drift west along 10°N. This movement becomes more obvious as the season progresses (Figures 9 and 10), and is particularly noticeable for objects entering the ocean in September. From June to October, both the CRCC and CSM turn west just off the Gulf of Tehuantepec (Figure 2), and the trajectories go to the NEC.

As in Area 1, the effect of El Niño events is to accelerate the westward drift after an initial move to the southeast (Figure 11). The pattern for 1977 is peculiar, with objects entering the ocean in August-December drifting southwest and eventually turning toward the east at 5°N in the Equatorial Counter Current (ECC) and returning to the coastal areas (Figure 12).

<u>Area 3:</u> This area is influenced by two current systems (Figure 2): (1) from May to January, the prevailing currents come from the ECC; and (2) during February to April, when the ECC withdraws to the west, the area is dominated by a cyclonic eddy around the Costa Rica Dome.

The trajectories of objects entering in this area show strong seasonal and annual variations (Figures 13 and 14). There are two distinct patterns during the rainy season: (1) objects entering the ocean between June and August drifted near their entry points, followed the coastline or moved southwest, in several cases finishing their year in the Gulf of Panama (Figure 14, June and July); (2) objects entering during September-November drift to the northwest to 10°N and, in some cases, turn west into the ECC. The CRCC is probably responsible for the first stage of this transport (Figure 13).

The effect of El Niño events in this area is interesting. During the early part of the 1982-1983 event (Figure 15), the drift to the northwest and then west along 10°N became faster, but after February 1983 the trajectories changed drastically, going to the southeast, entering the area where the ECC is normally found, and finally turning east, finishing at the mouth of the Gulf of Panama (Figure 16).

<u>Area 4:</u> This area shows very limited seasonal and annual variability. The Colombian coast has abundant precipitation during the whole year (Figure 4), and is probably an important source of

floating objects. However, most of them remain within the Panama Bight-Gulf of Panama area, even after a full year adrift.

The trajectories show several basic patterns: (1) some objects become stranded after short movements north or south (Figure 17a); (2) some drift north to the Gulf of Panama (Figure 17b); (3) some drift in a circular pattern or erratically near the origin (Figure 17c); and (4) some move southwest as far as the equator, and then return to the area of origin (Figures 18a and 18b). The most frequently observed patterns are (1) and (4). The displacement to the south may be caused by the effect of the ECC on the area, but the lack of seasonal variability in this pattern is hard to explain, given the strong seasonality shown by the ECC itself.

The annual variability is practically non-existent. The only visible El Niño effect is a more pronounced displacement to the south (Figure 18a).

The exceptionally low drift velocities, combined with the trajectories described above, make this area a major retention zone for floating objects, and perhaps for the tunas associated with them. It is likely that, at least for part of the year, the retention is caused by the presence of the ECC "blocking" westward movement from the Panama Bight (Williams, 1972) and by the coastal topography. Because of the abundance of floating objects entering the ocean in this area, and the high retention rate, this area probably has the highest density of floating objects in the EPO.

Area 5: Seasonal and annual variability are quite small in this area. Objects entering the ocean here generally have a net drift toward the southeast, zigzagging along the coast due to the effects of the Peru Current. Some seasonal variation is noticeable in the differences in penetration of the objects to the south. The year 1981 is a good example of this (Figure 19): objects entering the ocean during the rainy season (January-March) drift along the coast to the southeast, and after a year are found close to 8°S. Objects entering the ocean soon after those months reach much farther south (11°S). During the rest of the year, the trajectories stop short around 6°S, or head east toward the shore.

Another seasonal effect is the variability observed in the initial phases of the drift. In most cases, before heading south, the objects drift toward the northwest, probably due to changes in the intensity and location of the Peru Current. Objects entering the ocean in December to July show an initial movement to the northwest, or some deviations in that direction. Those deviations may take the object as far west as 90°W and, during the strong El Niño event of 1982-1983, to the 94°W meridian.

Of the annual variations, the effects of El Niño are the most conspicuous (Figure 20). The differences in the trajectories seem to indicate that during El Niño years the velocity of the drift is higher, the objects reach much farther south, and the initial northwest deviation is more pronounced.

Summary of Results: Drift of Floating Objects in the EPO

Summarizing our results, we can describe in general terms the main features of the circulation of objects entering the eastern Pacific Ocean. There are four basic characteristics, shown schematically in Figure 21.

(1) Most of the drift trajectories remain within the coastal zones, except in El Niño years, and in many cases remain close to the origin.

(2) The only area between 0° and 25°N where objects leave the coastal zone and move offshore is located at 10°N, between 90°W and 100°W. Objects can reach this area from both north or south, but in all cases they are driven westward to the NEC along the highly-productive equatorial front.

(3) The coastal water masses off Colombia and Panama are areas of low drift velocity and cyclic circulation patterns that result in long retention periods for objects entering the area. Of all the areas studied, this is probably the most isolated from neighboring areas.

(4) There is little evidence of transport of floating objects between the areas north and south of the equator.

Figure 21 shows, in addition to the basic patterns described above, the four main "circulation circuits" and their influence areas.

CONCLUSIONS

Perhaps the most significant conclusion is the prolonged retention time in the coastal zone that results from many of the trajectories. Either because of oscillating north- and south-drifting periods, or because of circular current patterns, most drifting objects appear to be very close to their sources even after a full year at sea. As most trees are likely to become waterlogged and sink in less than a year, it appears that much of this material will sink close to its source. This suggests that the continental contribution could have a patchy spatial distribution, with some areas receiving large amounts of material and others very little. Tunas, by associating with floating objects, would also remain within the productive coastal zone.

Another salient feature is the westward movement of many objects offshore along 10°N. This parallel marks the east-west axis of the purse-seine fishery and is biologically one of the richest offshore areas of the EPO. This is probably another reason for the adaptiveness of the association of tunas with floating objects; tunas that drift offshore with floating objects end up in a rich frontal zone rather than in the less productive central gyres to the north and south. Objects from the north and south eventually converge on this parallel.

There are many other possible uses of the simulation models, some of which are part of our future plans, among them:

- Study and experiment with a dispersion parameter in the Lagrangian model, to produce stochasticity in the trajectories.
- Generate probability contours for the dispersal of logs from each source over a given time.
- Introduce parameters related to the longevity of the various types of floating objects.
- Based on the previous two results, predict areas of possible accumulation of wood on the sea floor.
- Perform experiments with satellite-tagged logs.
- Simulate long-term dispersal with multiyear trajectories.
- Refine the model to include effects of coastal topography, tidal currents, and other features that are not incorporated in the present version.
- Simulate migratory movements of tunas using drift patterns for nocturnal movements and foraging patterns for daytime movements..

LITERATURE CITED

Anonymous. 1976. Atlas Climatologico e Hidrografico del Itsmo Centroamericano. Publ. Instituto Panamericano de Geografia e Historia. 367 pp. (9 maps).

Anonymous. 1988. Annual Report of the Inter-American Tropical Tuna Commission, 1987. 222 pp.

Anonymous. 1989. Annual Report of the Inter-American Tropical Tuna Commission, 1988. 288 pp.

Blackburn, M. 1962. An oceanographic study of the Gulf of Tehuantepec. U.S. Fish & Wildl. Serv., Spec. Sci. Rep. Fish. 404. 28 pp.

Busalacchi, A. and J. O'Brien. 1980. The seasonal variability in a model of the tropical Pacific. J. Physical Ocean. 10: 1929-1951.

Busalacchi, A. and J. O'Brien. 1981. Interannual variability of the equatorial Pacific in the 1960's. J. Geophys. Res. 86: 10901-10907.

Busalacchi, A., K. Takeuchi and J. O'Brien. 1983. On the interannual wind- driven response of the tropical Pacific Ocean. pp 155-195. In: Nihoul, J. (ed.) Hydrodynamics of the Equatorial Ocean. Elsevier Science Publishers. Amsterdam.

Cayré, P. and F. Marsac. 1990. Report and preliminary results of the tagging programme of natural drift logs in the tuna purse seine fishery area of the western Indian Ocean. 4th. Asian Tuna Conference. Bangkok, Thailand.

Hoffmann, J.A.J. 1975. Climatic Atlas of South America I. Maps of mean temperature and precipitation. OMM. WMO, UNESCO, Paris and Cartographia, Budapest.

Luther, M. and J. O'Brien. 1985. A model of the seasonal circulation in the Arabian Sea forced by observed winds. Prog. Oceanogr. 14: 352-385.

Parés-Sierra, A. and J. O'Brien. 1989. The seasonal and interannual variability of the California Current system: A numerical model. J. Geophys. Res. 94: 3159-3180.

Power, J. 1986. A model of the drift of northern anchovy, *Engraulis mordax*, larvae in the California Current. Fish. Bull. 84: 585-603.

Seckel, G.R. 1972. Hawaiian-caught skipjack tuna and their physical environment. Fish. Bull. 72: 763-787.

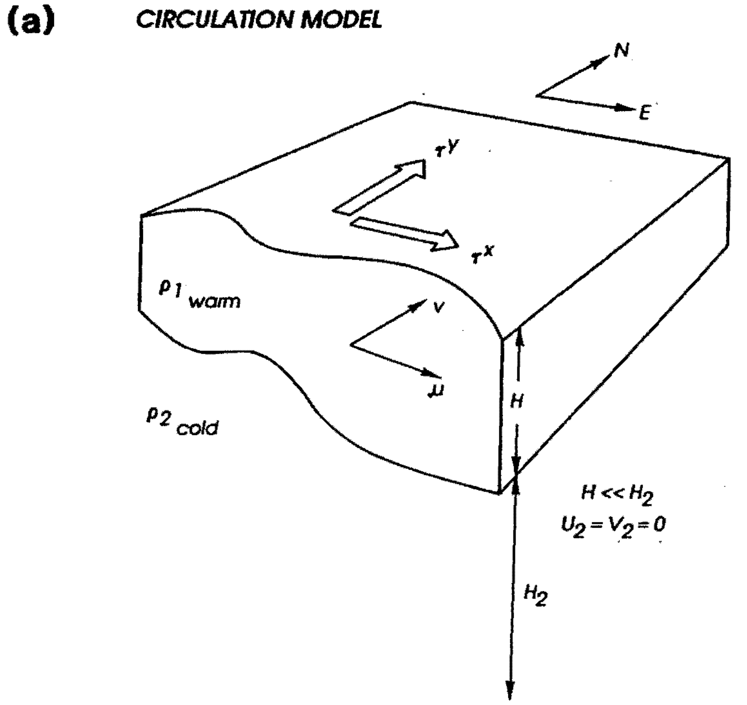
Steinhauser, F. 1979. Climatic Atlas of North and Central America I. Maps of mean temperature and precipitation. OMM. WMO, UNESCO, Paris and Cartographia, Budapest.

Williams, F. 1972. Consideration of three proposed models of the migration of young skipjack tuna (*Katsuwonus pelamis*) into the eastern Pacific Ocean. Fish. Bull. 70: 741-762.

Wyrtki, K. 1965. Surface currents of the eastern tropical Pacific Ocean. Bull. Inter-Amer. Trop. Tuna Commn. Vol. 5: 269-304.

Table 1. Recent ENSO events in the EPO.

	Started	**Ended**	**Peak warming**	**Comments**
1972-73	Jan 72	Mar 73	Jul-Aug 72	Strong over nearshore EPO
1976	Feb 76	Feb 77	Aug 76	Primarily equatorial
1982-83	Jul 82	Nov 83	Nov 82-Feb 83	Very strong over entire EPO
1986-87	Dec 86	Dec 87	Apr-May 87	Weak over tropics



$$\frac{\partial U}{\partial t} + \frac{1}{a \cos \theta} \frac{\partial}{\partial \phi} \left[\frac{U^2}{H}\right] + \frac{1}{a} \frac{\partial}{\partial \theta} \left[\frac{UV}{H}\right] - (2\Omega \sin\theta)V = \frac{-g'}{2a \cos \theta} \frac{\partial H^2}{\partial \phi} + \frac{\tau\phi}{\rho} + A\nabla^2 U \tag{2.a}$$

$$\frac{\partial U}{\partial t} + \frac{1}{a \cos \theta} \frac{\partial}{\partial \phi} \left[\frac{UV}{H}\right] + \frac{1}{a} \frac{\partial}{\partial \theta} \left[\frac{V^2}{H}\right] - (2\Omega \sin\theta)V = \frac{-g'}{2a} \frac{\partial H^2}{\partial \theta} + \frac{\tau^{\phi}}{\rho} + A\nabla^2 UV \tag{2.b}$$

$$\frac{\partial H}{\partial t} + \frac{1}{a \cos \theta} \left[\frac{\partial U}{\partial \phi} + \frac{\partial}{\partial \theta} (V \cos \theta)\right] = 0 \tag{2.c}$$

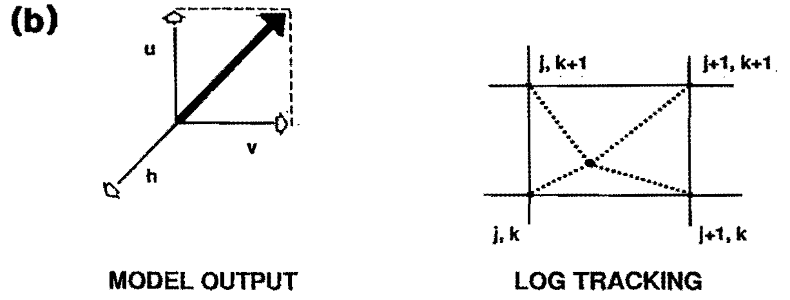


Figure 1. The circulation model: (a) Parés-Sierra and O'Brien non-linear, reduced-gravity model equations and symbols; (b) linear interpolation of the current components at the four corners of the 0.25-degree square in which the object is located.

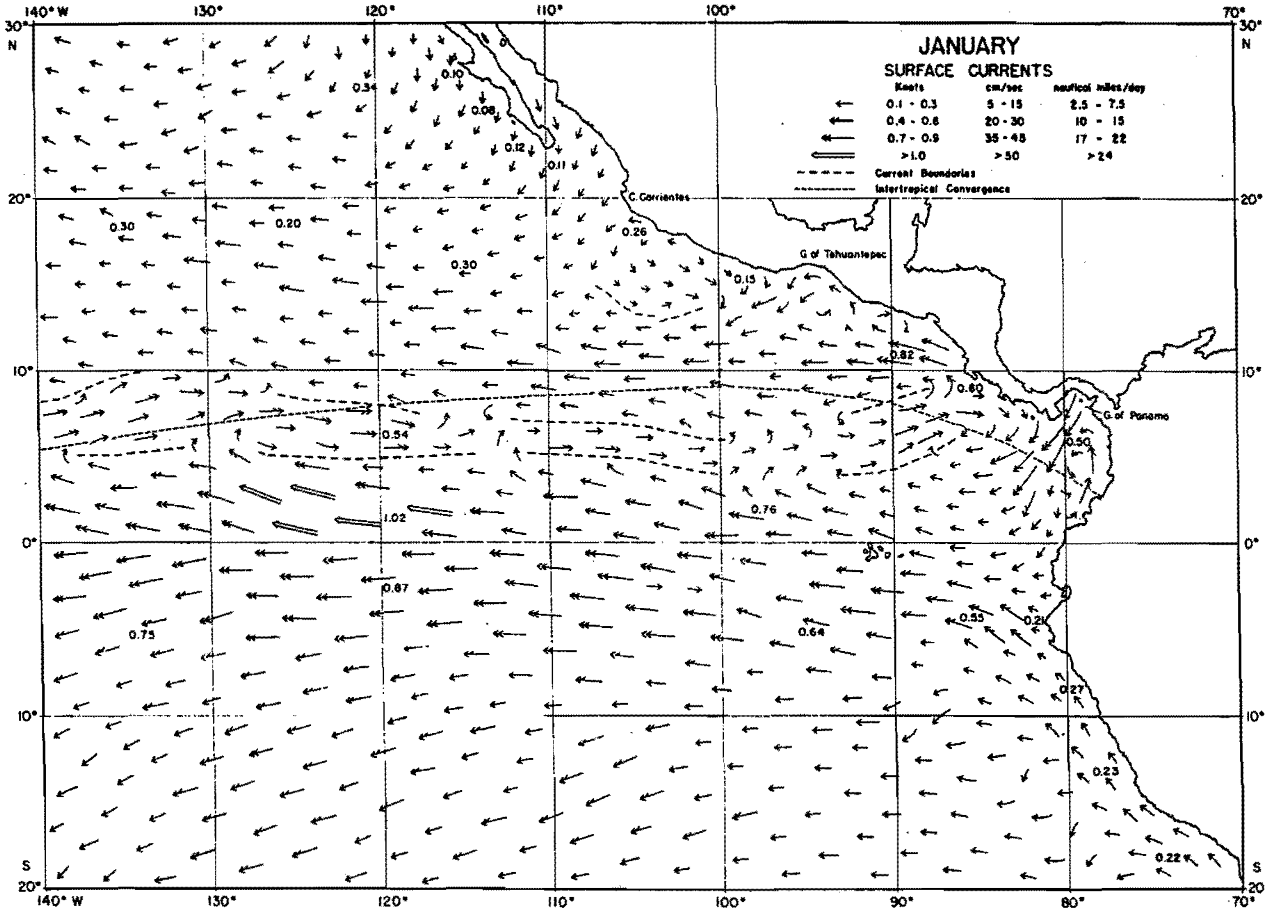
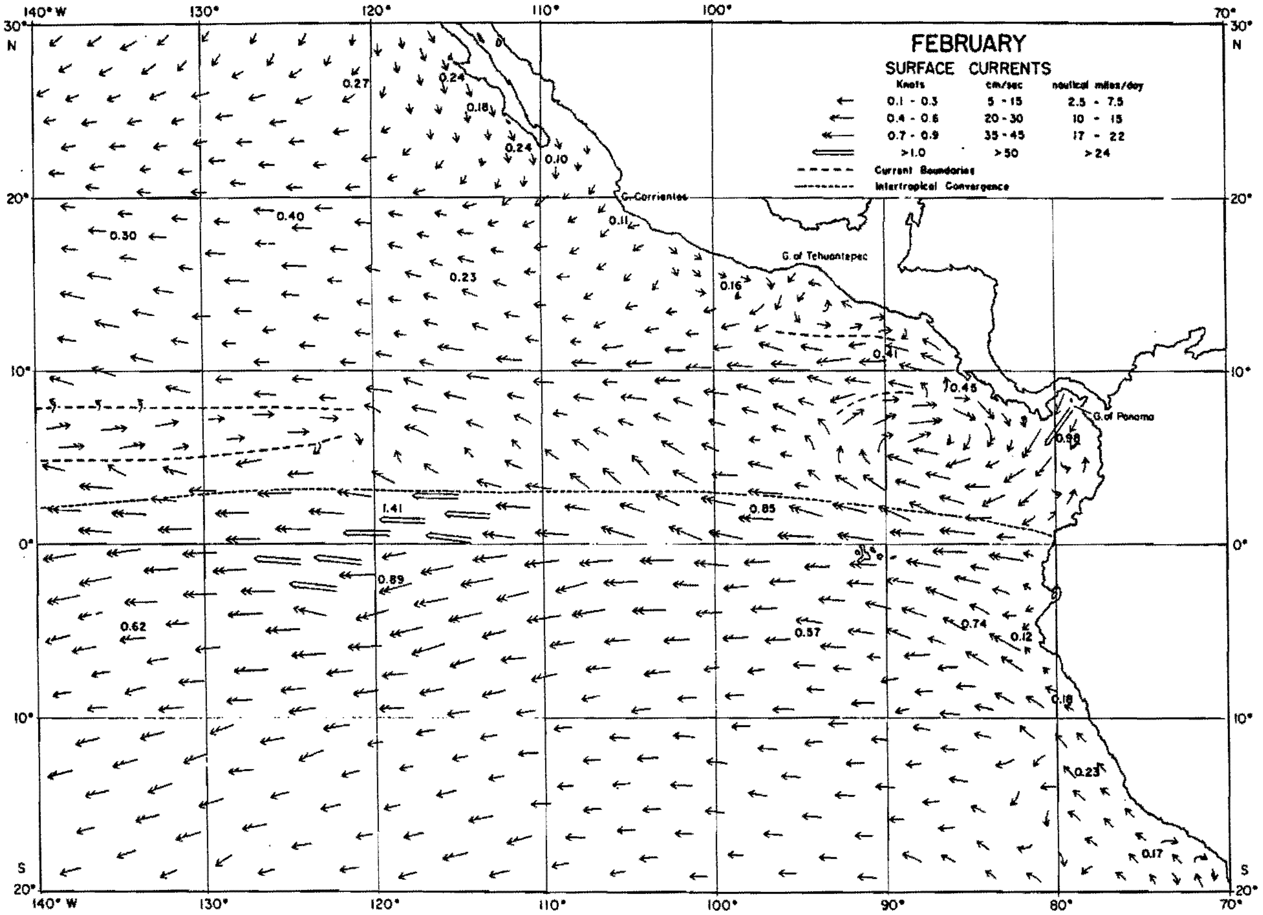


Figure 2. Eastern Pacific Ocean circulation charts (from Wyrtki, 1965).



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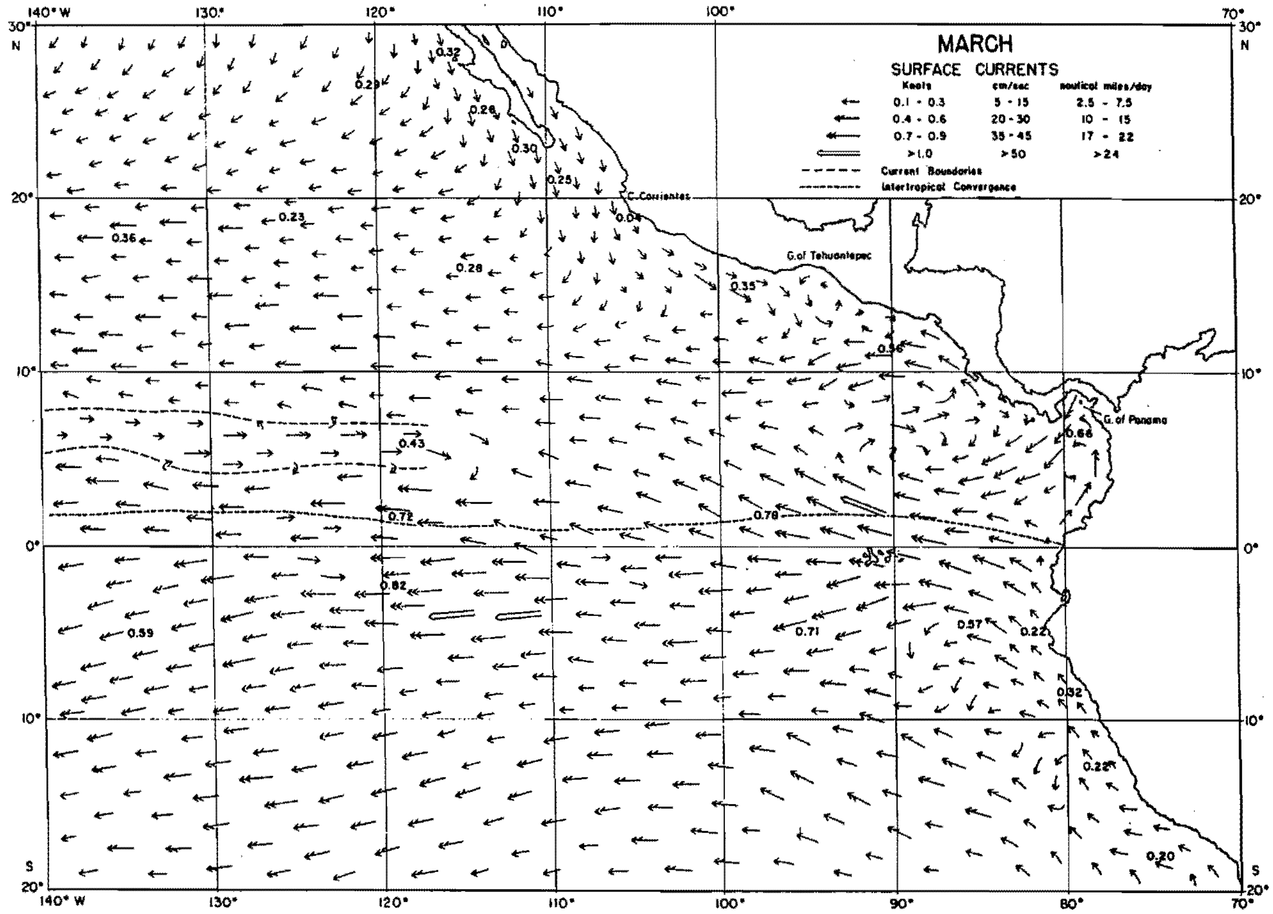

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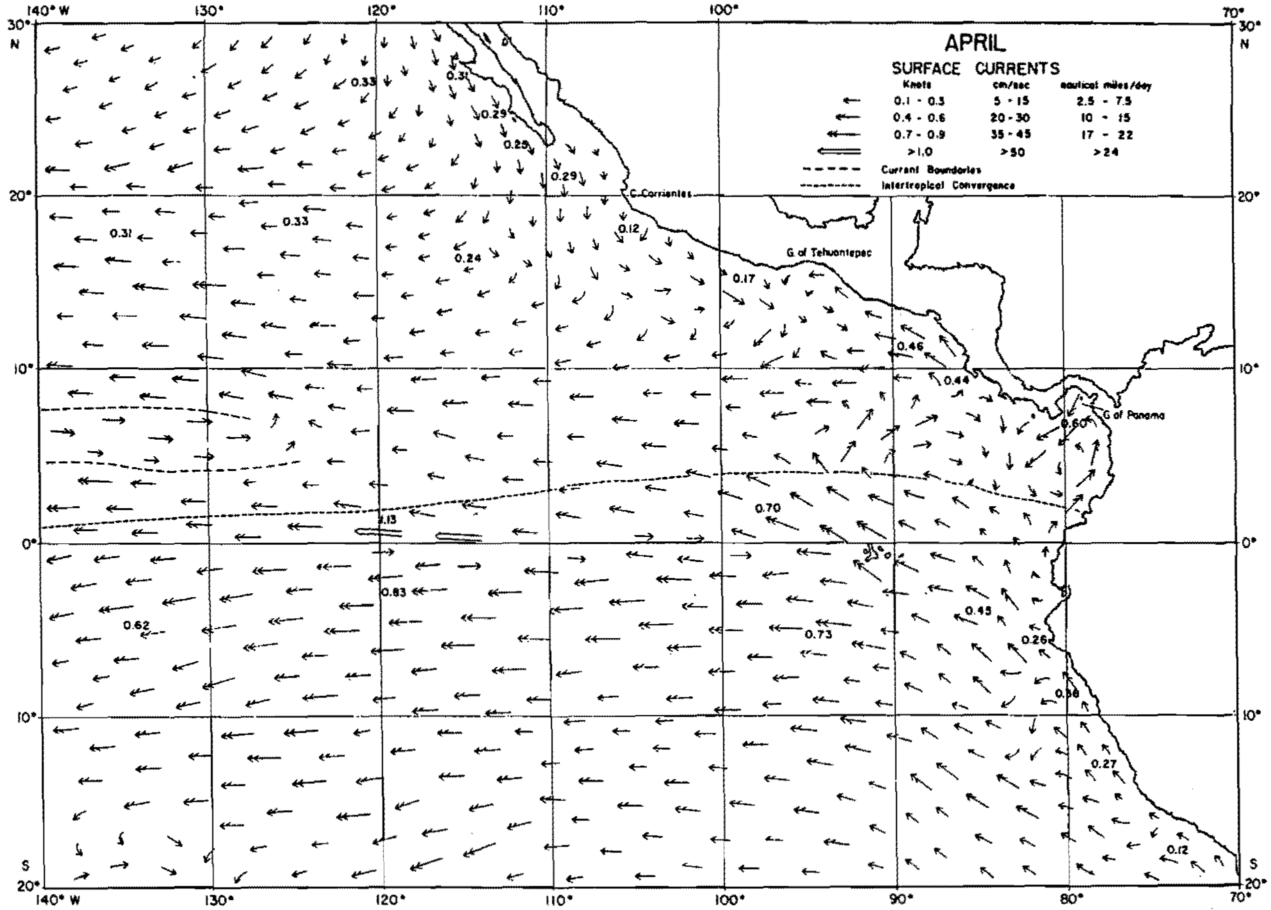

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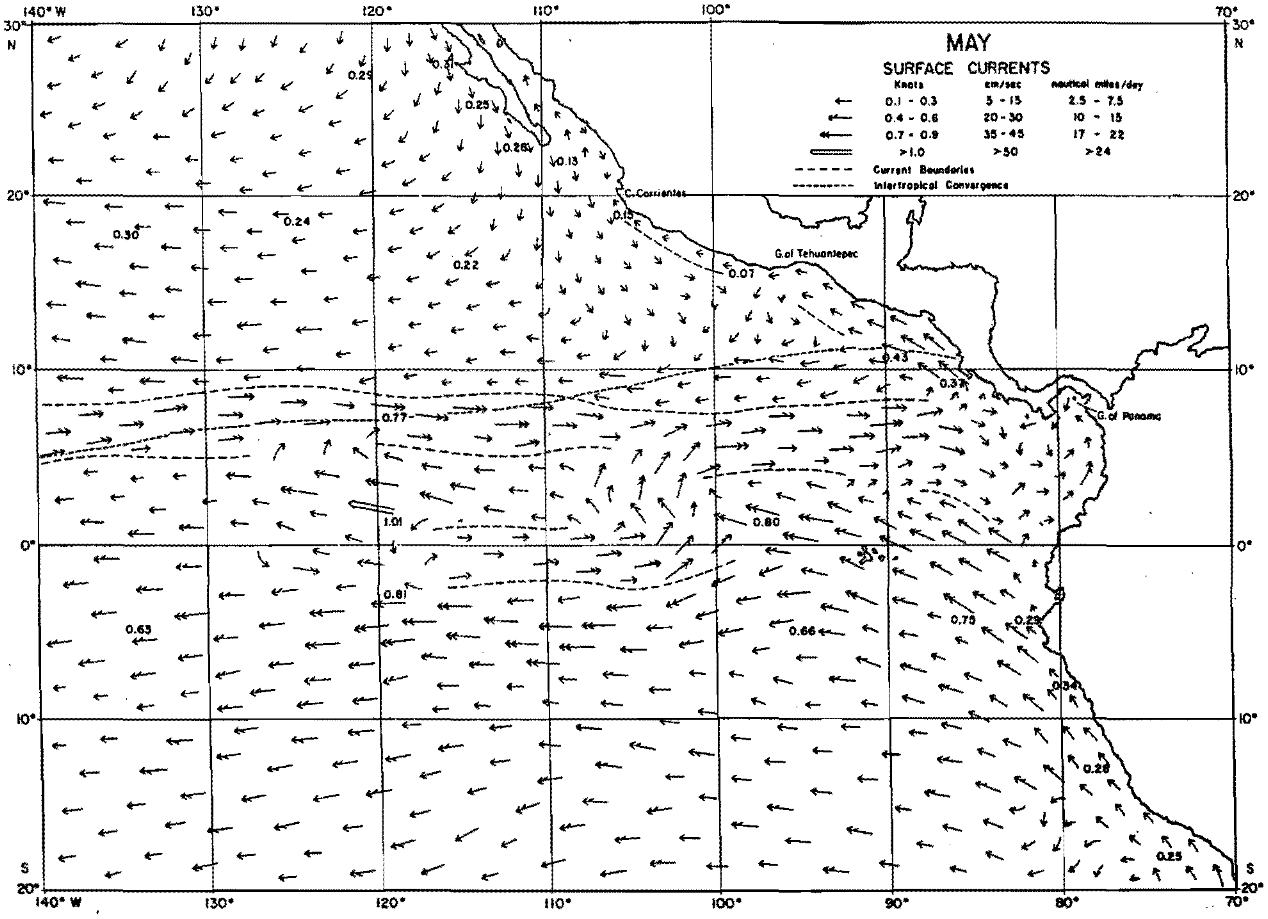

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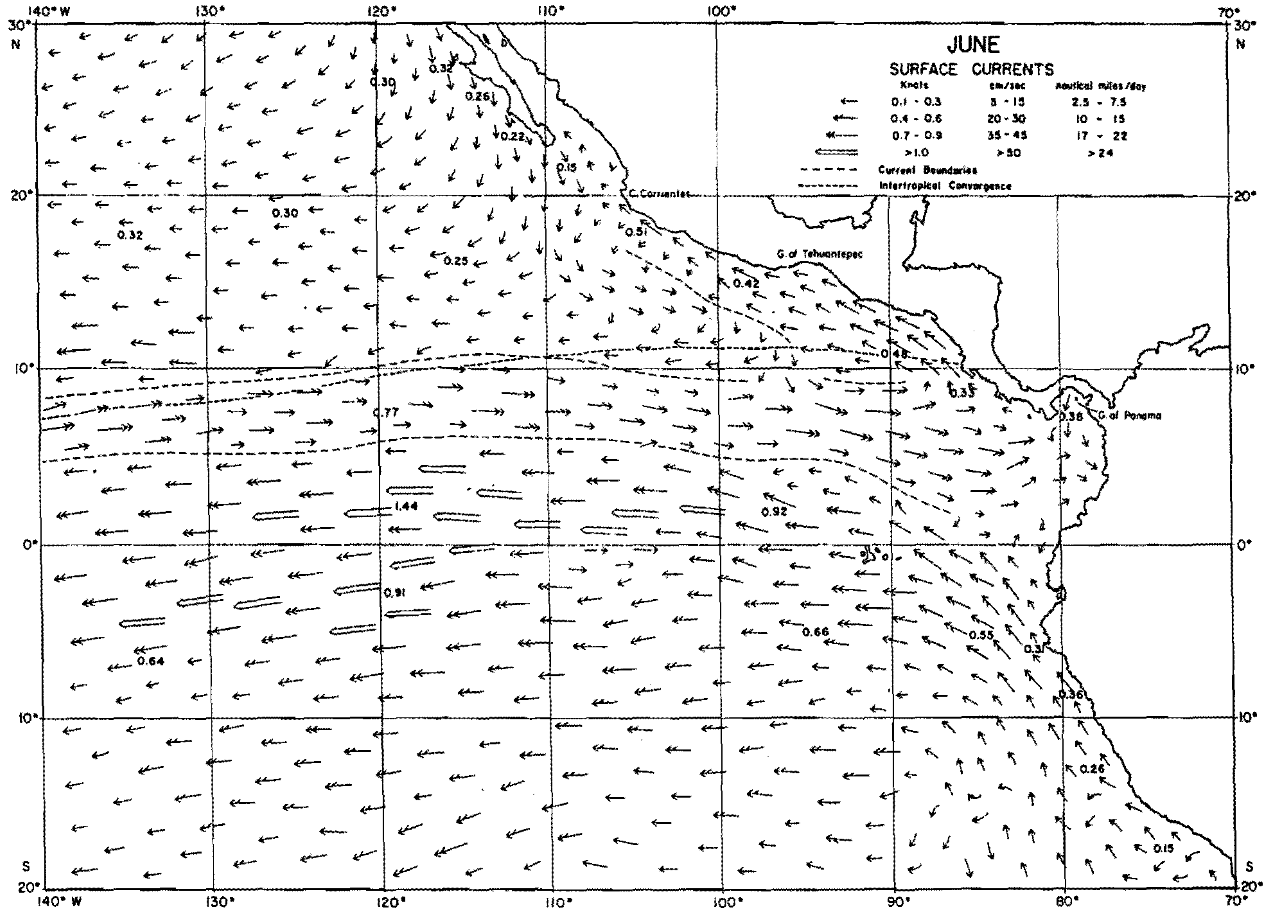

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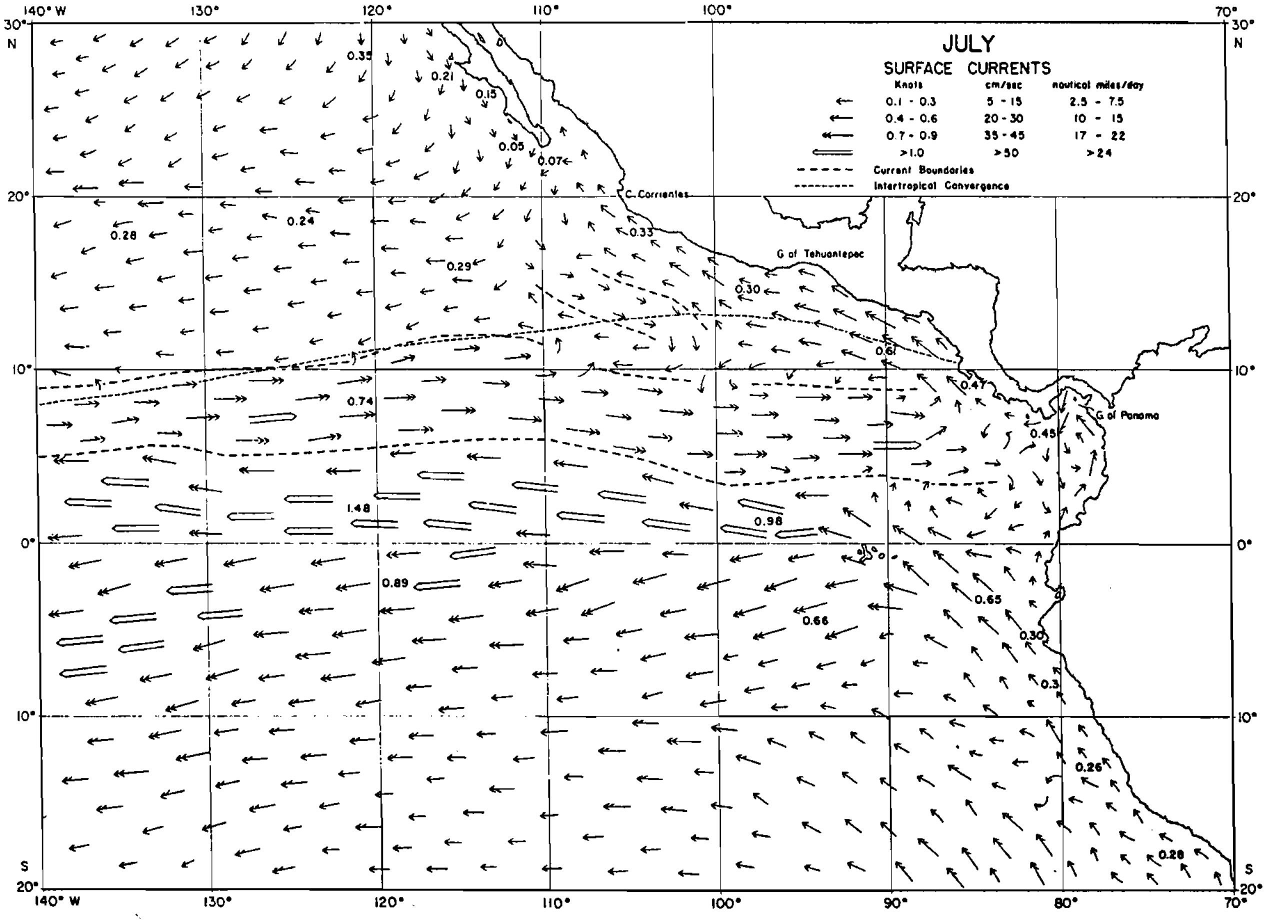

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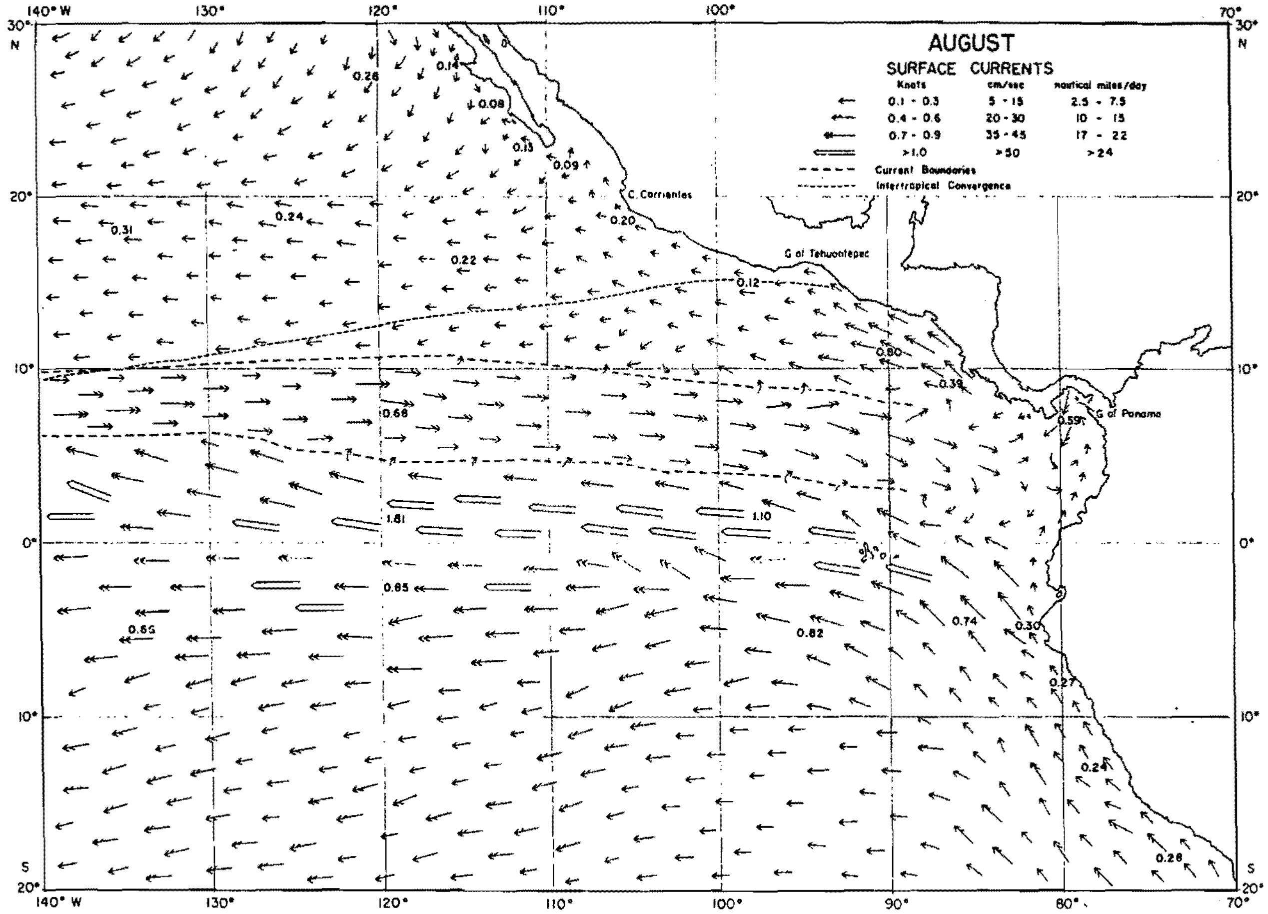

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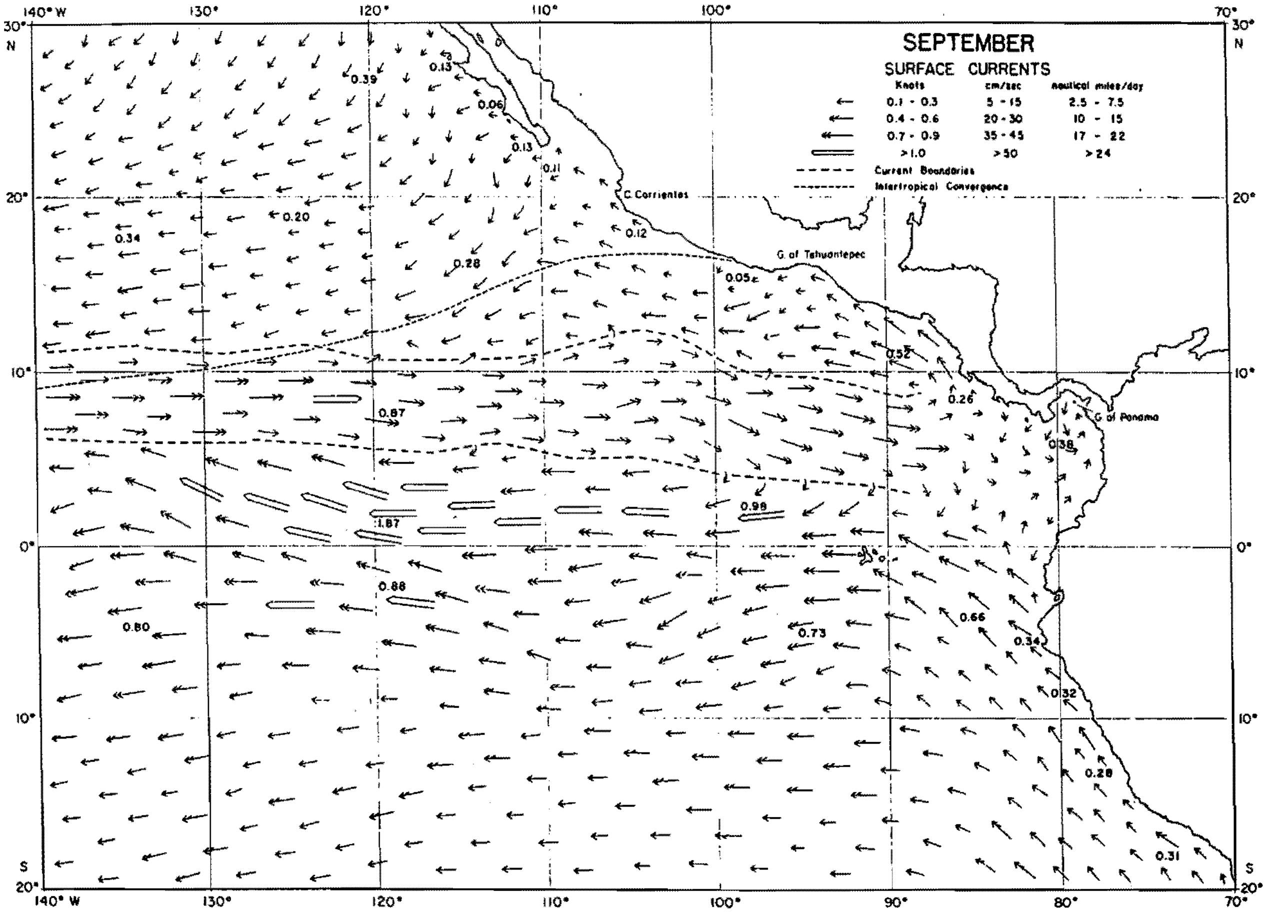

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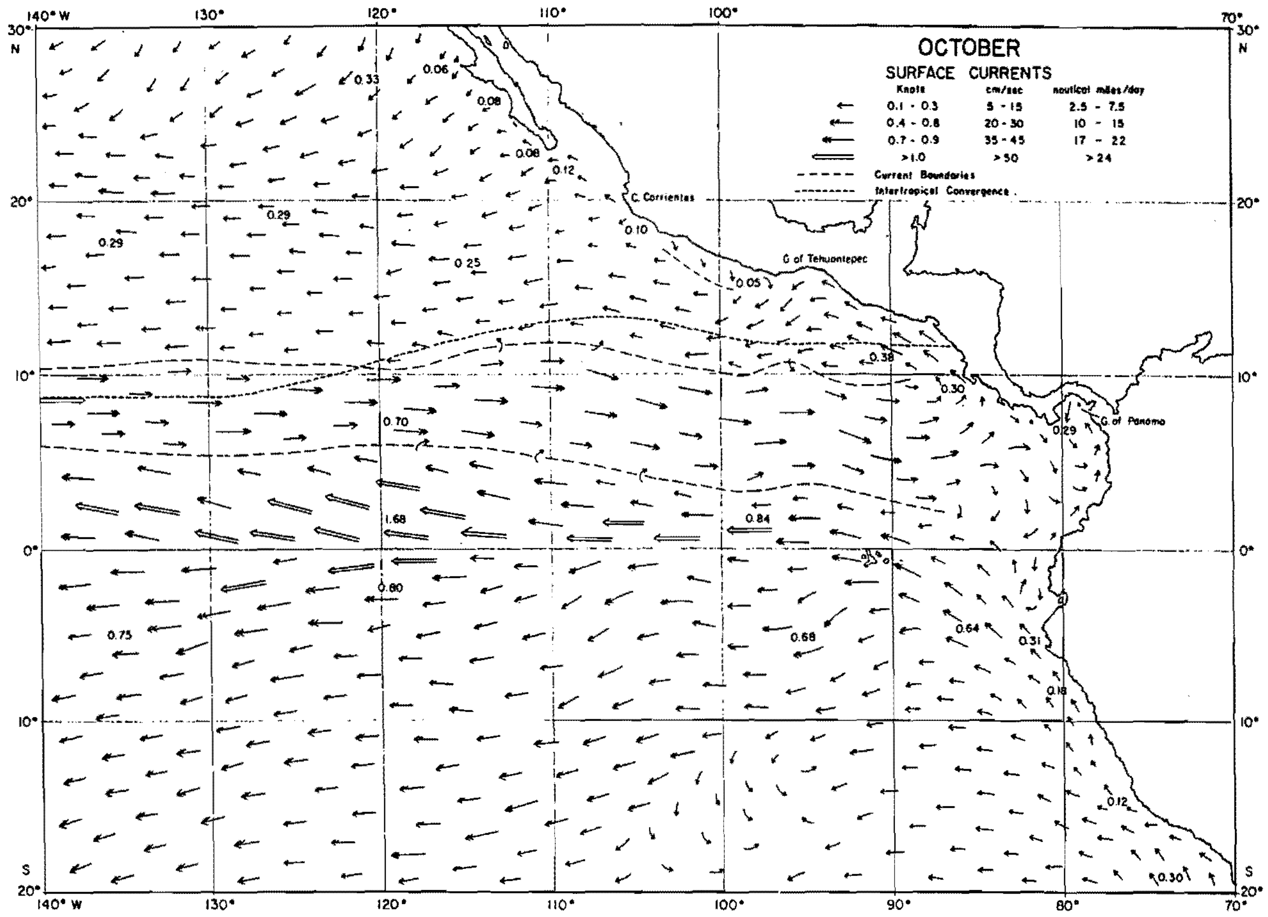

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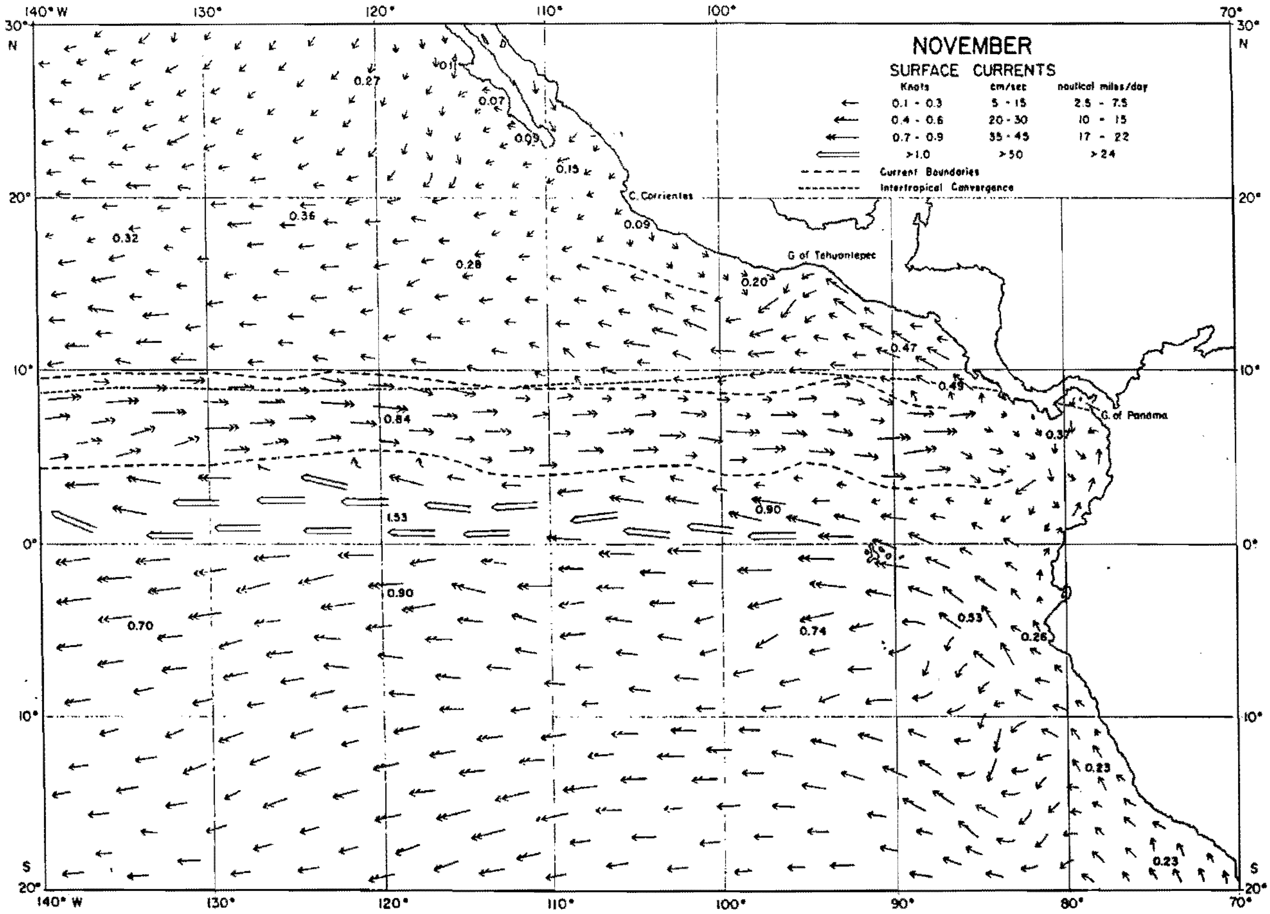

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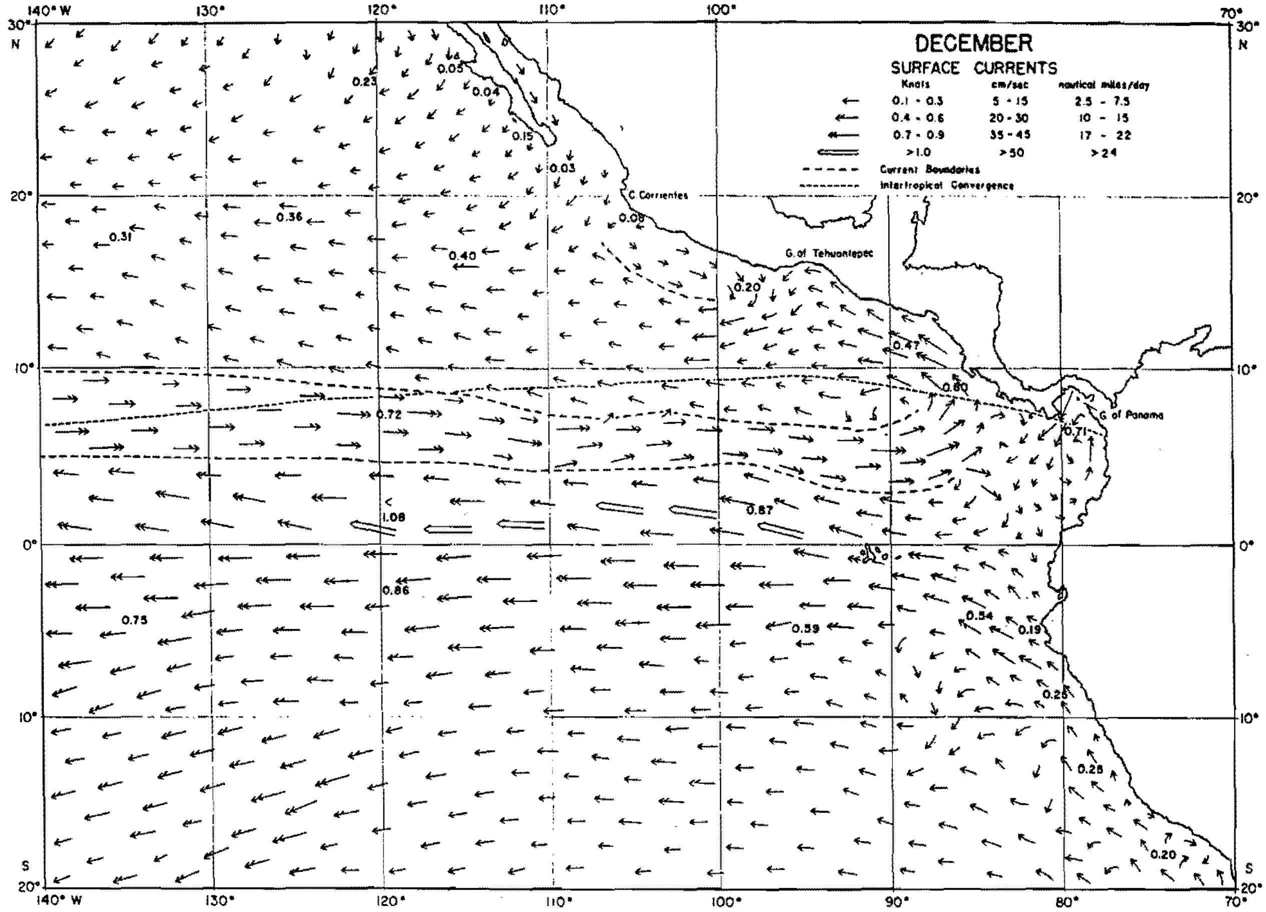

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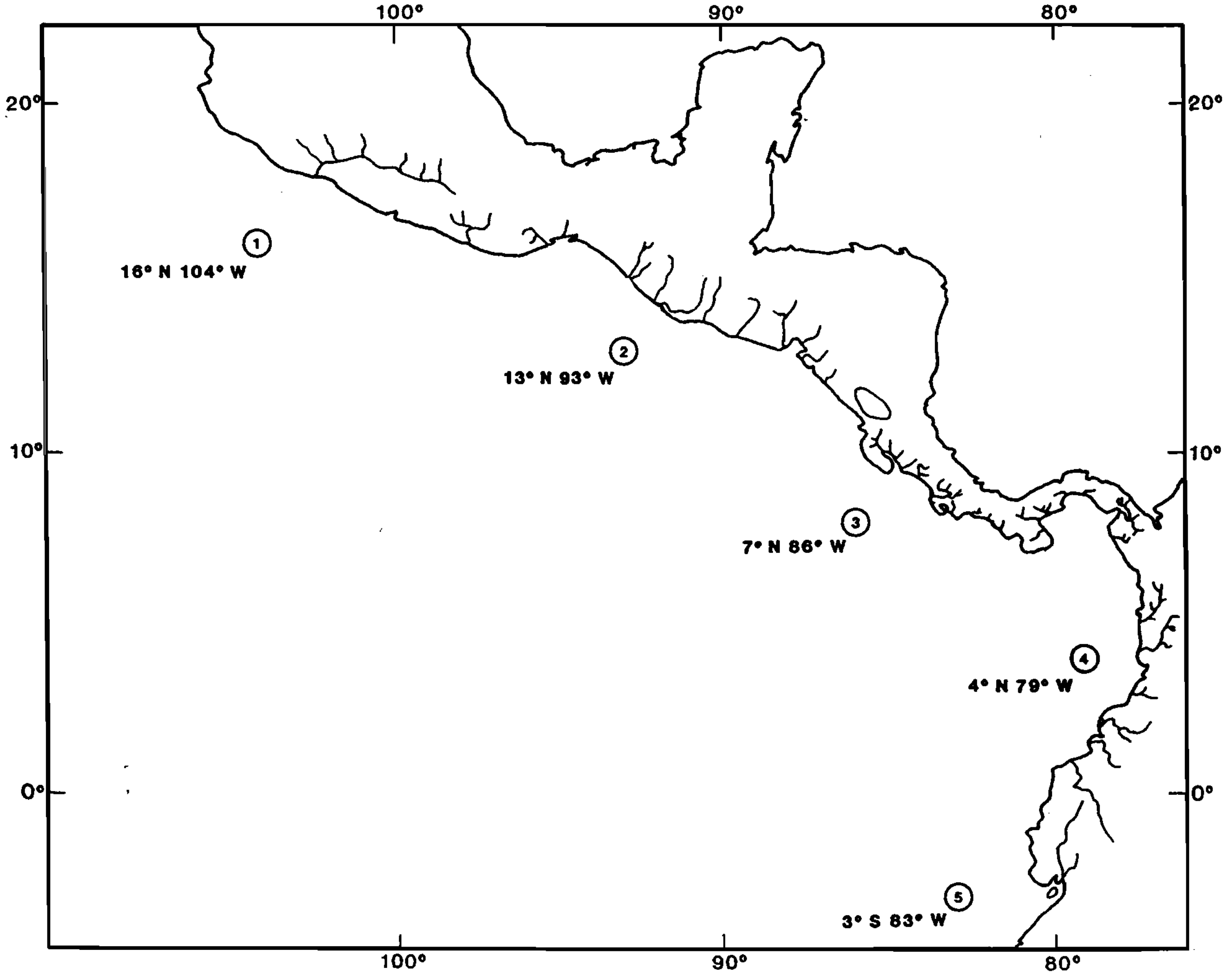


Figure 3. Location of the five areas used as entry points for the simulations.

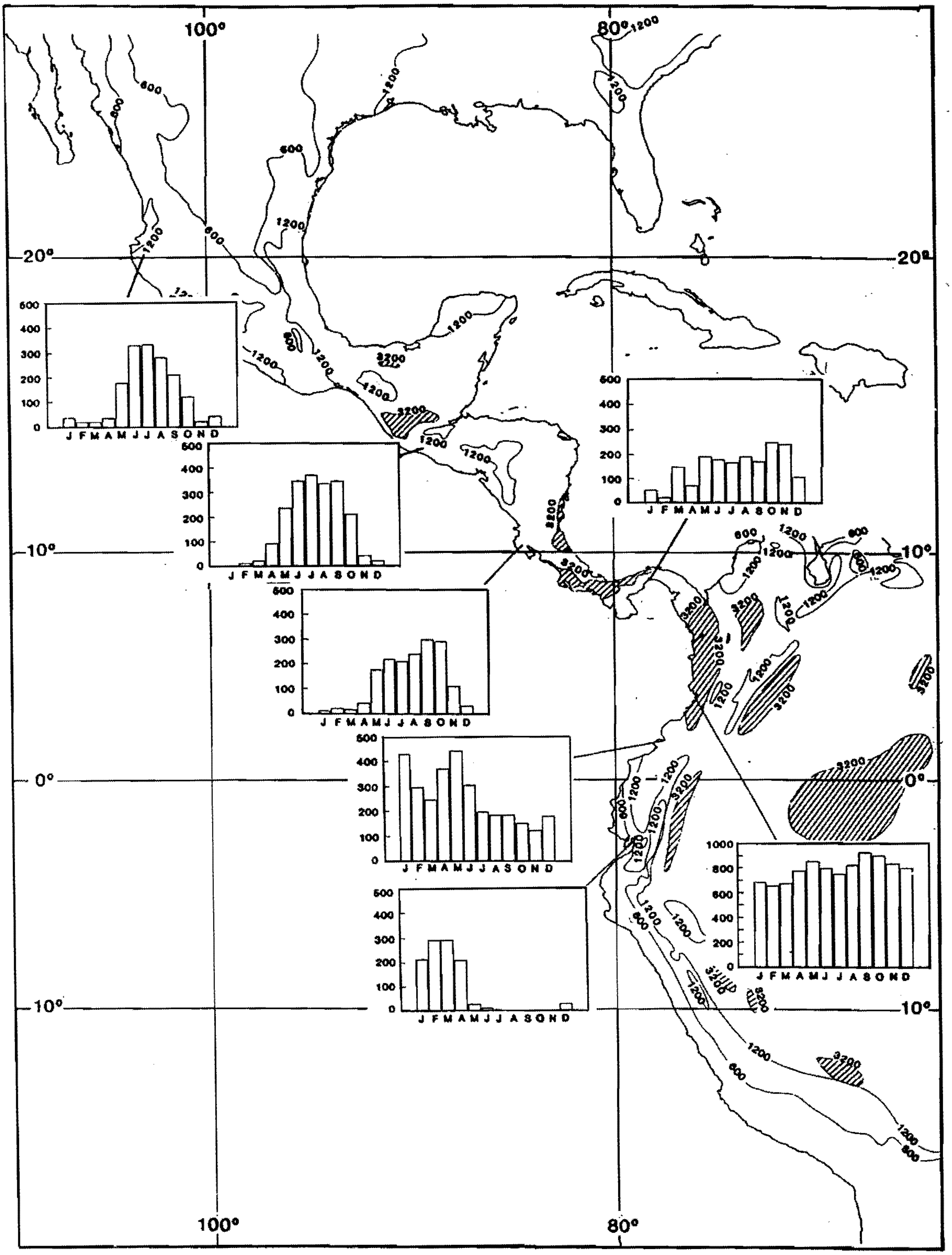


Figure 4. Mean annual precipitation (mm) in the continent and mean monthly precipitation (mm) at selected stations. Shaded areas indicate zones of high precipitation. Based on Hoffmann (1975), Anonymous (1976) and Steinhauser (1979).

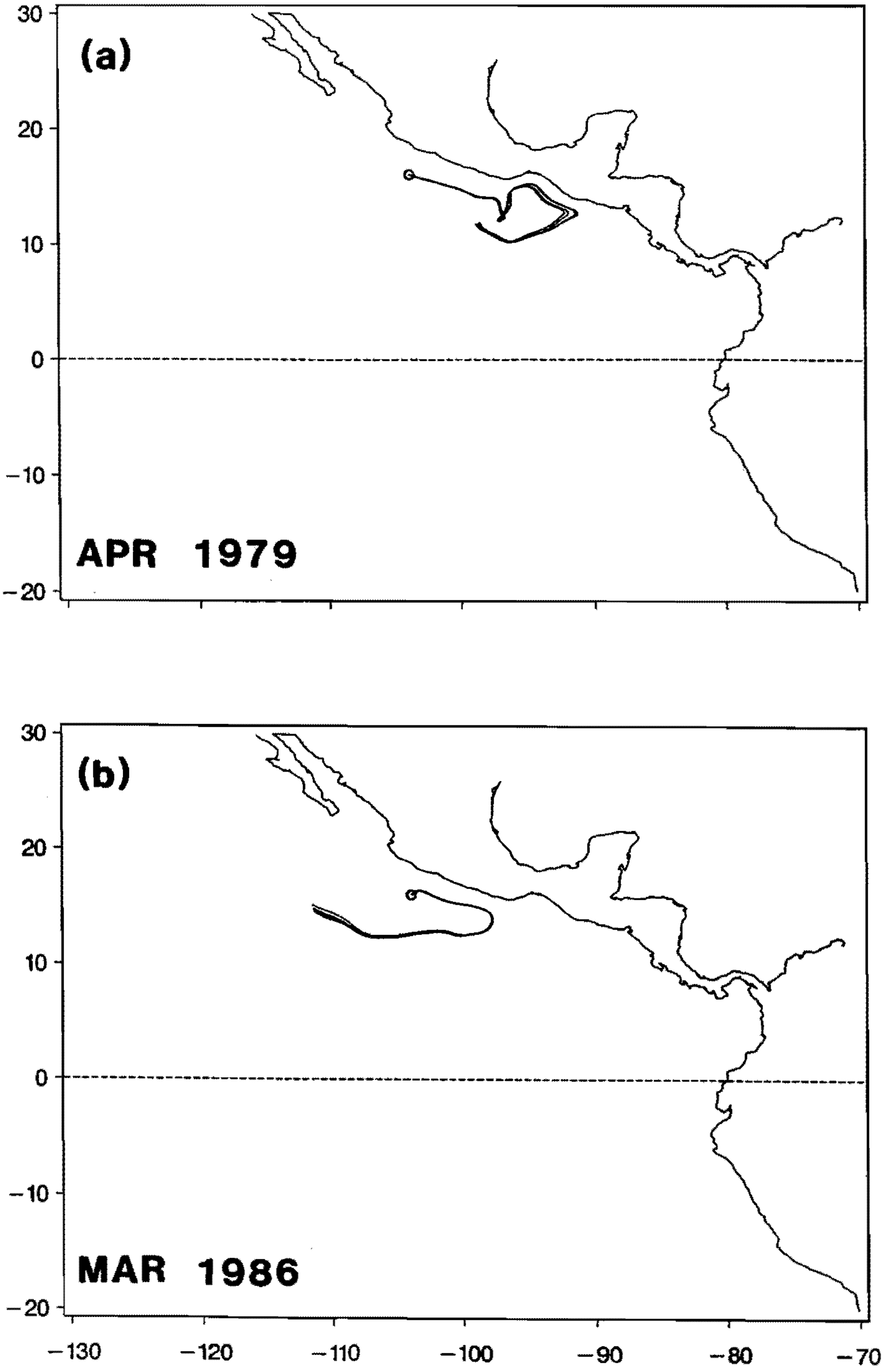


Figure 5. Variation of the westward turning point of objects entering Area 1: (a) year 1979, entry month April; westward turn is made at the edge of the Costa Rica Dome; (b) year 1986, entry month March; westward turn is made off the Gulf of Tehuantepec.

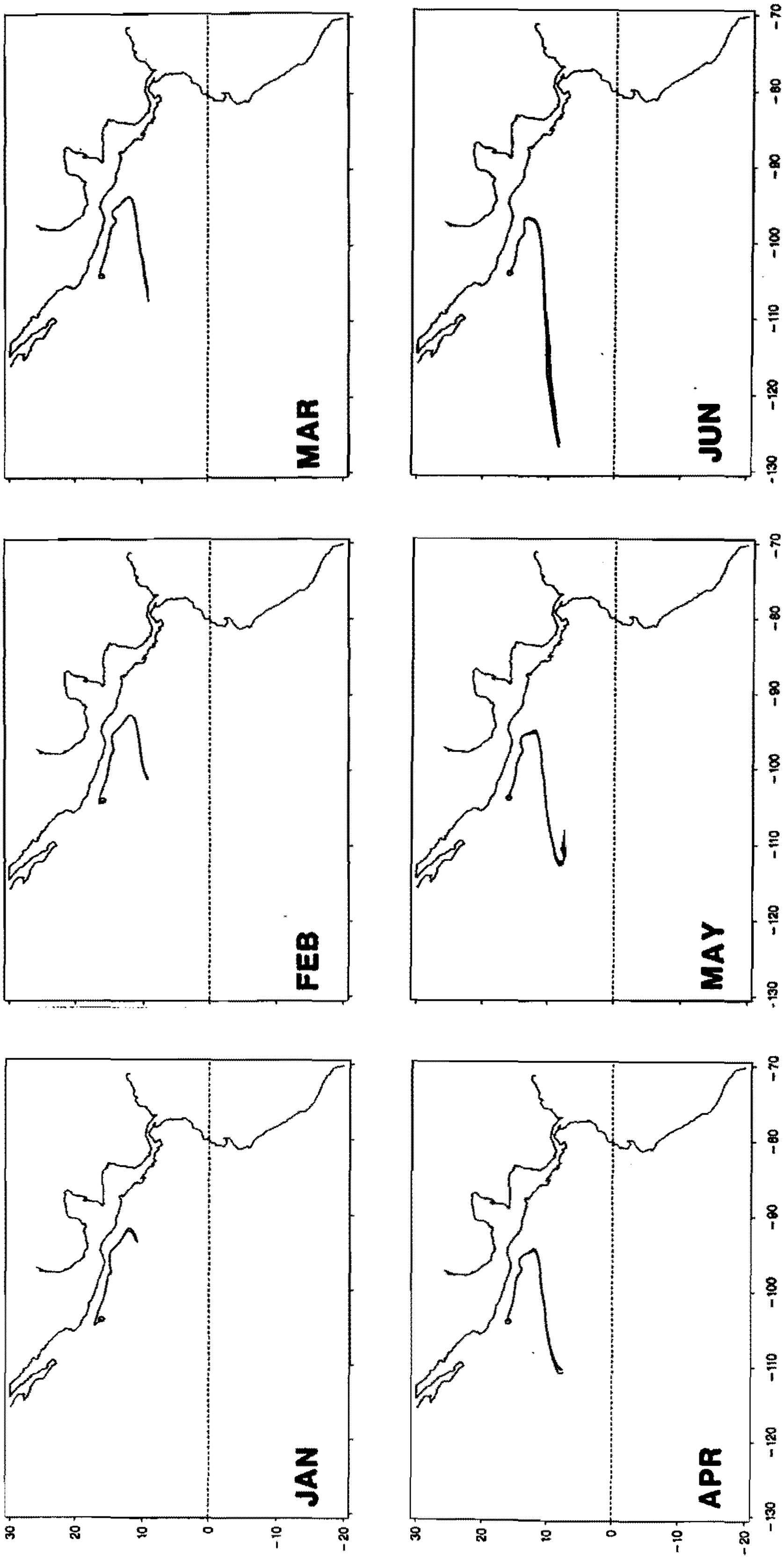
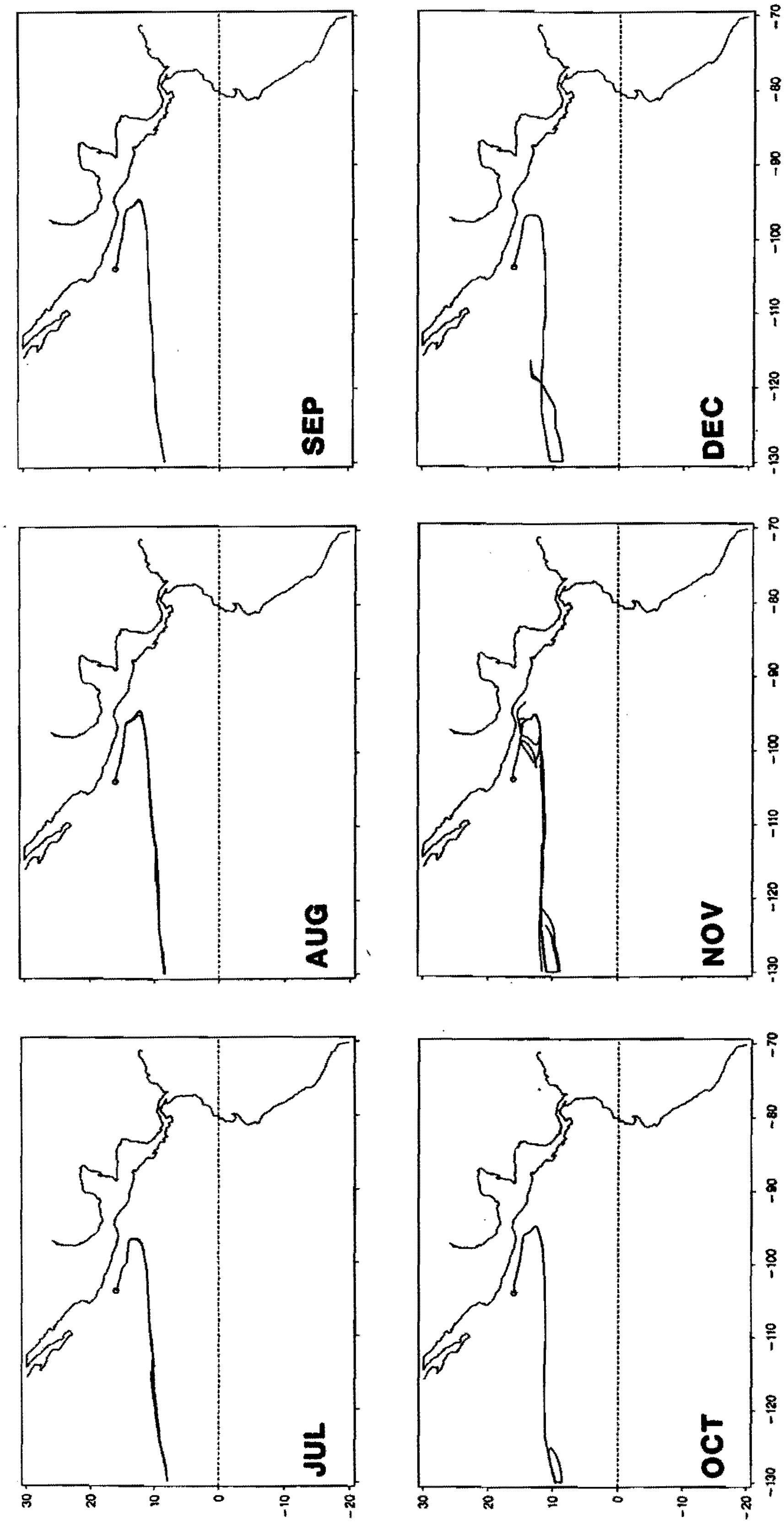


Figure 6. Simulated trajectory of objects entering Area 1, year 1983.



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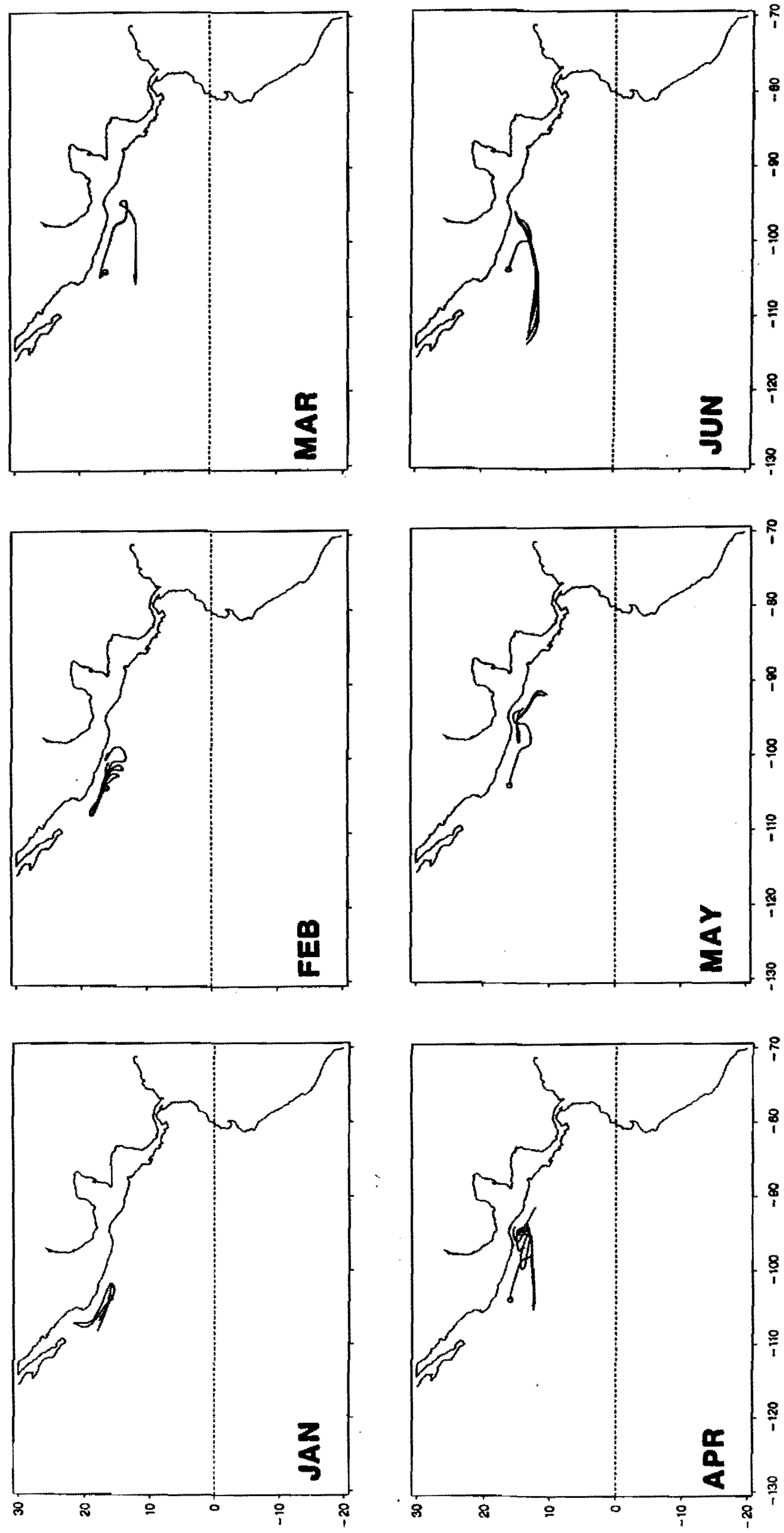


Figure 7. Simulated trajectory of objects entering Area 1, year 1976.

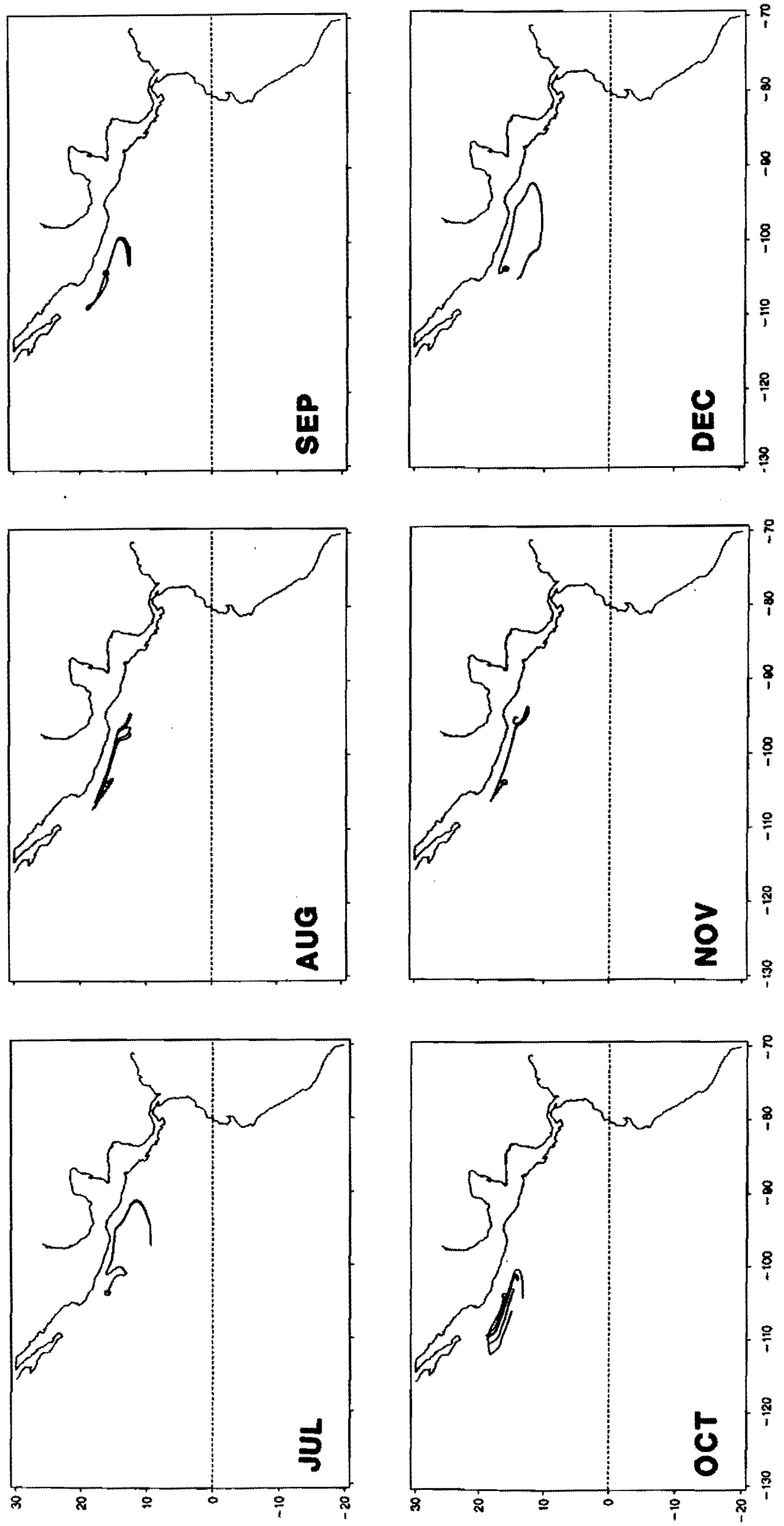


Figure 7. Continued.

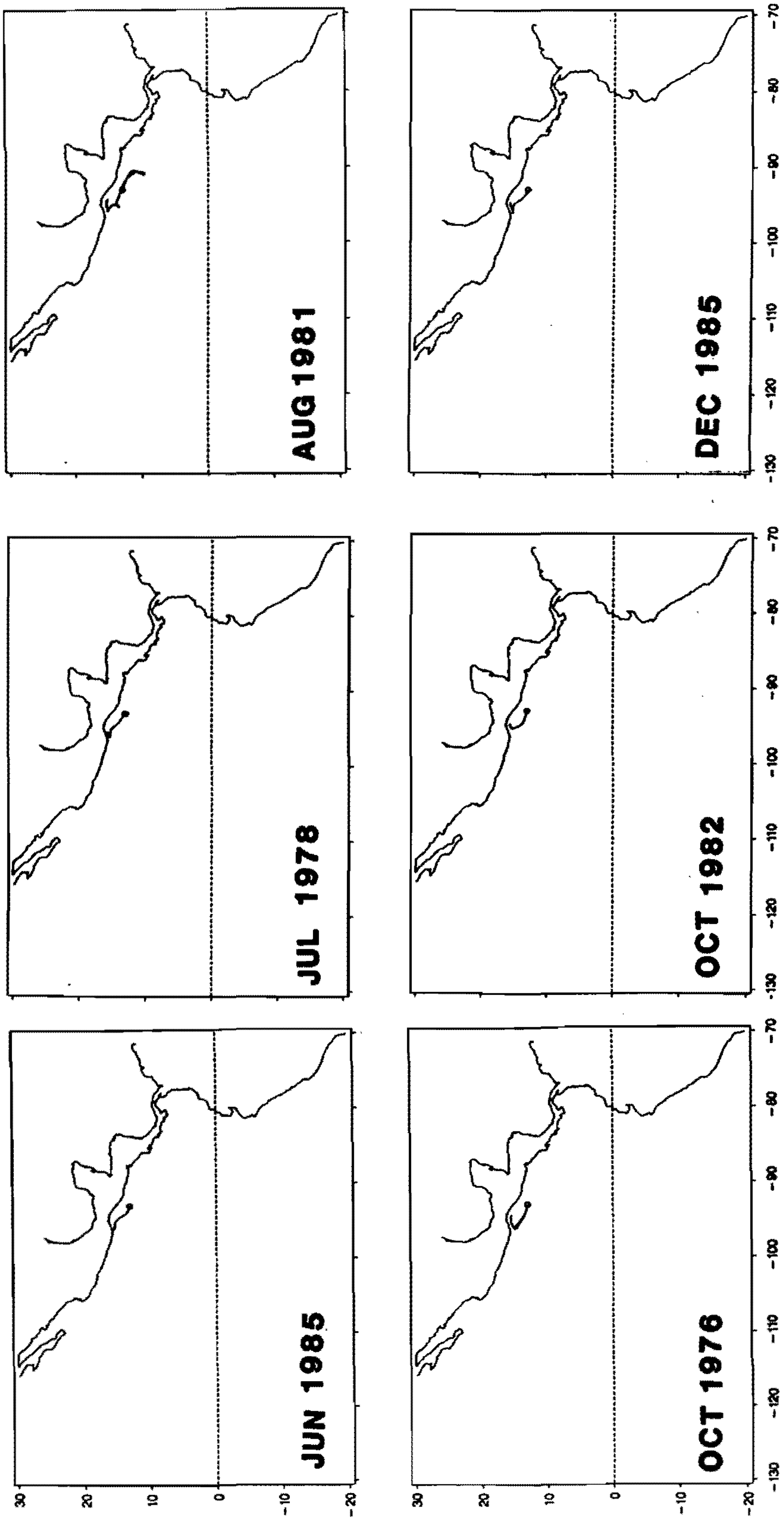


Figure 8. Examples of objects that entered Area 2 with trajectories stranding in the Gulf of Tehuantepec.

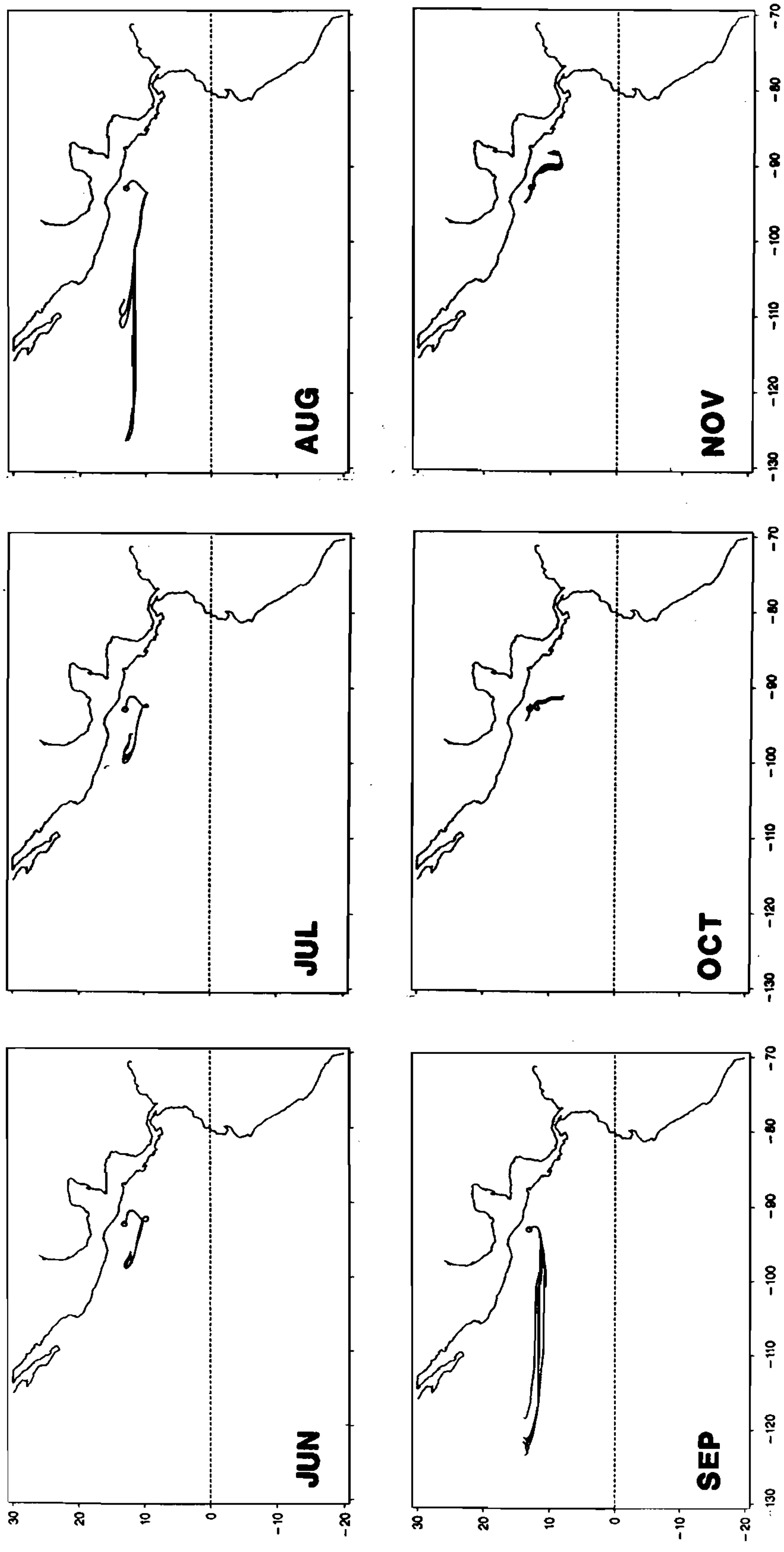


Figure 9. Simulated trajectory of objects entering Area 2, year 1980.

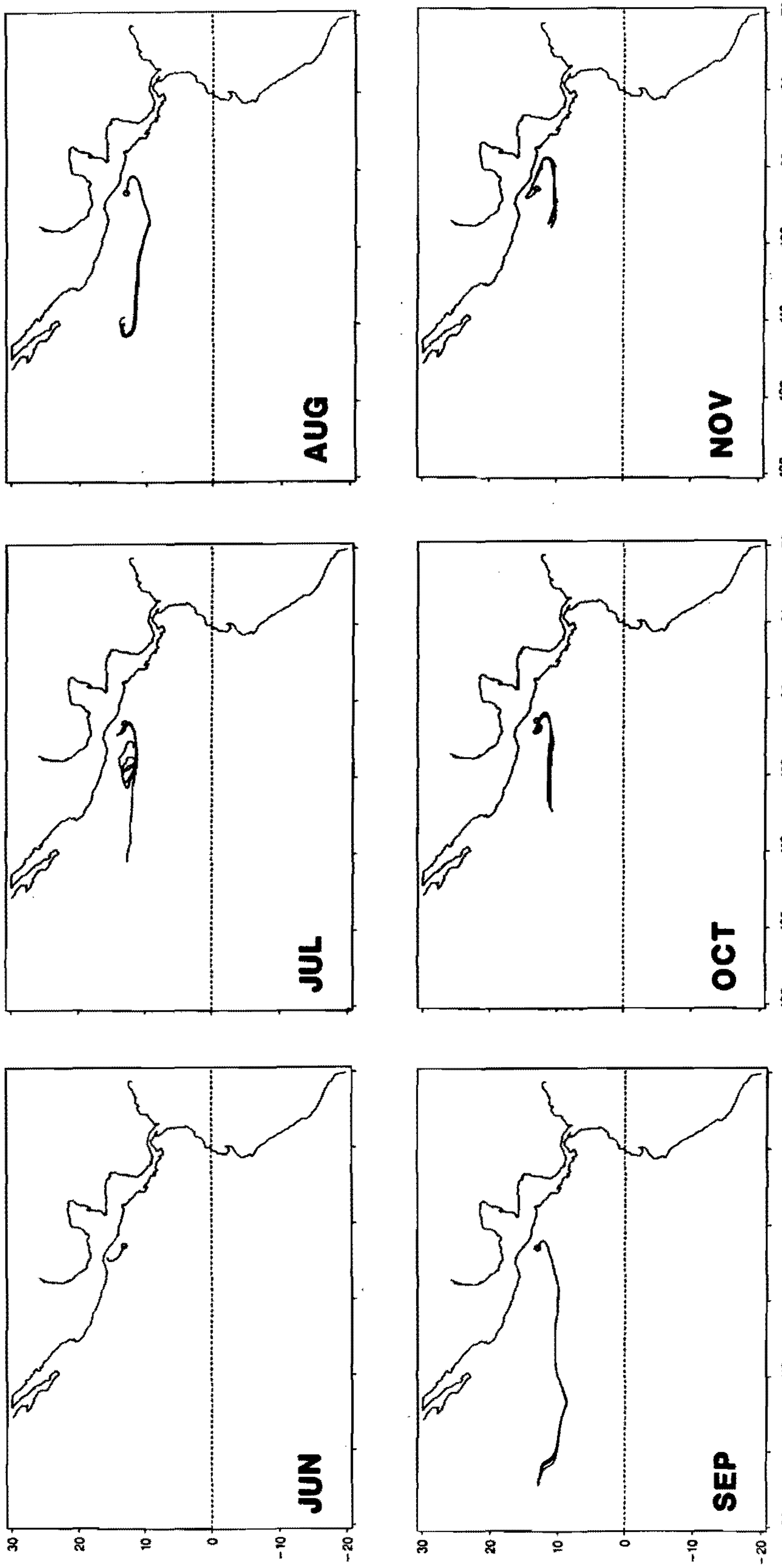


Figure 10. Simulated trajectory of objects entering Area 2, year 1986.

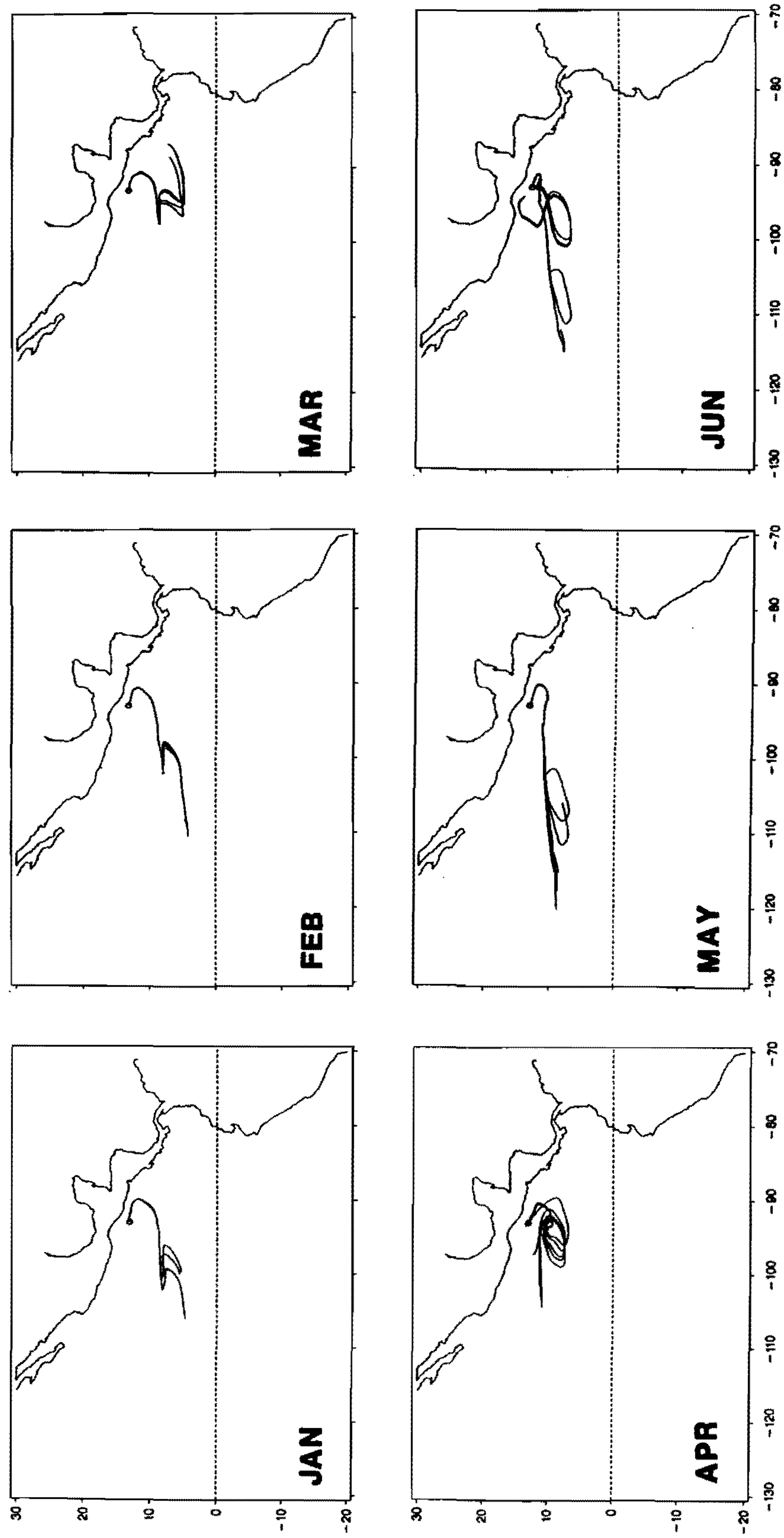


Figure 11. Simulated trajectory of objects entering Area 2, year 1983.

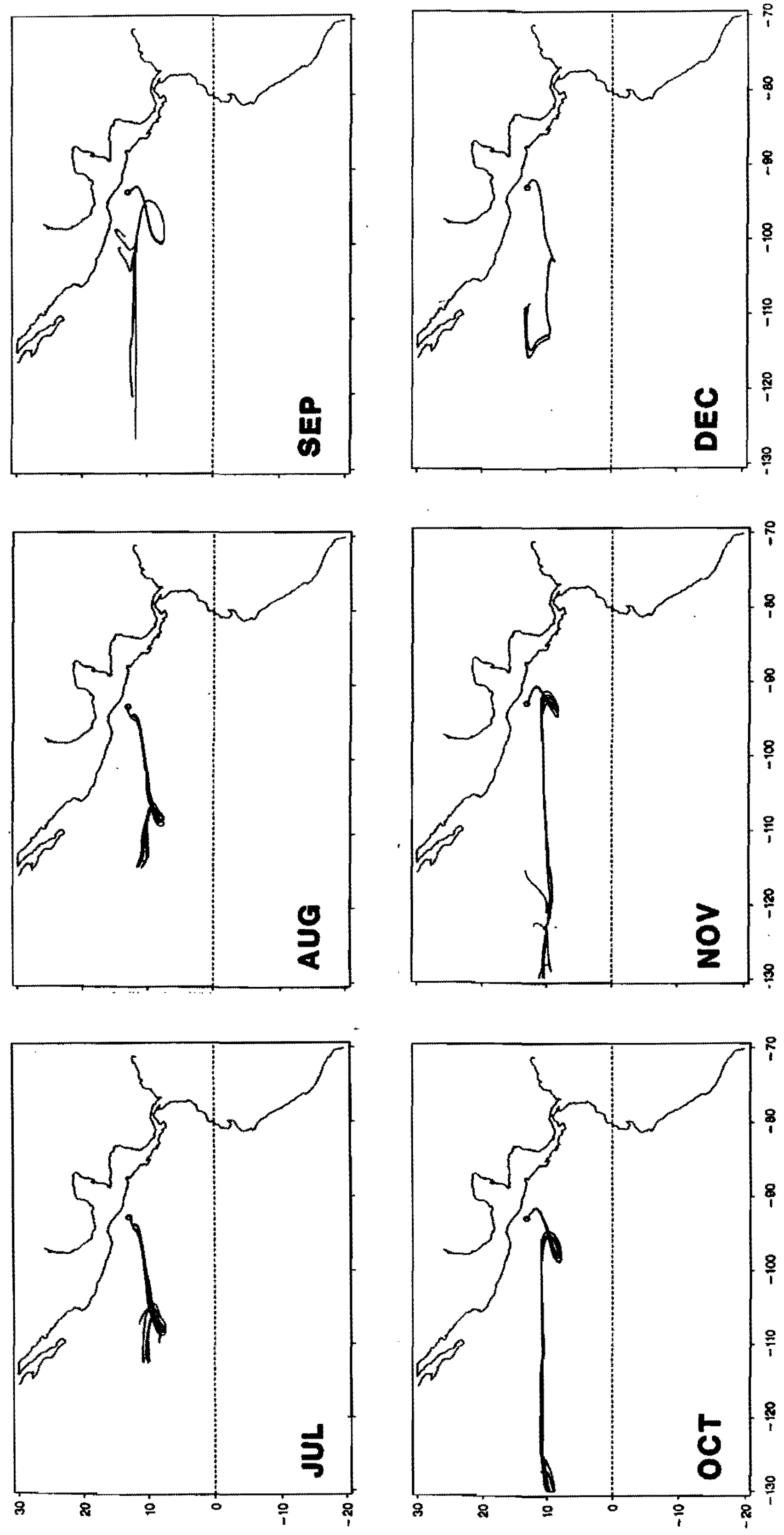


Figure 11. Continued.

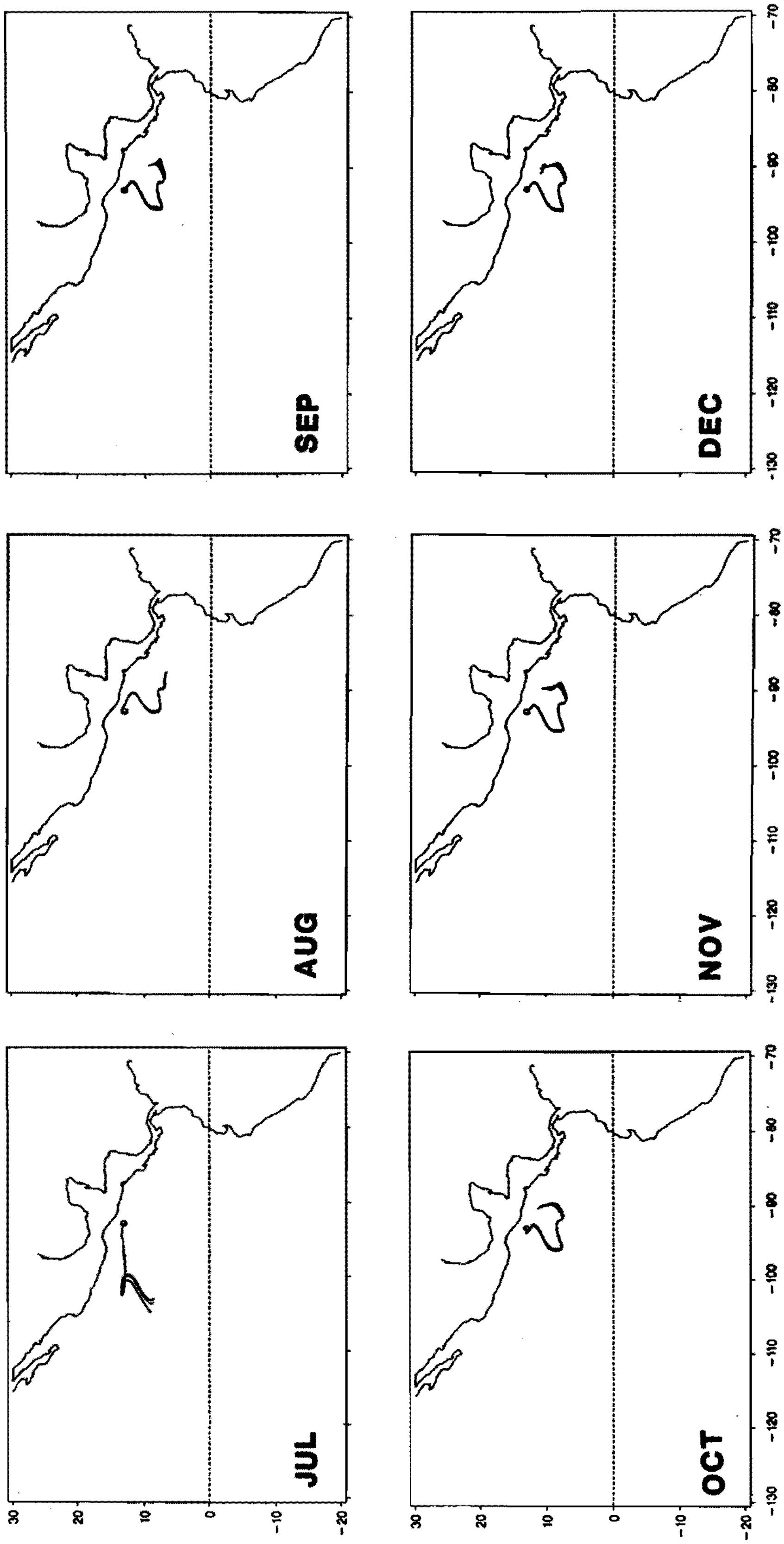


Figure 12. Simulated trajectory of objects entering Area 2, year 1977.

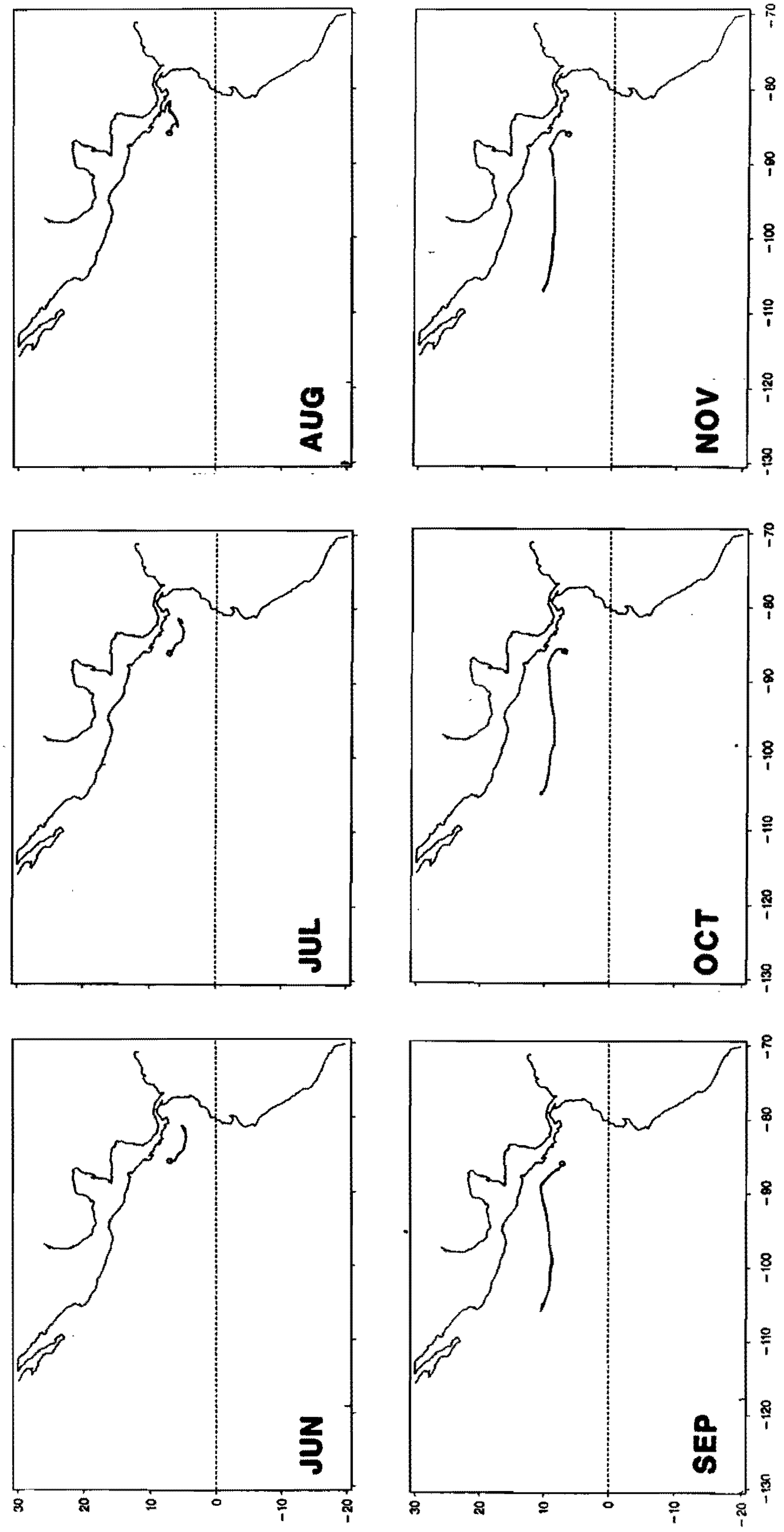


Figure 13. Simulated trajectory of objects entering Area 3, year 1980.

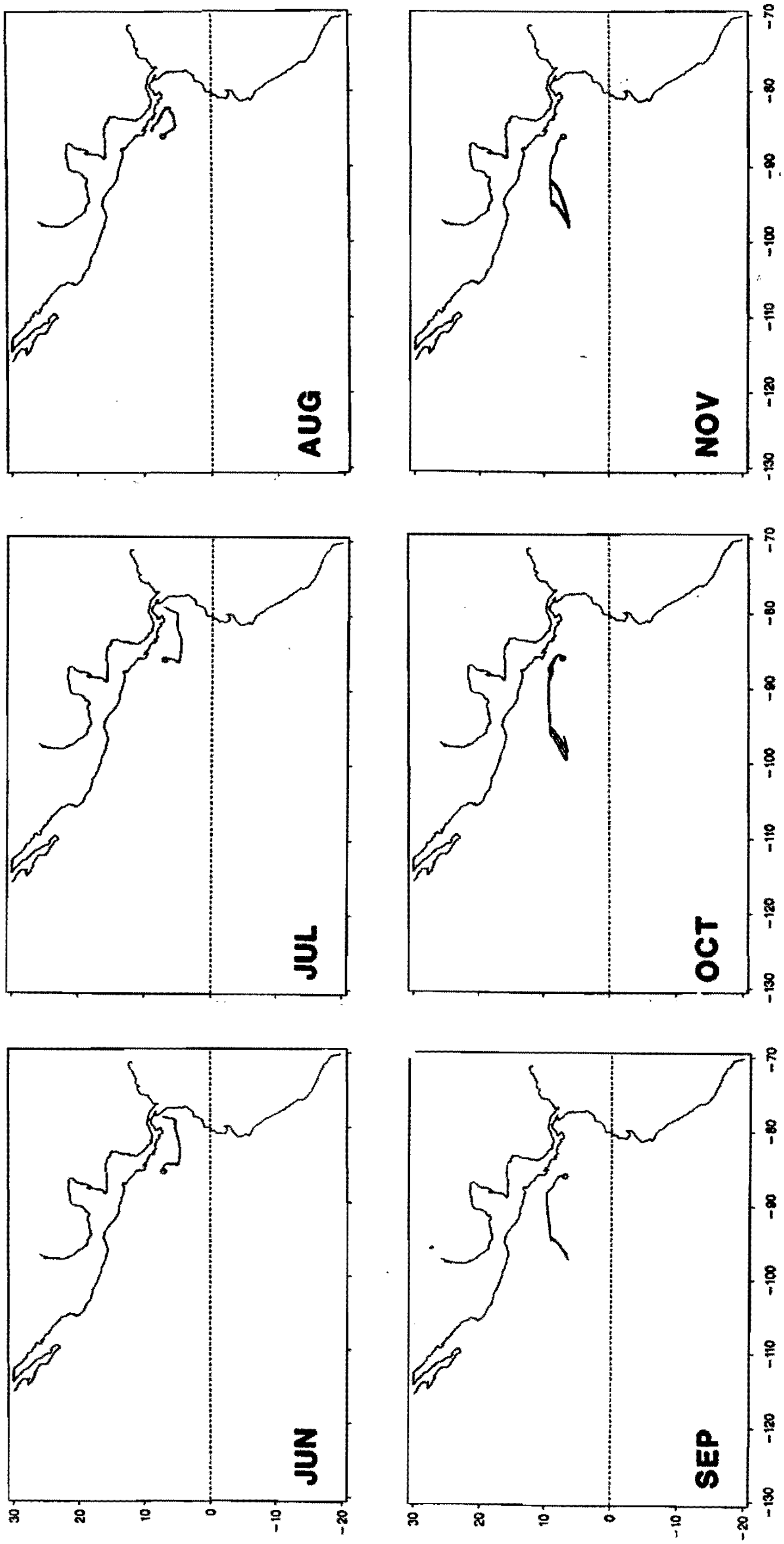


Figure 14. Simulated trajectory of objects entering Area 3, year 1981.

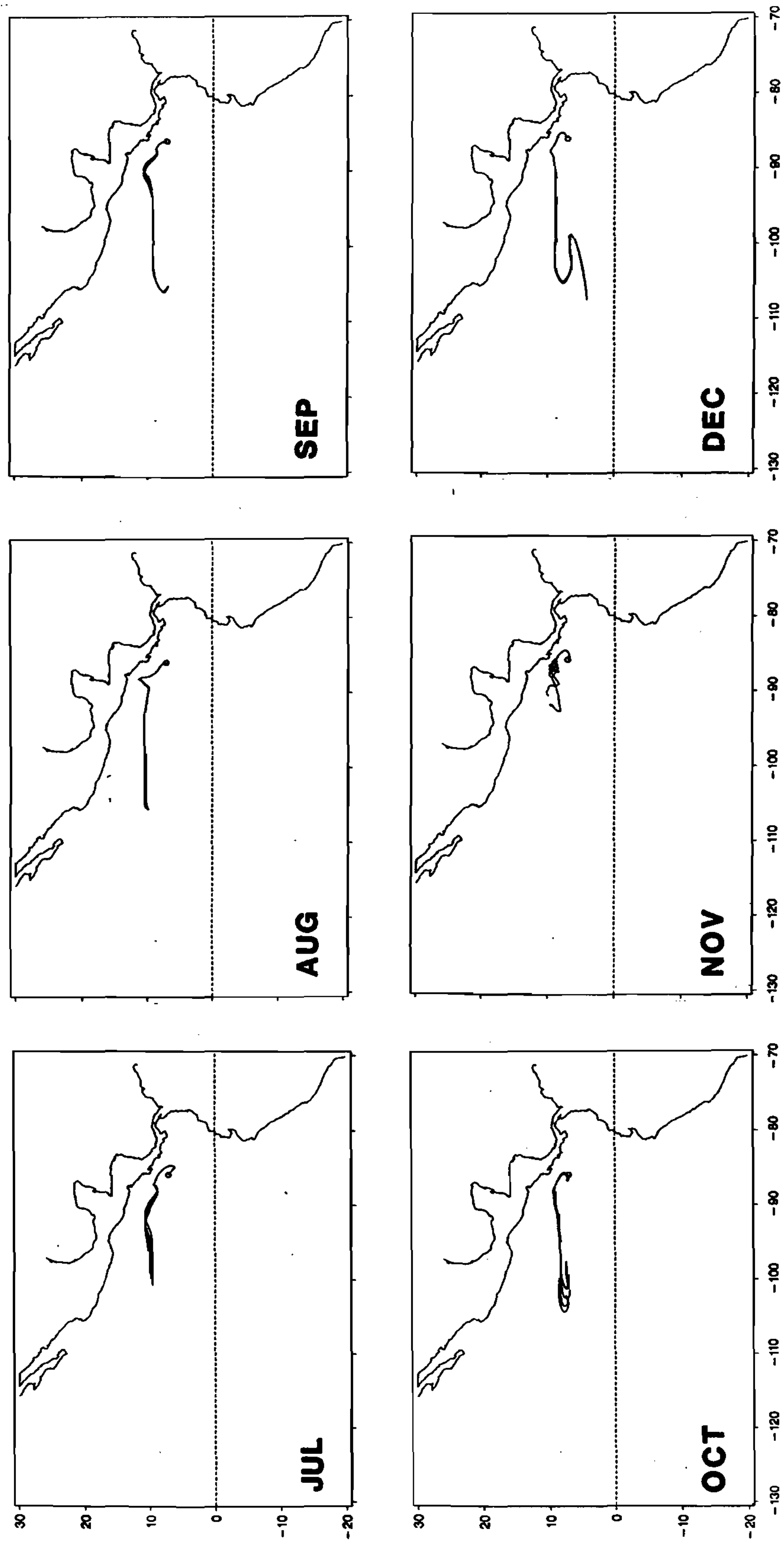


Figure 15. Simulated trajectory of objects entering Area 3, year 1982.

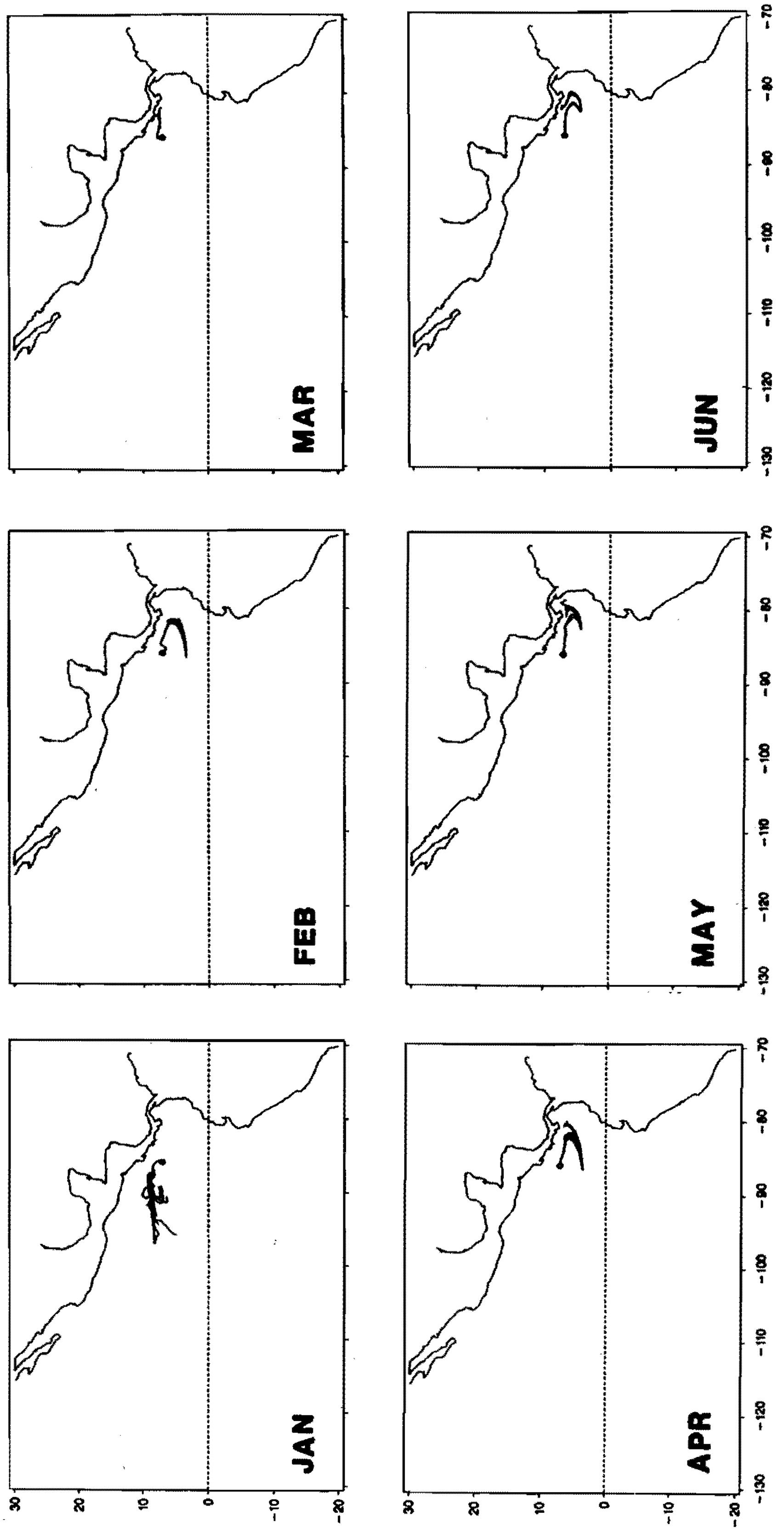
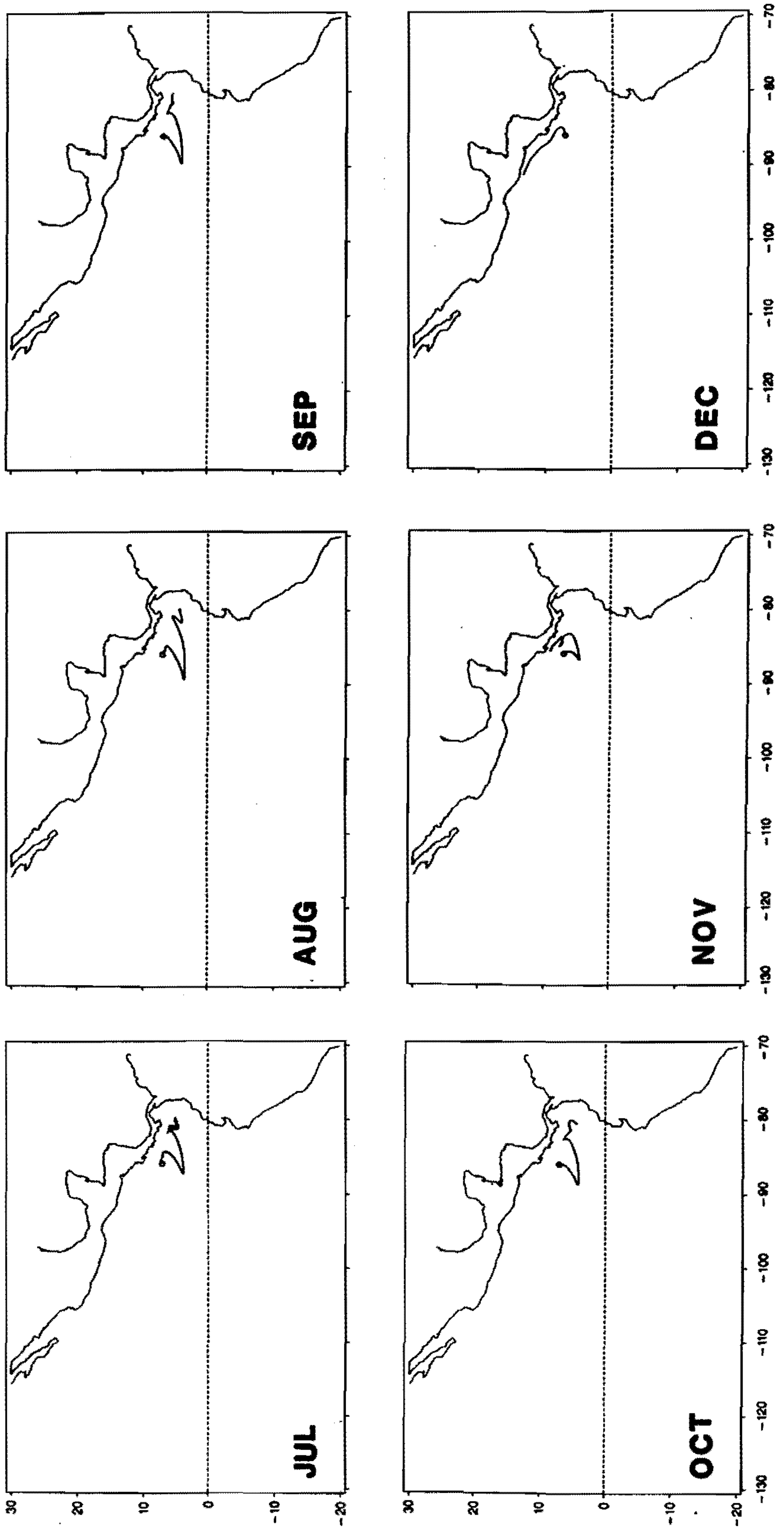


Figure 16. Simulated trajectory of objects entering Area 3, year 1983.



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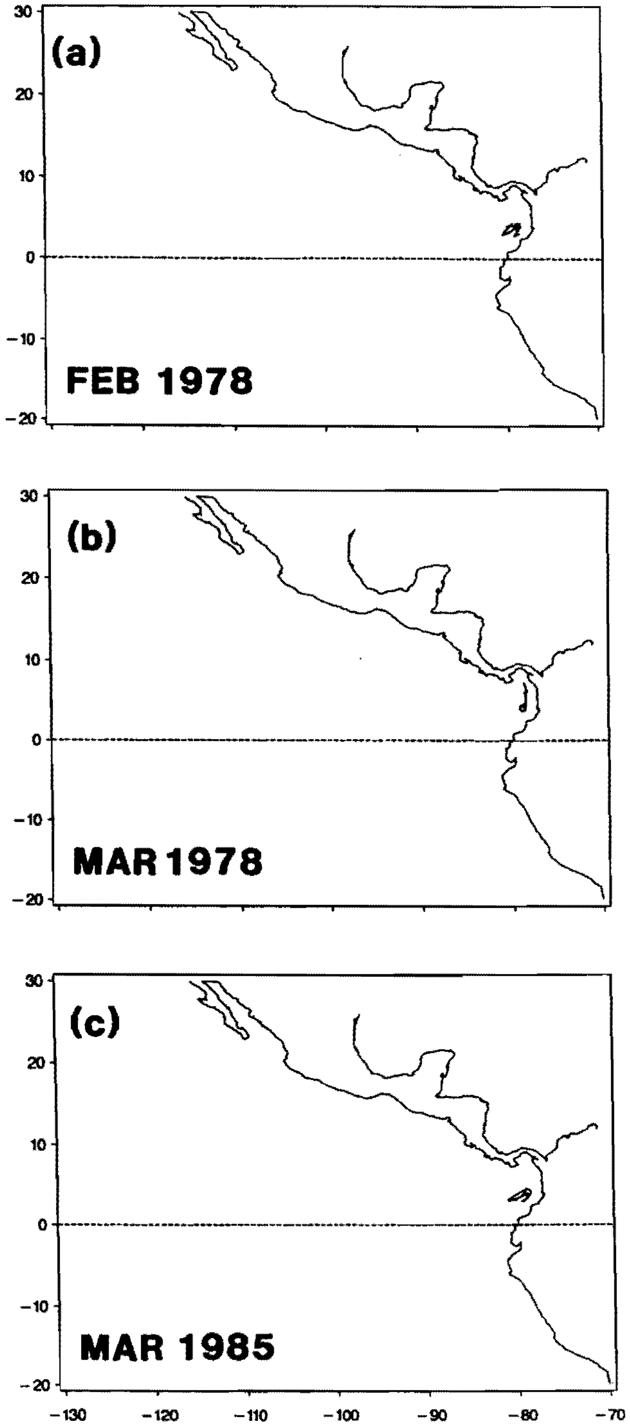


Figure 17. Three basic drift patterns for objects entering Area 4: (a) year 1978, entry month February; stranding after short erratic drifting; (b) year 1978, entry month March; drift toward the Gulf of Panama; (c) year 1985, entry month March; drift around the entry point.

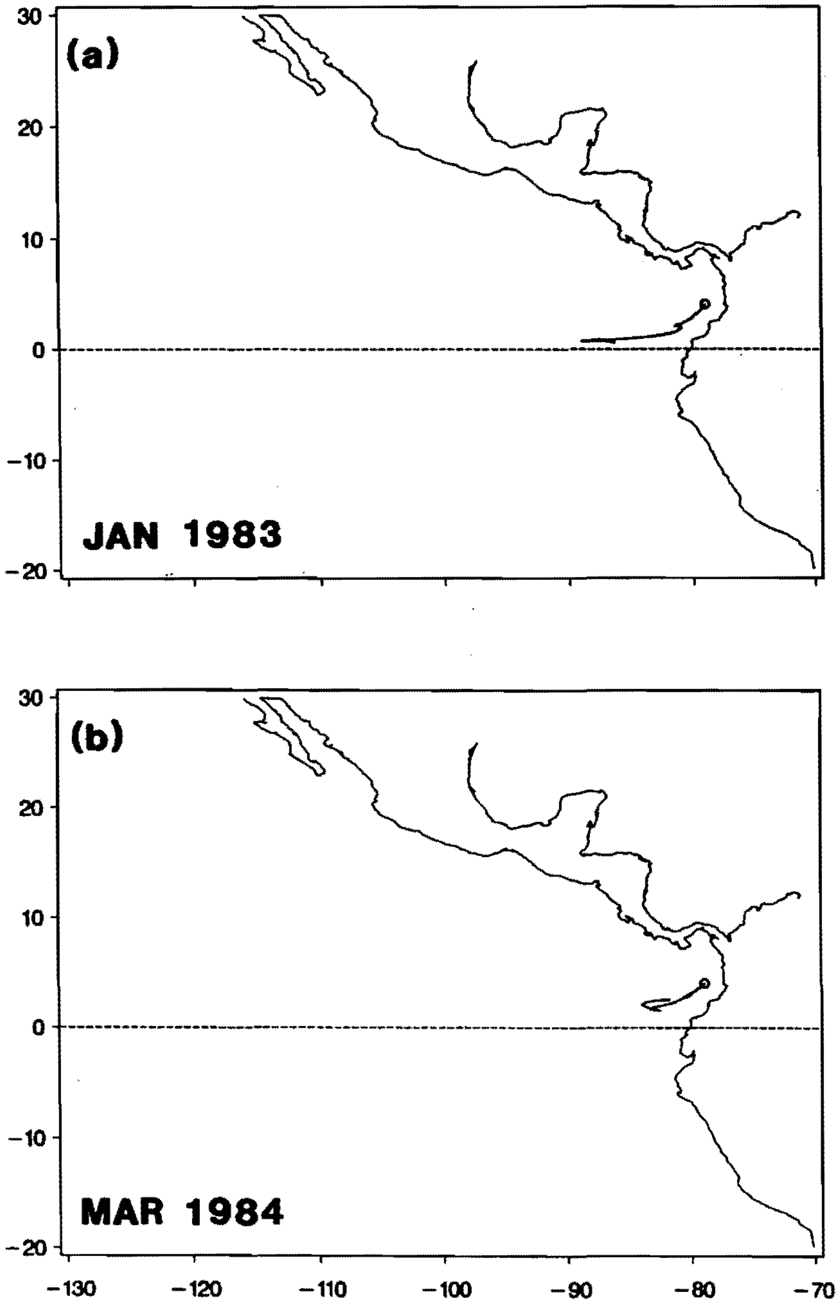


Figure 18. Examples of southwest drift of objects entering Area 4: (a) year 1983, entry month January; (b) year 1984, entry month is March.

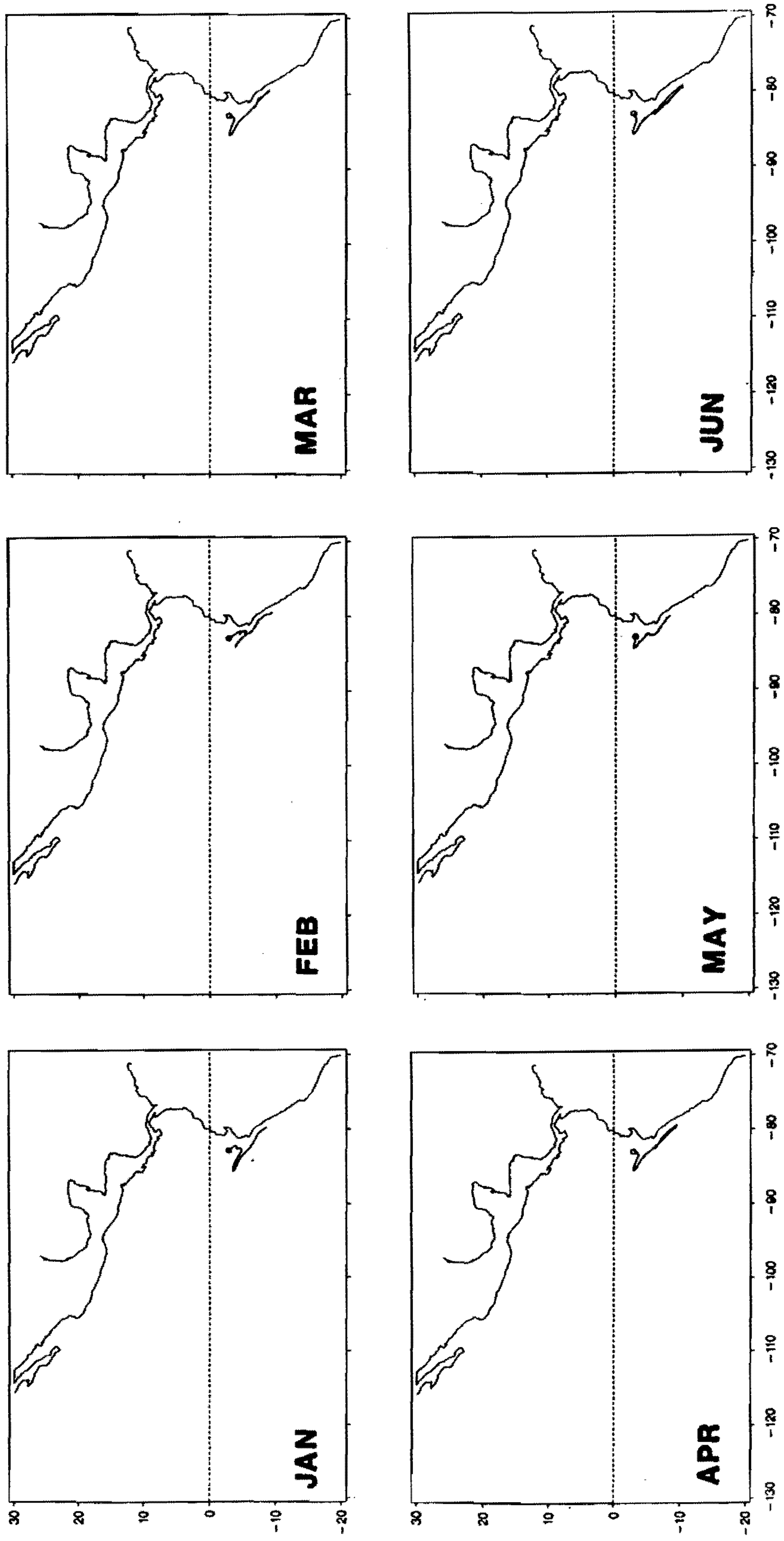


Figure 19. Simulated trajectory of objects entering Area 5, year 1981.

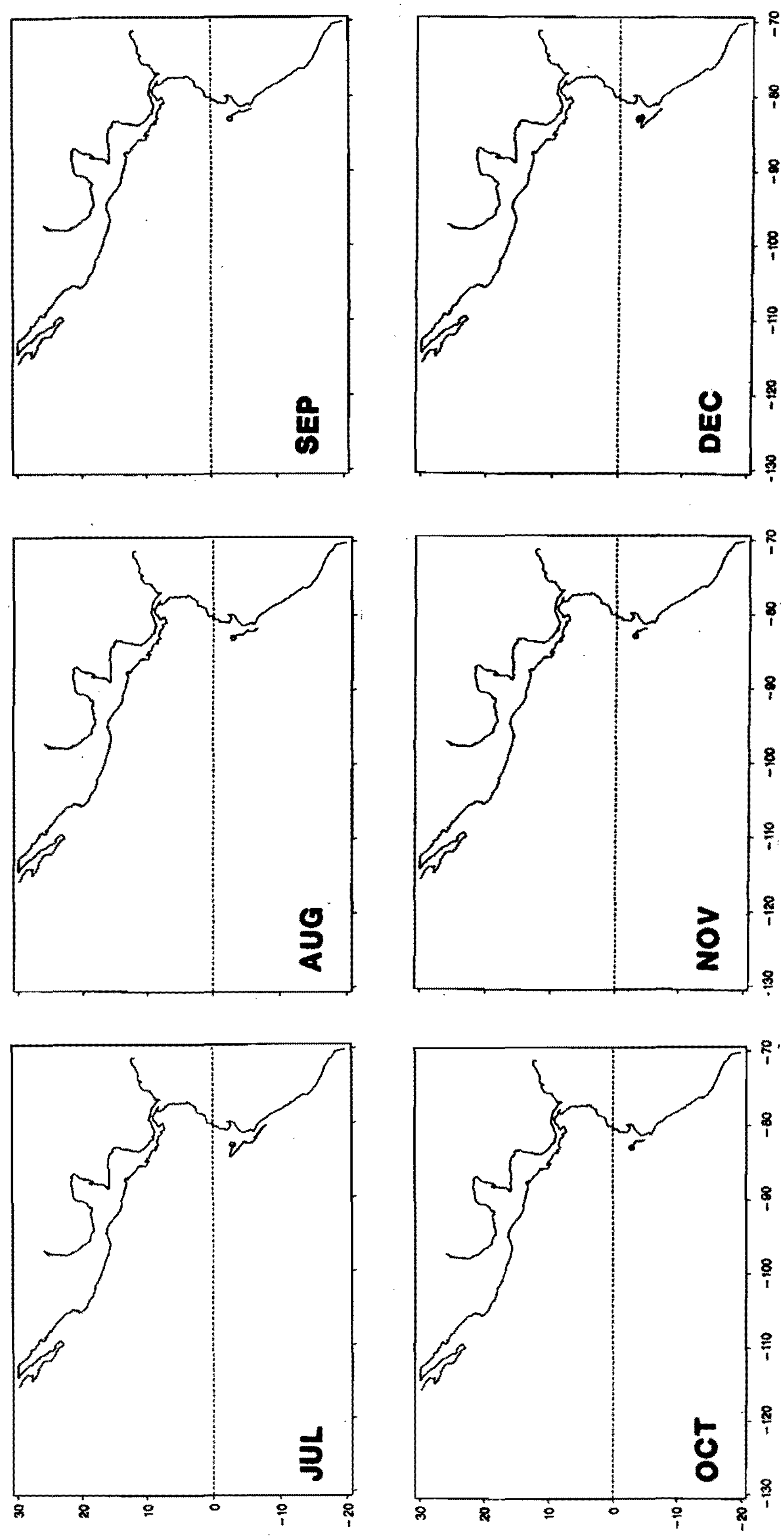


Figure 19. Continued.

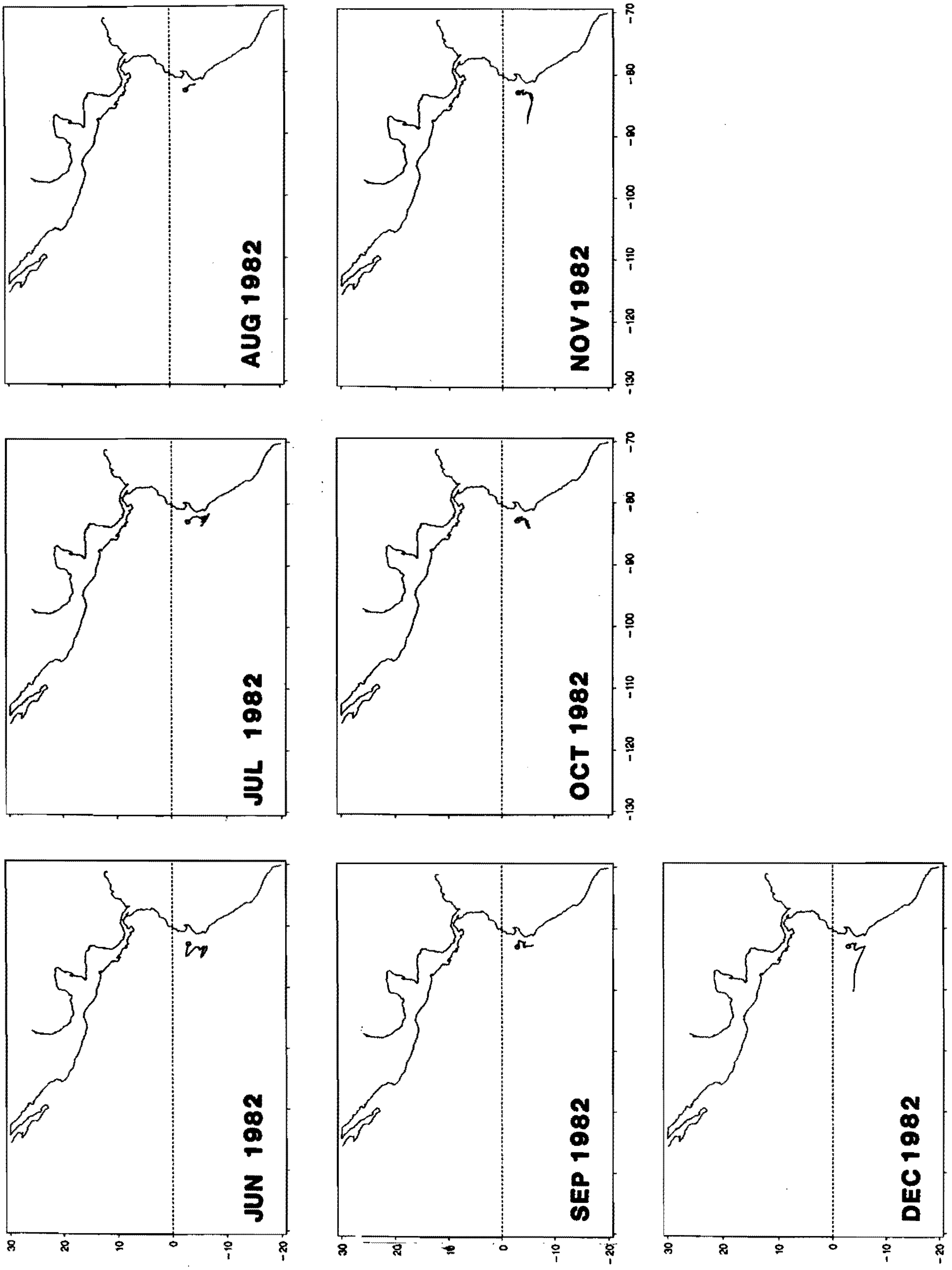


Figure 20. Simulated trajectory of objects entering Area 5, years 1982 and 1983.

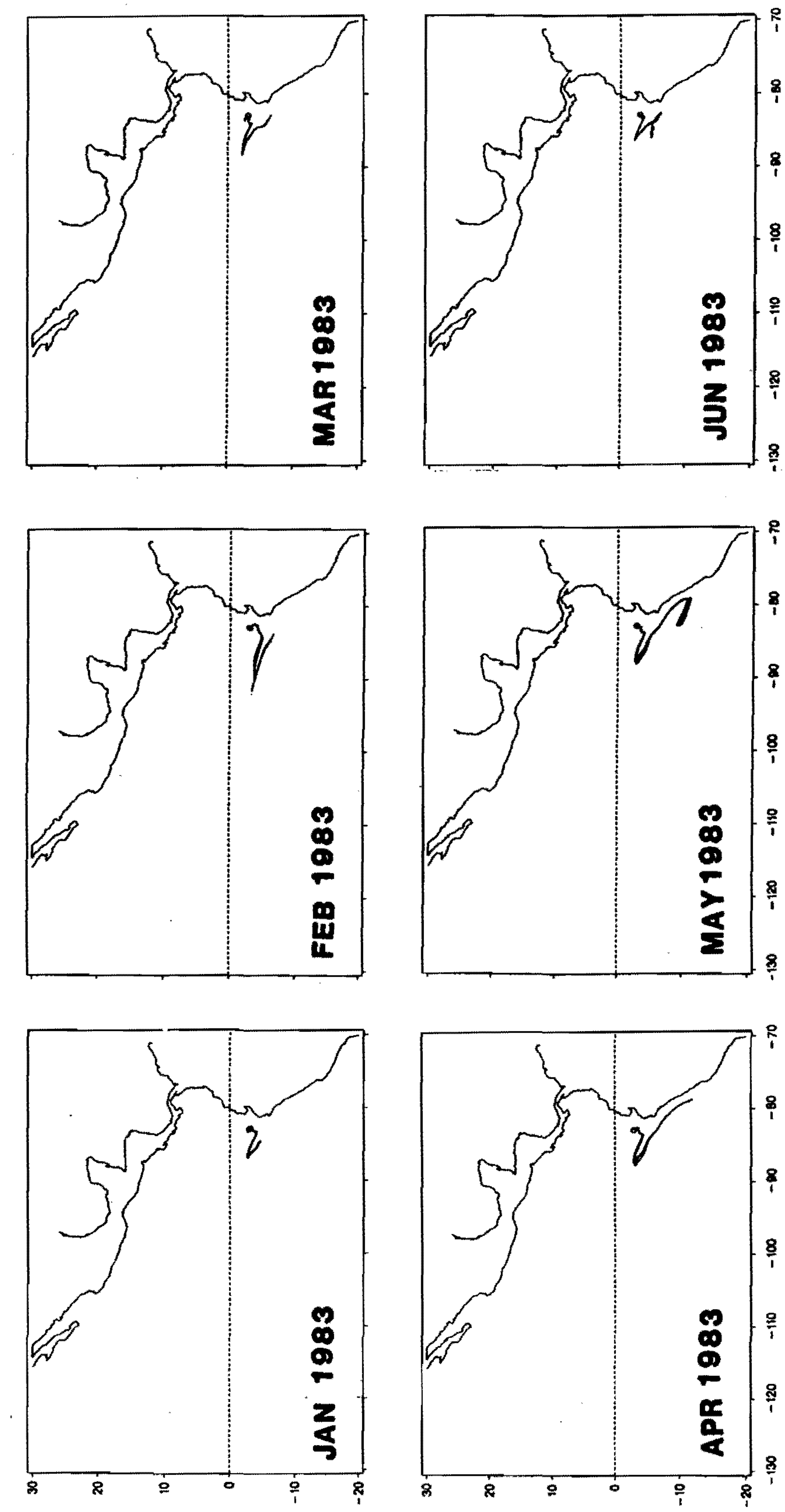
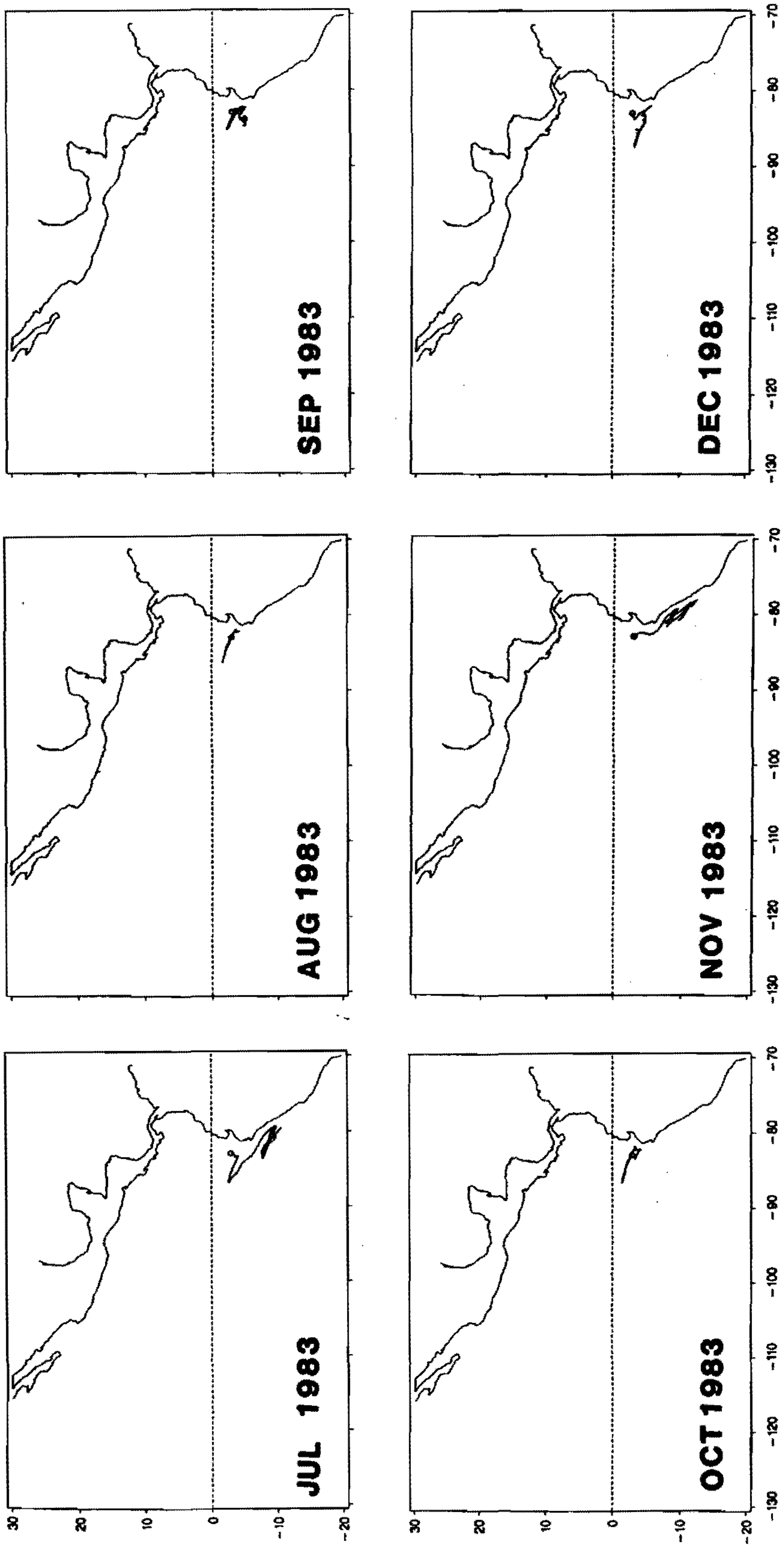


Figure 20. Continued.



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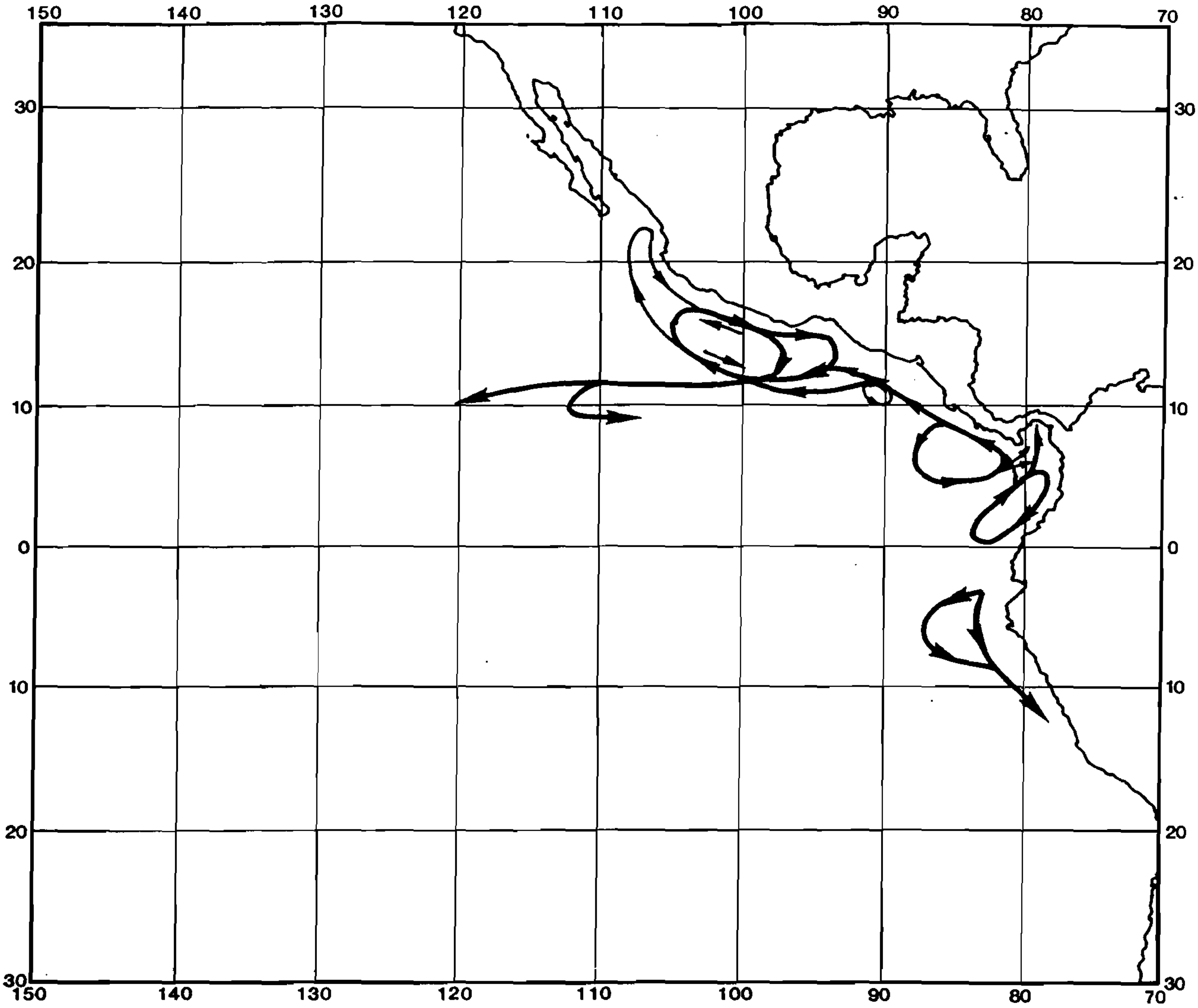

Figure 21. Scheme of possible drifting trajectories and circuits of objects in the eastern Pacific Ocean.

CHARACTERISTICS OF FLOATING OBJECTS AND THEIR ATTRACTIVENESS FOR TUNAS

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ABSTRACT

Marine mammal bycatch incidental to the international tuna purse-seine fishery for yellowfin tuna (*Thunnus albacares*) and skipjack tuna (*Katsuwonus pelamis*) in the eastern Pacific Ocean has been monitored by Inter-American Tropical Tuna Commission (IATTC) observers since 1979. In 1987, the data collection responsibilities of IATTC observers were expanded to include collection of data on the characteristics of floating objects and the bycatch of non-target species other than marine mammals. In this manuscript we present a summary of the data gathered by this program on the characteristics of these floating objects, the environmental conditions prevailing when the objects were encountered, and the amount of tuna caught in association with these objects between April 1987 and February 1991. Generalized linear model techniques were used to investigate relationships between object characteristics and environmental conditions, and catch of tunas. The analysis of the data was separated into two parts: a study of catch per successful set (a set catching more than one half ton of tuna; CSS) and a study of the probability of making a successful set. Results suggest that the most important factors affecting catch per set of all tunas caught have been the object's location, the time of day when the set was made and the number of sets made previously on the floating object. Season of deployment was one of the most important factors affecting CSS of yellowfin and skipjack tunas, suggesting that the choice of season for deployment of fish aggregating devices may depend on the target species. Generally, the characteristics of the floating object appear not to have had a significant effect on the CSS of tunas. However, given the sample sizes available, these results are tenuous and more data will be required to draw definitive conclusions.

INTRODUCTION

The eastern Pacific Ocean (EPO) fishery for yellowfin tuna (*Thunnus albacares*) is one of the most productive in the world (Anonymous, 1994: Table 1). This fishery has evolved from a coastal pole and line fishery which began in the early 1900s (Godsil, 1938; Joseph, 1973) to purse-seine and longline fisheries that are active from the coast to hundreds of miles offshore (Hall, *et al.*, this volume). Purse-seining for tunas involves encirclement of either free-swimming schools of tunas, schools of tunas associated with dolphins or schools of tunas associated with floating objects (Francis *et al.*, 1992; Hall, *et al.*, this volume). Although the tunas caught in association with dolphins are of optimal size in terms of market value and fishery management considerations (Joseph, 1994), increasing public opposition (primarily in the United States; Francis *et al.*, 1992; Joseph, 1994) to purse-seining techniques that involve the encirclement of herds of dolphins has revived interest in alternate methods that might yield yellowfin tuna of sizes comparable to those caught in association with dolphins (Francis *et al.*, 1992). For schools of tunas that are found in association with floating objects, interest has turned towards understanding why the association of tunas with floating objects developed and the environmental constraints of this association. It is hoped that this type of information will lead to the development of man-made floating objects (fish-aggregating devices, or FADs) that will attract tunas larger than most of those presently caught in association with floating objects (see Hall *et al.* (this volume) for a discussion of yellowfin size *versus* mode of purse-seining).

Tunas are found in association with floating objects in tropical waters of all of the world's oceans. Descriptions of fisheries for tuna associated with floating objects in other oceans are available, but detailed descriptions of the type of floating objects are generally lacking. A study of the fishery for tunas associated with floating objects in the EPO (with some description of the types of floating objects) was made by Greenblatt (1979). Information on the types of floating objects found by tuna fisheries in other oceans is available for the western Pacific (Uda, 1933; Uda and Tsukushi, 1934; Yabe and Mori, 1950; Kimura, 1954; Inoue *et al.*, 1963, 1968a, 1968b), the eastern Atlantic (reviewed by Cayré *et al.*, 1988; Pereira, 1990; Ariz *et al.*, 1991), the Caribbean (Medina-Gaertner and Gaertner, 1991), and the Indian Ocean (Hallier, 1985, 1991, 1995; Stequert and Marsac, 1989; Montaudouin and Lablache, 1991).

In an attempt to answer, among other things, questions regarding the type of floating objects found in association with tunas and the effects of the characteristics of the floating object on the catches of tuna per set, a program was initiated in 1987 by the Inter-American Tropical Tuna Commission (IATTC) to collect data on the characteristics of floating objects encountered at sea by observers assigned to tuna purse-seine vessels as part of the IATTC's Tuna-Dolphin Program (Anonymous, 1988, 1991). Observers recorded information on each floating object encountered while at sea. Between April 1987 and February 1991, information on 2,510 successful sets (sets catching more than one-half ton of tuna) on floating objects and on 2,725 observations that did not lead to a catch ("sightings") were gathered in the course of 497 trips by vessels from the international tuna purse-seine fleet; unsuccessful sets were not used in this analysis. In this manuscript, we present of summary of the types of floating objects encountered, the associated catches of tuna (when present), and the environmental conditions prevailing at the times of observation. Also, we present results of a preliminary analysis of factors that might have affected catches per set of tunas associated with floating objects.

DATA SOURCES

Data presented in this manuscript were collected by IATTC Tuna-Dolphin Program observers aboard purse-seiners of the international tuna fleet in the EPO between April, 1987, and February, 1991. Data recorded for each object included the date, position (latitude and longitude to the nearest tenth of a minute), number of previous sets on the floating object by the boat (an indicator of local depletion, if it occurs), time of day, environmental conditions prevailing when the object was encountered, and the characteristics of the object. Environmental conditions recorded were sea-surface temperature (in degrees Fahrenheit), cloud cover (on a scale of 0 to 9: 0 = no clouds, 1 = 1/8 cloud cover, ..., 8 = sky completely covered by clouds, 9 =

too dark to see), water clarity (clear, turbid or very turbid), wind index (Beaufort scale), and current strength (presence or absence of a strong current). Characteristics of the floating object recorded were type (natural or artificial; wood, other biological, other material, or FAD), tree characteristics, shape, material, origin, color, percentage submerged, estimated time adrift, percentage covered by epibiota, angle of inclination, and size (dimensions estimated to the nearest centimeter). Natural objects included whole trees and other plant or animal matter that had not been altered by man. Artificial objects included all objects from human activities (*e.g.*, cut trees, wooden planks, oil drums, abandoned fishing gear or FADs). In the case of parts of trees, additional information was recorded on whether the trees were cut and whether roots, branches, bark, and leaves were present. The estimated time adrift (short, medium or long; a subjective characterization based on the condition of the floating object, and percentage of its surface area covered by epibiota) and percentage of the surface covered by epibiotons were recorded as indicators of the object's time at sea.

The measurements of the object were used to estimate its longest dimension and to produce a rough estimate of its surface area and its volume. For spherical objects, the longest dimension was taken to be the diameter. Surface area and volume were estimated from formulae appropriate for the general shape of the object (*e.g.*, cylindrical). These data, along with the estimated percentage submerged, were used to estimate the effective surface area and effective volume (area and volume below the sea surface) of the object.

DATA SUMMARY

Below we present a summary of the number of sightings (sets which did not lead to a catch), numbers of successful sets, and catches per successful set (CSSs) for each of the variables discussed above. Unsuccessful sets on floating objects (sets in which 0.5 tons or less of tuna were caught) were excluded from our analyses, because we assumed that tunas were present in sufficient quantity to initiate the set, but probably escaped. The total numbers of sets and sightings may vary from table to table due to missing data for some of the variables. Percentages in the tables may not sum to exactly 100% due to rounding error. Catch data are reported in numbers of short tons. The "all tunas" group includes yellowfin, skipjack and other tuna species including black skipjack tuna (*Euthynnus lineatus*) and bigeye tuna (*Thunnus obesus*). The percentage of sets and sightings, and the median CSSs of tuna (with lower and upper quartiles) were computed for the various levels of each variable to provide a descriptive overview of the data. Median CSS and quartile values were rounded up to the nearest whole short ton. (The measure of catch used herein, median catch per successful set, is different from that used in most sections of Hall *et al.* (this volume), in which catch data are generally presented as average CSS (sum of all catches divided by the number of successful sets).) Because the majority of the data from the 2,510 sets and 2,725 sightings presented in this paper were collected in 1989 and 1990, data were pooled across years in all analyses. The number of sets and sightings by year are shown in Table 1. (The number of sets and sightings presented below sum to less than 2,510 and 2,725, respectively, due to a few observations for which the year was not recorded.)

Table 1.

Year	Number of sightings	Number of successful sets
1987	87	185
1988	417	606
1989	785	711
1990	1,322	945
1991	110	62
Total	2,721	2,509

Temporal and spatial variables

Month

Data on sightings, successful sets and CSSs during each month are given in Table 2. Between January and May, sightings occurred more frequently than successful sets; in June-July the situation was reversed, and during the rest of the year it varied from month to month. Two low periods in the number of sightings of floating objects occurred: 1) in January-February, coinciding with the driest months in Costa Rica, Panama, and northern Colombia when the abundance of terrestrially-derived natural debris may be at a seasonal low, and 2) in June-September, when most of the fleet is fishing far offshore (Hall, *et al.*, this volume). The median CSS of all tunas was relatively constant between June and November, with some variability between December and May. Median CSS of yellowfin was highest between June and August, and in November. On the other hand, median CSS of skipjack was highest between August and October and between January and April.

Table 2.

Month	Sightings % (n=2,715)	Successful sets % (n=2,508)	Median CSS (1st, 3rd quartiles) All tunas	Yellowfin	Skipjack
January	7.0	5.8	23 (10, 52)	6 (2, 18)	12 (5, 30)
February	4.8	4.3	23 (9, 47)	8 (2, 22)	10 (3, 26)
March	9.0	8.3	27 (11, 67)	5 (2, 16)	15 (6, 50)
April	10.3	8.7	30 (11, 56)	5 (2, 15)	20 (7, 48)
May	12.0	9.6	19 (6, 35)	5 (2, 10)	7 (2, 23)
June	5.5	8.0	26 (12, 52)	15 (5, 32)	5 (1, 22)
July	7.3	10.3	28 (11, 55)	13 (5, 26)	6 (2, 22)
August	8.5	7.6	28 (15, 52)	11 (5, 25)	11 (3, 26)
September	5.1	6.4	27 (12, 49)	8 (3, 20)	10 (4, 22)
October	10.1	8.8	27 (13, 64)	9 (3, 19)	12 (5, 33)
November	11.2	12.8	28 (13, 53)	12 (5, 24)	8 (3, 25)
December	9.3	9.3	22 (11, 44)	8 (3, 17)	8 (2, 19)

Location

Figure 1 shows the locations of the sightings of and sets on floating objects. It must be stressed that these data represent areas searched by the tuna fleet; there were no data available for other areas. Reports from fishermen, scientists, and others who have been in these other areas seem to agree that there are fewer floating objects there, but there are no quantitative data. The inshore edge of the fishery is most likely limited by water depth, which must exceed 200 meters to accommodate the depth of the purse seine. Both sets and sightings occurred along the coasts of Central America and Colombia, especially off the mouth of the Gulf of Panama. To the south and west of the Gulf of Fonseca (13°N, 88°W) sets were observed more frequently than sightings; the opposite occurred off Baja California. There are two gaps in the distribution of sets, one along the Mexican coast north of the Gulf of Tehuantepec (15°N, 95°W) and the other at the Costa Rica Dome (9°N, 89°W,). The first, especially evident because it begins just north of an area of high concentration for sets, is a region where the currents flowing along the coast from the south turn west just off the Gulf of Tehuantepec. These currents probably carry floating objects offshore that would otherwise have reached the coast to the north (Hall, *et al.*, this volume; García *et al.*, this volume). In the case of the Costa Rica Dome, the circular current patterns may tend to drive the floating objects north, into the Costa Rica Coastal Current, and away from the central part of the Dome. Figure 1 also shows the proportion of observations that were sets by 5° areas. The patterns described above are clear, with the exception of the Costa Rica Dome, which has disappeared because of the scale of the plot. (The sample sizes were very small for the two darkest areas, and these should be ignored.) The value of floating objects as indicators of the presence of tunas is evidenced by the fact that even in the offshore area between 25% and 50% of sightings of floating objects led to sets. A general description of the spatial distribution of catches of tuna in this fishery between 1980 and 1990 can be found in Hall *et al.* (this volume).

Time of day

Data on sightings, successful sets, and CSSs at different times of the day are given in Table 3. Sets were observed predominantly in the early morning, while the number of observed sightings were distributed uniformly throughout the day. Approximately 43% of the observed sets, but only 6% of the observed sightings, occurred before 0700. Median CSS of all tunas increased in the morning, peaked around 0900-1059, then declined markedly toward the late afternoon, with a hint of an increase at the end of the day. Given that in the early morning the median CSS was around 30 tons and that at the end of the day it was less than 20 tons, it seems clear that an influx of tunas to the floating objects must take place during the evening or night. Median CSSs of yellowfin and skipjack followed a similar pattern.

Table 3.

Time of day	Sightings % (n=1,971)	Successful sets % (n=2,510)	Median CSS (1st, 3rd quartiles) All tunas	Yellowfin	Skipjack
before 0500	0.1	0.8	30 (11, 52)	8 (6, 22)	13 (3, 33)
0500 - 0559	0.6	14.9	25 (12, 49)	9 (3, 20)	10 (2, 25)
0600 - 0659	5.1	26.9	28 (13, 56)	10 (4, 22)	10 (3, 28)
0700 - 0759	7.1	7.9	29 (15, 55)	11 (5, 22)	15 (5, 34)
0800 - 0859	8.7	6.9	29 (10, 60)	8 (2, 17)	11 (3, 37)
0900 - 0959	9.4	6.4	35 (14, 67)	8 (2, 20)	20 (4, 42)
1000 - 1059	9.5	6.0	30 (14, 65)	12 (3, 20)	10 (5, 35)
1100 - 1159	7.9	7.4	25 (13, 45)	8 (2, 20)	10 (3, 25)
1200 - 1259	7.5	5.3	26 (10, 48)	10 (4, 20)	10 (2, 25)
1300 - 1359	8.1	5.5	22 (9, 40)	7 (3, 15)	10 (3, 21)
1400 - 1459	9.1	4.8	25 (11, 53)	8 (3, 25)	8 (3, 24)
1500 - 1559	8.3	3.5	15 (7, 30)	7 (3, 15)	5 (2, 12)
1600 - 1659	7.7	2.3	14 (6, 26)	6 (2, 14)	5 (3, 14)
1700 - 1759	7.6	1.2	12 (6, 21)	6 (3, 13)	4 (1, 7)
1800 - 1859	3.1	0.2	18 (14, 41)	10 (8, 11)	26 (6, 45)
after 1900	0.3	0.0	-	-	-

Previous sets

A description of CSS in repeated sets on the same floating object can be found in Hall *et al.* (this volume). In general, it was found that the CSS decreased with increasing number of previous sets. The main problem with these data is that it was impossible to know if other, unobserved sets were made on the floating object by other boats between observed sets. Therefore, data on the number of previous sets may not be representative of the true number of sets on the floating object, so they must be interpreted with caution.

Environmental variables

Sea-surface temperature

Data on sightings, successful sets, and CSSs at different temperatures are given in Table 4. The sea-surface temperatures for the majority of the observed sightings and sets ranged between 78°-86°F, with a peak between 80° and 84°. Median CSSs of all tunas was greatest for sets made in waters with temperatures between 78° and 80°F. Median CSS of yellowfin increased slightly with increasing temperature; median CSS of skipjack followed the opposite pattern, peaking at about 76°-80°F, and then declining markedly.

Table 4.

Sea-Surface Temperature (°F)	Sightings % (n=2,252)	Successful sets % (n=2,506)	Median CSS (1st, 3rd quartiles) All tunas	Yellowfin	Skipjack
< 66	0.6	0.0	-	-	-
66 - 69.9	2.0	0.4	25 (10, 30)	10 (2, 17)	18 (2, 26)
70 - 73.9	4.3	1.5	15 (6, 32)	6 (2, 17)	10 (3, 34)
74 - 75.9	4.0	2.2	22 (5, 78)	5 (1, 19)	12 (2, 35)
76 - 77.9	4.1	4.9	24 (12, 60)	4 (2, 16)	17 (6, 47)
78 - 79.9	11.2	14.6	31 (16, 58)	8 (2, 18)	17 (6, 39)
80 - 81.9	29.0	35.8	26 (13, 50)	10 (3, 20)	10 (3, 27)
82 - 83.9	29.4	27.3	25 (10, 51)	9 (4, 20)	7 (2, 22)
84 - 85.9	12.0	10.9	24 (11, 45)	11 (4, 23)	7 (3, 17)
> 86	3.4	2.6	20 (11, 44)	10 (5, 19)	4 (1, 15)

Cloud cover

Most observations were made under at least partially cloudy skies (Table 5). The median CSSs were less at lower cloud cover values, and was relatively stable (yellowfin) or increasing (skipjack) with increasing cloud cover.

Table 5.

Cloud Cover	Sightings % (n=2,062)	Successful sets % (n=2,427)	Median CSS (1st, 3rd quartiles) All tunas	Yellowfin	Skipjack
0	1.0	0.7	16 (7, 40)	9 (3, 20)	4 (1, 8)
1	7.2	4.9	25 (11, 46)	10 (3, 20)	8 (1, 17)
2	8.6	6.3	24 (13, 51)	9 (4, 19)	6 (2, 20)
3	10.2	9.8	25 (13, 55)	8 (3, 20)	10 (3, 25)
4	10.5	11.5	24 (12, 49)	9 (3, 20)	10 (3, 30)
5	9.0	9.2	22 (10, 50)	8 (3, 20)	8 (3, 22)
6	14.2	13.2	28 (13, 55)	9 (2, 21)	11 (3, 29)
7	16.5	16.4	27 (11, 53)	10 (3, 20)	10 (3, 30)
8	22.0	24.9	28 (13, 53)	10 (3, 20)	12 (4, 30)
9	0.7	3.0	25 (13, 66)	10 (4, 20)	13 (1, 43)

Water clarity

Data on sightings, successful sets, and CSSs at different stages of water clarity are given in Table 6. Because "very turbid" conditions were seldom observed, "turbid" and "very turbid" observations were combined into one category. Most observations were made in "clear" water. There was little difference between the median CSS in clear conditions and the median CSS in turbid conditions.

Table 6.

Water Clarity	Sightings % (n=2,387)	Successful sets % (n=2,369)	Median CSS (1st, 3rd quartiles)		
			All tunas	Yellowfin	Skipjack
Clear	74.2	70.0	25 (12, 55)	9 (3, 20)	10 (3, 30)
Turbid	25.8	30.0	27 (12, 49)	9 (3, 20)	9 (2, 24)

Wind index

Data on sightings, successful sets, and CSSs at Beaufort levels are given in Table 7. The highest recorded Beaufort value (an indicator of wind speed) in the database was 8, but most of the observations occurred during Beaufort indices 1 to 4. Higher median CSS values occurred at higher Beaufort values for all tunas and skipjack. The median CSS of yellowfin decreased slightly with increasing Beaufort values.

Table 7.

Beaufort Number	Sightings % (n=2,057)	Successful sets % (n=2,409)	Median CSS (1st, 3rd quartiles)		
			All tunas	Yellowfin	Skipjack
0	1.2	3.2	26 (11, 54)	14 (5, 37)	5 (2, 20)
1	20.3	22.2	25 (11, 44)	10 (3, 20)	9 (2, 20)
2	33.0	34.9	24 (12, 50)	9 (3, 20)	9 (3, 25)
3	28.3	26.8	28 (12, 59)	9 (2, 20)	12 (3, 34)
4	14.8	11.0	30 (13, 56)	7 (3, 18)	15 (6, 40)
5	1.9	1.7	31 (17, 60)	10 (4, 20)	15 (6, 30)
6 and greater	0.4	0.3	40 (25, 150)	9 (1, 15)	14 (10, 85)

Current strength

Close to 30% of the observed sets and sightings were made in strong currents (Table 8). Median CSS values were very similar for both categories.

Table 8.

Strong Current	Sightings % (n=1,849)	Successful sets % (n=2,431)	Median CSS (1st, 3rd quartiles)		
			All tunas	Yellowfin	Skipjack
Present	28.3	29.9	25 (12, 51)	9 (3, 20)	10 (3, 28)
Absent	71.5	70.1	26 (11, 52)	9 (3, 20)	10 (3, 28)

Characteristics of the floating object

Object type

The types of object most frequently encountered were classified into several general groups (Table 9). The most frequently encountered group was plant material; over 45% of all floating objects observed were unidentified trees or parts of trees. This group also includes palm, banana, and mangrove trees, bamboo, and other types of canes. Another frequently observed group consisted of wooden objects originating in human activities; these included pallets, planks, plywood, boats and parts of boats, and cable drums. Discarded fishing gear and other nautical materials, principally rope and buoys, were also common. Dead animals such as whales, pinnipeds, and sea turtles also were encountered. Other types of debris are more difficult to classify (tires, foam, plastic and metal drums, other plastic objects, and general trash) and can originate almost anywhere on land or sea. The category FADs includes all objects that were assembled by fishermen to attract fish. FADs were constructed from a variety of materials (*e.g.*, a wooden pallet tied to a plastic drum and to a dead animal) and include elements from the other categories, but were classified as a whole, rather than their component parts.

Median CSS of all tunas and skipjack were highest in sets involving wooden man-made objects, non-wooden man-made objects and discarded equipment. Median CSS of yellowfin was highest in sets involving wooden man-made objects, FADs and unidentified debris.

Table 9.

Type of Object	Sightings % (n=2,723)	Successful sets % (n=2,491)	Median CSS (1st, 3rd quartiles) All tunas	Median CSS (1st, 3rd quartiles) Yellowfin	Median CSS (1st, 3rd quartiles) Skipjack
Terrestrial Plant Material	48.4	47.2	25 (11, 50)	8 (3, 20)	8 (3, 25)
Unidentified Tree	44.4	44.0			
Palm tree	1.0	0.7			
Banana tree	0.1	0.1			
Mangrove tree	0.3	0.3			
Bamboo	1.5	1.7			
Cane	0.8	0.4			
Hay/straw	<0.1	<0.1			
Fruits	0.1	0.0			
Kelp	5.5	0.8	10 (2, 25)	6 (2, 10)	6 (2, 17)
Man-MadeWooden Objects	17.0	17.8	28 (12, 61)	10 (3, 22)	12 (4, 34)
Boats/boat parts	0.9	1.0			
Pallets	6.6	8.3			
Planks	5.8	5.1			
Plywood	1.7	1.8			
Cable drums	1.9	1.7			
Dead Animals	4.8	3.2	23 (10, 45)	7 (2, 17)	11 (3, 22)
Whale	2.6	2.4			
Other animals	1.1	0.6			
Unidentified turtle	1.0	0.1			
Olive Ridley	0.1	0.0			
Discarded Equipment	13.6	11.8	32 (15, 57)	9 (3, 19)	17(5, 44)
Rope	3.3	6.2			
Fishing gear	3.6	2.2			
Buoy	5.7	2.9			
Life preservers	0.3	0.0			
Rafts	0.2	0.1			
Other	0.6	0.3			

Table 9. (continued)

Type of Object	Sightings % (n=2,723)	Successful sets % (n=2,491)	Median CSS (1st, 3rd quartiles) All tunas	Yellowfin	Skipjack
Man-made Non-wooden Objects	6.0	5.8	30 (12, 60)	7 (2, 20)	16(2, 42)
Tires	0.1	0.5			
Foam	0.9	0.2			
Plastic drums	1.2	1.8			
Other plastic	1.8	2.1			
Trash	0.4	0.2			
Metal drums	1.4	0.3			
Research buoys	0.1	0.7			
FADs	3.1	12.6	25 (12, 44)	11 (5, 32)	8 (3, 20)
Other and Unidentified Objects	1.7	0.7	26 (8, 70)	13 (2, 25)	2 (1, 10)
Other objects	1.6	0.7			
Unidentified	0.1	<0.1			

Tree characteristics

Trees, the most predominant of floating objects, were further classified into the categories listed in Table 10. Most floating objects that were trees were uncut and without bark, leaves, branches, or roots.

Table 10.

	Sightings (%) (n = 928)	Successful sets (%) (n = 760)
Cut trees	37.0	43.8
Uncut trees	63.0	56.2
	(n = 972)	(n = 812)
With roots	25.2	27.1
Without roots	74.8	72.9
	(n = 985)	(n = 808)
With branches	38.6	37.7
Without branches	61.4	62.3
	(n = 926)	(n = 754)
With bark	33.6	28.0
Without bark	66.4	72.0
	(n = 919)	(n = 739)
With leaves	2.0	0.9
Without leaves	98.0	99.1

Shape

The most commonly observed shapes were cylindrical, irregular, and polygonal (Table 11). The category "aggregated" refers to flotsam consisting of two or more objects combined in some way. Median CSS values of yellowfin were similar for all shapes. The highest median CSS values of skipjack occurred in sets involving polygonal floating objects and the poorly defined "other" category; the highest median CSS values of all tunas occurred in sets involving irregular and polygonal floating objects and floating objects in the "other" category.

Table 11.

Shape of Object	Sightings % (n=2,716)	Successful sets % (n=2,487)	Median CSS (1st, 3rd quartiles) All tunas	Yellowfin	Skipjack
Cylindrical	46.8	42.2	25 (11, 50)	8 (3, 20)	10 (3, 25)
Irregular	22.3	21.7	27 (12, 52)	9 (3, 20)	11 (4, 30)
Polygonal	16.8	16.0	26 (12, 60)	10 (3, 22)	12 (3, 34)
Aggregated	7.5	16.5	23 (10, 43)	10 (4, 21)	9 (2, 21)
Spherical	3.5	1.3	24 (18, 45)	10 (4, 20)	11 (5, 30)
Other	3.1	2.2	40 (18, 66)	10 (4, 20)	12 (3, 38)

Material

Floating objects are made of a wide variety of materials, which were grouped into the four categories listed in Table 12. The distribution of successful sets and sightings by material type were similar, with exception that the proportion of sightings was lowest on FADs, whereas the proportion of successful sets was lowest on "other biological materials." Median CSS of yellowfin was greatest on FADs; median CSS of skipjack and all tunas was greatest on objects in the "other" category.

Table 12.

Type of Material	Sightings % (n=2,716)	Successful sets % (n=2,487)	Median CSS (1st, 3rd quartiles) All tunas	Yellowfin	Skipjack
Wood	66.1	65.3	25 (11, 51)	9 (3, 20)	10 (3, 25)
Other biological	9.5	3.9	21 (7, 38)	6 (2, 15)	10 (2, 22)
Other	21.2	18.2	31 (15, 60)	8 (2, 20)	16 (4, 42)
FADs	3.1	12.6	25 (12, 44)	11 (5, 23)	8 (3, 20)

Origin

Over half the floating objects observed were of "artificial" origin (Table 13). Trees that entered the ocean as a result of logging also were included in the “artificial” category. Slightly higher median CSS occurred in sets on artificial objects (which included FADs).

Table 13.

Origin of Object	Sightings % (n=2,723)	Successful sets % (n=2,491)	Median CSS (1st, 3rd quartiles) All tunas	Yellowfin	Skipjack
Natural	46.1	37.9	25 (11, 48)	8 (3, 20)	8 (2, 22)
Artificial	53.9	62.1	26 (12, 55)	10 (3, 20)	11 (3, 30)

Color

Data on sightings, successful sets, and CSSs for the color of the floating object are given in Table 14. The most commonly observed color was brown, as is to be expected given the high proportion of trees observed. For most colors, the proportion of sightings and sets were similar with the exception of black, which was more common in sets than sightings. Silver and black objects produced the highest median CSS of all tunas; blue and green produced the lowest. Silver and red floating objects produced the highest median CSS of yellowfin, whereas black, blue and green objects produced the highest median CSS of skipjack.

Table 14.

Color	Sightings % (n=1,910)	Successful sets % (n=1,497)	Median CSS (1st, 3rd quartiles) All tunas	Yellowfin	Skipjack
Brown	57.8	57.2	25 (11, 50)	10 (4, 22)	8 (3, 22)
Yellow	13.6	12.1	25 (12, 49)	10 (4, 20)	11 (3, 34)
White	7.5	8.6	25 (11, 49)	8 (2, 18)	10 (2, 35)
Orange	6.8	4.5	24 (11, 50)	6 (2, 20)	11 (5, 21)
Red	5.0	5.4	25 (15, 51)	11 (4, 24)	10 (2, 22)
Black	3.6	7.2	32 (15, 67)	8 (2, 20)	18 (5, 50)
Silver	2.3	1.3	35 (19, 83)	14 (1, 40)	6 (4, 33)
Blue	1.8	2.7	23 (10, 45)	6 (2, 20)	12 (3, 29)
Green	1.7	0.9	20 (12, 32)	5 (3, 9)	13 (5, 31)

Percent submerged

The majority of the objects were at least partially submerged, with more sets on largely submerged objects (Table 15). Median CSS of all tunas was slightly higher for largely submerged and slightly submerged objects (<10% and 20 to 29%). Median CSS of yellowfin generally increased with increasing percentage submerged; median CSS of skipjack was slightly higher for partially submerged floating objects.

Table 15.

Percent Submerged	Sightings % (n=1,957)	Successful sets % (n=1,571)	Median CSS (1st, 3rd quartiles) All tunas	Yellowfin	Skipjack
< 10	3.8	2.0	27 (12, 53)	5 (2, 10)	11 (5, 33)
10 – 19	5.8	2.2	22 (8, 35)	4 (1, 11)	8 (1, 22)
20 – 29	4.4	2.2	29 (9, 67)	8 (3, 26)	10 (2, 33)
30 – 39	4.9	1.8	23 (11, 53)	6 (2, 18)	11 (3, 28)
40 – 49	3.9	2.6	26 (11, 44)	6 (3, 17)	10 (3, 30)
50 – 59	18.7	16.4	25 (11, 56)	11 (3, 25)	10 (3, 30)
60 – 69	9.2	8.8	22 (9, 47)	9 (3, 20)	10 (3, 22)
70 – 79	12.3	13.9	22 (10, 49)	8 (3, 20)	8 (2, 22)
80 – 89	16.9	17.1	22 (11, 45)	10 (4, 25)	7 (2, 20)
> 90	20.1	32.9	30 (14, 58)	12 (4, 23)	10 (3, 29)

Estimated time adrift

Data on sightings, successful sets, and CSSs for the estimated time the floating object had been in the water are given in Table 16. The length of time an object has been in the water (an indicator of the object's "age") has been frequently mentioned in connection with its “attractiveness” (Kojima, 1956; Yamaguchi and Murabayashi, 1981). Fewer observations led to a successful set on "younger" (adrift = "short") objects. More successful sets were made on "older" (adrift = "long") objects but the median CSS of all tunas, yellowfin and skipjack varied little with the estimated time adrift.

Table 16.

Time Adrift	Sightings % (n=1,925)	Successful sets % (n=1,515)	Median CSS (1st, 3rd quartiles) All tunas	Yellowfin	Skipjack
Short	31.4	25.5	25 (12, 45)	11 (5, 21)	10 (3, 25)
Medium	36.9	35.8	23 (10, 50)	9 (3, 20)	8 (2, 25)
Long	31.7	38.6	25 (12, 53)	10 (4, 21)	10 (3, 26)

Epibiota

More than 50% of the observations involved objects whose surface was estimated to be less than 20% covered with epibiota (Table 17). Some authors believe that a floating object's epifauna and infauna are important for its "attractiveness" (Tominaga, 1957; Inoue *et al.*, 1968a, 1968b). The differences between the distributions of the number of sightings and the number of successful sets are quite small, lesser-covered objects being slightly less attractive. Median CSS of yellowfin, skipjack, and all tunas varied with the percentage of the object covered with epibiota; however, no trends are apparent.

Table 17.

Percent Covered	Sightings % (n=1,165)	Successful sets % (n=1,008)	Median CSS (1st, 3rd quartiles)		
			All tunas	Yellowfin	Skipjack
< 10	43.4	40.6	25 (12, 51)	10 (3, 22)	9 (3, 27)
10 – 19	14.5	15.2	22 (11, 52)	10 (4, 21)	6 (2, 22)
20 – 29	9.4	8.4	19 (7, 48)	11 (4, 22)	5 (1, 11)
30 – 39	8.6	8.3	25 (11, 59)	10 (4, 27)	7 (3, 22)
40 – 49	4.7	4.4	27 (14, 57)	10 (4, 18)	11 (6, 35)
50 – 59	3.7	3.5	22 (10, 53)	10 (4, 20)	10 (4, 26)
60 – 69	3.9	3.2	23 (10, 42)	12 (5, 28)	8 (4, 15)
70 – 79	3.8	5.3	32 (13, 80)	16 (9, 30)	6 (2, 35)
80 – 89	4.6	5.7	21 (12, 40)	6 (2, 15)	10 (3, 21)
> 90	3.4	5.6	25 (12, 50)	14 (5, 25)	14 (2, 30)

Angle in water

The majority of objects observed floated horizontally or at angles of 10° or less relative to the water's surface (Table 18). Median CSS of all tunas appears to have decreased with increasing angle, but increased again markedly for objects floating at angles of 70° or more. A similar pattern is seen for median CSSs of yellowfin; the pattern is less evident for skipjack.

Table 18.

Angle (degrees)	Sightings % (n=1,994)	Successful sets % (n=1,640)	Median CSS (1st, 3rd quartiles)		
			All tunas	Yellowfin	Skipjack
< 10	85.0	81.8	25 (12, 51)	10 (3, 21)	10 (3, 25)
10 – 19	2.8	2.6	29 (11, 50)	18 (5, 36)	5 (2, 20)
20 – 29	1.7	1.6	15 (11, 45)	6 (3, 25)	8 (6, 14)
30 – 39	1.4	1.5	17 (8, 30)	6 (3, 10)	8 (2, 15)
40 – 49	1.7	2.0	24 (14, 45)	6 (3, 19)	10 (3, 27)
50 – 59	0.2	0.4	20 (5, 31)	10 (1, 20)	1 (0, 4)
60 – 69	0.3	0.3	23 (14, 48)	13 (2, 20)	3 (1, 15)
70 – 79	0.8	0.5	43 (21, 64)	39 (6, 62)	2 (1, 10)
> 80	6.4	9.3	35 (13, 60)	10 (5, 25)	16 (4, 36)

Longest dimension

The estimated longest dimension of over 50% of the observed objects was less than 3 meters (Table 19). Observations on very small objects (<1 meter) generally led to fewer successful sets than objects larger than 1 meter. Median CSSs of yellowfin declined with increasing largest dimension. Median CSSs of skipjack and of all tunas were more variable.

Table 19.

Length (m)	Sightings % (n=2511)	Successful sets % (n=2339)	Median CSS (1st, 3rd quartiles)		
			All tunas	Yellowfin	Skipjack
< 0.5	4.1	1.9	29 (16, 55)	10 (4, 23)	10 (4, 30)
0.5 - 0.99	9.6	6.0	23 (13, 46)	6 (2, 16)	12 (4, 27)
1.0 - 1.49	15.2	13.6	26 (12, 49)	8 (3, 20)	10 (4, 25)
1.5 - 1.99	11.6	14.2	26 (11, 53)	10 (4, 23)	9 (2, 25)
2.0 - 2.49	11.5	13.6	26 (11, 51)	10 (5, 20)	9 (2, 30)
2.5 - 2.99	6.7	6.4	24 (9, 46)	10 (3, 21)	8 (3, 17)
3.0 - 3.49	8.9	8.7	30 (15, 59)	11 (4, 22)	11 (5, 30)
3.5 - 3.99	4.9	5.3	27 (13, 66)	11 (4, 20)	15 (5, 35)
4.0 - 4.49	5.7	5.4	24 (13, 48)	9 (2, 25)	10 (3, 22)
4.5 - 4.99	2.1	3.2	21 (10, 41)	5 (3, 15)	9 (1, 21)
5.0 - 5.99	4.9	5.2	25 (10, 51)	7 (2, 17)	10 (2, 30)
6.0 - 6.99	4.0	4.6	29 (12, 55)	10 (3, 21)	11 (3, 21)
7.0 - 7.99	2.5	4.0	22 (9, 58)	6 (2, 16)	11 (3, 22)
8.0 - 8.99	1.7	2.1	26 (12, 55)	5 (3, 20)	8 (3, 30)
9.0 - 11.99	3.6	3.4	25 (11, 47)	10 (2, 20)	7 (2, 22)
> 12	3.1	2.8	18 (8, 44)	5 (2, 13)	6 (3, 22)

Estimated surface area

Over half of all observed objects had an estimated surface area of less than 2 square meters (Table 20). Results were similar for the estimated "surface area submerged," so these are not shown. The distribution of the number of successful sets by estimated surface area parallels that for the largest dimension. The percentage of sightings involving small objects was higher than the percentage of successful sets, yet over 50% of all successful sets (and 65% of all sightings) involved objects with an estimated surface area of less than 2 meters. Median CSSs were variable, with no clear pattern.

Table 20.

Surface Area (m^2)	Sightings % (n=2363)	Successful sets % (n=2208)	Median CSS (1st, 3rd quartiles)		
			All tunas	Yellowfin	Skipjack
< 0.50	24.8	16.0	26 (13, 50)	8 (3, 20)	10 (3, 26)
0.5 - 0.99	19.1	15.2	25 (11, 46)	10 (3, 20)	10 (3, 24)
1.0 - 1.49	13.4	15.3	24 (11, 50)	8 (3, 20)	10 (3, 26)
1.5 - 1.99	8.5	10.3	30 (15, 56)	13 (3, 23)	10 (2, 29)
2.0 - 2.49	7.0	6.7	24 (11, 45)	10 (3, 20)	10 (2, 30)
2.5 - 2.99	3.4	4.2	27 (10, 58)	13 (3, 28)	10 (3, 40)
3.0 - 3.49	3.8	3.5	28 (12, 58)	8 (4, 18)	10 (3, 34)
3.5 - 3.99	2.5	2.9	19 (10, 35)	6 (2, 12)	8 (2, 25)
4.0 - 4.99	3.0	5.3	26 (11, 55)	10 (4, 20)	10 (4, 22)
5.0 - 5.99	2.2	4.0	25 (15, 55)	11 (5, 20)	11 (5, 22)
6.0 - 7.99	3.3	4.4	31 (13, 60)	10 (3, 20)	11 (2, 30)
8.0 - 9.99	1.9	2.1	27 (13, 57)	14 (5, 30)	10 (3, 22)
10.0 - 11.99	1.2	2.2	29 (13, 61)	8 (3, 20)	9 (2, 30)
12.0 - 14.99	1.6	1.9	40 (15, 66)	8 (4, 18)	15 (4, 39)
> 15.00	4.4	5.9	22 (11, 44)	8 (3, 17)	8 (2, 22)

Estimated volume

Floating objects of small estimated volume (<0.60 m^3) made up more than 50% of the observations (Table 21). In general, lower median CSSs of all tunas and of skipjack occurred for successful sets on objects with intermediate volumes; median CSSs of yellowfin were more variable. Similar patterns were seen for the estimated "volume submerged" (not shown).

Table 21.

Volume (m^3)	Sightings % (n=2275)	Successful sets % (n=2135)	Median CSS (1st, 3rd quartiles) All tunas	Yellowfin	Skipjack
< 0.20	41.1	31.4	25 (12, 50)	9 (3, 20)	10 (3, 28)
0.20 - 0.39	14.7	14.5	28 (13, 55)	11 (4, 25)	10 (3, 30)
0.40 - 0.59	6.6	6.9	25 (11, 55)	9 (3, 20)	10 (2, 25)
0.60 - 0.79	6.2	5.2	32 (11, 62)	11 (3, 25)	11 (3, 25)
0.80 - 0.99	4.1	3.7	20 (9, 35)	7 (3, 17)	8 (2, 22)
1.00 - 1.19	2.9	2.9	22 (12, 45)	10 (4, 23)	5 (1, 23)
1.20 - 1.39	2.0	2.6	21 (8, 40)	6 (2, 14)	5 (2, 12)
1.40 - 1.59	2.3	2.1	19 (10, 51)	9 (2, 15)	8 (3, 24)
1.60 - 1.99	2.5	3.1	27 (16, 41)	7 (2, 18)	13 (2, 25)
2.00 - 2.99	4.1	5.0	25 (10, 40)	10 (3, 20)	10 (3, 20)
3.00 - 3.99	2.1	3.9	28 (13, 68)	11 (3, 25)	11 (3, 30)
4.00 - 6.99	3.1	7.9	25 (14, 55)	10 (5, 20)	13 (4, 30)
> 7.00	8.4	10.8	27 (12, 55)	8 (3, 19)	8 (2, 22)

FACTORS AFFECTING CATCH PER SET

To identify the most important factors contributing to variability in catch per set of tunas, analysis of the data was separated into two parts: a study of CSS and a study of the probability of making a successful set. The independent variables used in these analyses are presented in Tables 22 and 23, and Figure 2. The variable "type/origin" represents a combination of the variables "type" and "origin" discussed in the previous section. Due to numerous observations with missing data, less than half the original data set could be used in this analysis (Table 24). To investigate the relationship between the independent variables in Table 22 and CSS of all tunas, we assumed that variability in the logarithm of CSS could be described by a linear combination of some subset of the independent variables shown in Table 22 and a test of the effect of these independent variables on the logarithm of CSS was formulated as a multiple regression problem. The influence of these independent variables on the CSSs of yellowfin and of skipjack was also explored, to see if the effect on the CSS of any of the independent variables might be species-specific. In the second part of this section, we provide some statistical evidence of factors that affect the probability of making a successful set, using a stepwise logistic regression analysis of the odds of making a successful set (odds = probability of a successful set/ (1 – probability of a successful set). This analysis was performed with the catches of all tunas because, by definition, it was not possible to attribute sightings to a particular species. Details of the statistical methodology used in these analyses can be found in Appendix A.

CSS of all tunas

The area where the object was found, the distance to the coast, and the percentage submerged were found to be the most significant independent variables affecting CSS of all tunas (Table 25). There was some evidence that the time of day, bimonthly period, and the type/origin of the object may be of importance as well (Table 25). Results suggest that the CSS was significantly greater in Area 8 than in Area 4 and greater in Area 4 than in the other areas(for a given distance to the coast; Table 26). Within each area, CSS appeared to increase with increasing distance to the coast and percentage of the object that was submerged (Table 26). There is an apparent contradiction between the observations that CSS increased with increasing distance to the coast and that the areas with the greatest CSSs tended to be coastal, but this may be explained by a gradient within each area, which is probably more heavily influenced by coastal observations, which predominate in the data base. These results suggest that the location of the floating object has a greater effect on CSS than its characteristics. The only independent variable describing object characteristics that appeared to be of primary importance for CSS was percentage submerged. The percentage submerged is probably correlated with the age of the object, as well as the distance to the coast, although it is noted that it was still influential when independent variables representing location were included in the analysis.

CSS for yellowfin

Time of year (bimonthly period) was one of the more significant factors affecting CSS of yellowfin (Tables 27). Seasonality in the CSS of yellowfin on floating objects would be expected, given the seasonality in CSS of yellowfin observed for the purse-seine fishery as a whole (Hall *et al.*, this volume). Restricting attention to Area 4, CSS of yellowfin was higher, in general in May-June and July-August and lower in March-April than it was in November-December (Table 28). These bimonthly periods correspond to the rainy season (May-December) and the end of the dry season (March-April) of the Panama Bight. Seasonal variability in CSS may be related to a seasonal abundance of logs in the Panama Bight (see discussion in Hall *et al.*, this volume).

There appeared to be a significant areal effect on CSS of yellowfin (Table 27). Relative to the CSS in Area 4 in November-December, CSS in Area 8 and in Area 3, which lies offshore from one of the major concentrations of log sets in the coastal zone (Fig. 1; Hall *et al.*, this volume), tended to be higher (Table 28). However, while distance to the coast made a significant contribution toward explaining variability in CSS of all tunas, it appeared to have somewhat less explanatory power for CSS of yellowfin (Table 27). The only object characteristic that contributed significantly to explaining variability in CSS of yellowfin was the percentage of the object submerged (Table 6). Results suggest that CSS of yellowfin increased with the percentage of the object that was submerged (Table 28).

CSS for skipjack

As with yellowfin, location and time of year appear to be two of the most important independent variables describing variability in CSS of skipjack (Table 29). The importance of time of year appears to have been opposite to that for yellowfin. Restricting attention to Area 4, relative to the November-December period, higher CSS of skipjack tended to occur in March-April (Table 30), a period of generally lower CSS of yellowfin (Table 28). Similarly, relative to CSS in November-December, CSS tended to be higher in September-October, and lower in May-June, a period of greater-than-average CSS of yellowfin. This might explain why the seasonal effect on CSS of all tunas was not highly significant: the differing trends for the two species tend to cancel each other.

Relative to the CSS in Area 4 (in the November-December period), CSS in Area 8 appears to be significantly higher and CSS in Area 3 significantly lower (Table 30). CSS of skipjack increased with increasing distance to the coast (Table 30). It would appear that the type of object was more important for CSS of skipjack than the percentage submerged, although it is noted that this importance can be attributed largely to one category, discarded fishing gear (Table 29). There is some evidence that color and shape may have some effect as well, although these factors are not highly significant (Table 29). The degree of cloud cover appears to affect CSS of skipjack (Table 29); however, the basis for a relationship between cloud cover and CSS of skipjack is not obvious. The importance of cloud cover might reflect areal differences, possibly related to the Inter-Tropical Convergence Zone; however, cloud cover contributes significantly to explaining variability in CSS even after independent variables representing location had been included in the model.

Factors affecting the probability of making a successful set

The results of the stepwise logistic regression analysis are presented in Tables 31 and 32. Of the factors listed in Table 23, time of day appears to have the most influence on the odds that an observation will lead to a successful set (Table 31), with the early morning period (at or before 7 a.m.) being the most likely time for such an outcome (for a given number of previous sets; Table 32). This confirms other results and observations showing that the association of tunas with logs is primarily nocturnal (Hall *et al.*, this volume). The likelihood of a set being a successful one appears to increase with the number of previous sets, indicating that an object that has produced one set is more likely to produce another (for a given time of day; Table 32). Unfortunately, the absence of previous sets in our database for a particular floating object does not mean that no sets were made by another vessel on that object. However, this uncertainty would tend to dilute any trend in CSS with the previous number of recorded sets. As noted earlier, Hall *et al.* (this volume) found that, in general, CSS decreased with increasing previous number of sets. Therefore, it would appear from these analyses that some catch on a previously visited object may be more likely than one not fished before, but the amount of catch will tend to be less than that of earlier visits. In addition, there was some evidence that the percentage submerged and the object's location significantly affected the likelihood of a set being a successful one (Table 31). As was found in the analysis of CSS, the characteristics of the floating object and most of the environment variables were not of primary importance.

CONCLUSIONS

Before presenting the main conclusions from this study with regard to the design and deployment of FADs, a strong note of caution is in order: the information analyzed corresponds to the fishery on logs in its present form, namely a coastal fishery that catches tunas usually less than about 80 to 90 cm in length. Our objective with regard to yellowfin is to develop a fishery which catches large yellowfin under floating objects. The results would therefore be used to extrapolate outside the observed data, a risky and uncertain undertaking. In addition, the results could be used to improve or intensify this fishery, which could be detrimental to the catch of yellowfin from a yield-per-recruit standpoint, but increase catches of skipjack.

Moreover, it should be noted that the data used in this analysis were sparse, to the extent that some categories specified by the various models tested contained no observations, and partial confounding of some factors occurred (Tables 33-35). Floating objects of a particular material tended to be of the same shape and some colors were only rarely observed (Table 33). Areas 4, 5, and 6 tended to be fished year-round, whereas fishing in other areas was seasonal (Table 34). The greatest dimension of polygonal objects was, on average, much smaller than that of any of the other shapes and the previous number of sets showed a marked increase for aggregated objects over other shapes (Table 35). Unfortunately, some catagories of interest (*e.g.*, the percentage of the object covered with epibiota) could not be included in the analyses because of sample size limitations.

Nonetheless, the salient results are:

1) The most important factor when deploying a FAD is location.

2) Season of deployment is one of the most important factors affecting CSS of yellowfin and skipjack tunas, suggesting that the choice of season for FAD deployment may depend on the target species. However, season of deployment was not one of the most important factors affecting CSS of all tunas.

3) Subsurface FADs, with only the communication system at the surface, should be tested.

4) Of all the types of floating objects considered, discarded fishing gear was the only one significantly better than the others. Many of the objects in this rather heterogeneous class include tangled fragments of netting which, if incorporated into FADs, pose the undesirable problem of entanglement of other animals in the FADs. We need to find out which of the characteristics of the fishing gear make it attractive and develop FADs with those properties.

5) Although color has been considered a potentially important factor in attracting tunas to floating objects, the color of the object was not found to affect CSS significantly in this analysis. It may be that color provides a more important visual cue to the fishermen than to the tunas. If tunas return to logs at night, they may rely on non-visual cues to locate the object. In fact, the detection of the log may be only part of the process that brings tunas into association with floating objects. In order for a school to associate with a log, the tunas must

not only "perceive" the log, but also find it "attractive." The color of the log may play no role in this process.

6) We had expected that the time at sea, or "age," would likely be an important factor as suggested previously (*e.g.*, Yamaguchi and Murabayashi, 1981; Kojima, 1956). Certain factors likely to be correlated with time at sea were significant - the percentage submerged and the distance from the coast. The variable "age" itself, however, was not statistically significant with the data at hand. While this variable may be problematic because it is a judgmental estimate by the observer, we suspect that this factor will be found to be influential when examined with a larger data set.

LITERATURE CITED

Anonymous. 1988. Annual Report of the Inter-American Tropical Tuna Commission, 1987. 227 pp.

Anonymous. 1991. Annual Report of the Inter-American Tropical Tuna Commission, 1989. 270 pp.

Anonymous. 1994. Annual report of the Inter-American Tropical Tuna Commission, 1993. 316 pp.

Ariz, J., P. Pallarés, A. Delgado de Molina and J.C. Santana. 1991. Análisis de los datos obtenidos en campañas de observadores en el Atlántico intertropical durante el Programa Año del Rabil. I.C.C.A.T. Coll.Vol.Sci.Papers 36:109-157.

Cayre, P., J.B. Amon Kothias, J.M. Stretta and T.Diouf. 1988. Biologie des thons. pp. 157-268. In A.Fonteneau and J.Marcille (eds) Ressources, peche et biologie des thonidés tropicaux de l'Atlantique Centre-Est. F.A.O. Doc. Tech. Peches, 292. 391 pp.

Coe, R. and R.D. Stern. 1984. A model fitting analysis of daily rainfall data. J. R. Statist. Soc. A. 147: 1-34.

Francis, R.C., F.T. Awbrey, C.L. Goudey, M.A. Hall, D.M. King, H. Medina, K.S. Norris, M.K. Orbach, R. Payne, and E. Pikitch. 1992. Dolphins and the Tuna Industry. National Academy Press, Washington, D.C.:xii, 176 pp.

Godsil, H.C. 1938. The high seas tuna fishery of California. Fish Bulletin, Bureau of Marine Fisheries, Division of Fish and Game of California. No. 51. 44 pp.

Greenblatt, P.R. 1979. Associations of tuna with flotsam in the eastern tropical Pacific. Fish. Bull. 77(1): 147-155.

Hallier, J.-P. 1985. Purse seining on debris-associated schools in the western Indian Ocean. I.P.T.P. Coll.Vol.Work.Doc. TWS/85/30: 150-156.

Hallier, J.-P. 1991. Tuna fishing on log-associated schools in the western Indian Ocean: An aggregation behavior. I.P.T.P. Coll. Vol.Work.Doc. 4: 325-342.

Hallier, J.-P. 1995. Tropical tuna fishing with purse seine and log. Inforfish Internat. 4(95): 53-58.

Inoue, M., R. Amano and Y. Iwasaki. 1963. Studies on environments alluring skipjacks and other tunas. I. On the oceanographical condition of Japan adjacent waters and the drifting substances accompanied by skipjack and other tunas. (In Japanese with English summary. Rept. Fish. Res. Lab., Tokai Univ. 1(1):12-23.

Inoue, M., R. Amano, Y. Iwasaki and M. Yamauti. 1968a. Studies on environments alluring skipjacks and other tunas. II. On the driftwoods accompanied by skipjack and tunas. Bull. Jap. Soc. Sci. Fish. 34(4):283-287.

Inoue, M., R. Amano, Y. Iwasaki and M. Yamauti. 1968b. Studies on environments alluring skipjacks and other tunas. III. Tagging experiments on the experimental driftwoods as part of ecological study of tunas. Bull. Jap. Soc. Sci. Fish. 34(4):288-294.

Joseph, J. 1973. Tropical tuna management in the eastern Pacific. Fish News International 12(2):12-14,17.

Joseph, J. 1994 The tuna-dolphin controversy in the eastern Pacific Ocean: Biological, economic, and political impacts. Ocean Development and International Law 25:1-30.

Kimura, K. 1954. Analysis of skipjack (*Katsuwonus pelamis*) shoals in the waters of "Tohoku Kaiku" by its association with other animals and objects based on the records by fishing boats. (In Japanese with English summary). Bull. Tohoku Reg. Fish. Res. Lab. 3: 1-88.

Kojima, S. 1956. Fishing for dolphins in the western part of the Japan Sea --II. Why do the fish take shelter under floating materials? Bull. Jap. Soc. Sci. Fish. 21(10): 1049-1052. (Translation, Van Campen, W.G. 1962. U.S. Fish & Wildl. Serv.).

Lambert, D. 1992. Zero-inflated Poisson regression, with an application to defects in manufacturing. Technometrics 34:1-14.

Landwehr, J.M., D. Pregibon, and A.C. Shoemaker. 1984. Graphical methods for assessing logistic regression models. JASA, 79(385): 61-83.

Lo, N.C.H., L.D. Jacobson, and J.L. Squire. 1992. Indices of relative abundance for fish spotter data based on Delta-lognormal models. Can. J. Fish. Aquat. Sci. 49:2515-2526.

McCullagh, P., and J.A. Nelder. 1989. Generalized linear models, second edition. Chapman Hall. 511 pp.

Medina-Gaertner, M. and D. Gaertner. 1991. Factores ambientales y pesca atunera de superficie en el Mar Caribe. I.C.C.A.T. Coll. Vol. Sci. Papers, 36:523-550.

Montaudouin, X.de and G. Lablache. 1991. The Seychelles Observer Program (1986 -1989). I.P.T.P. Coll. Vol. Work. Doc. 4: 208-215.

Pereira, J. 1990. Indices de detection et taille des thons dans les bancs associes a objets flottants. I.C.C.A.T. Coll. Vol. Sci. Papers 35:192-195.

Stefánsson, G. 1991. Analysis of groundfish survey data: combining the GLM and delta approaches. International Council for Exploration of the Sea, C.M.1991/D:9. Statistics Committee.

Stequert, B. and F. Marsac. 1989. Tropical tuna - surface fisheries in the Indian Ocean. F.A.O. Fish. Tech. Paper 282. 213 pp.

Tominaga, S. 1957. "Katuwo". (In Japanese). Ishizaki-Shoten, Tokyo, 60-65.

Uda, M. 1933. Types of skipjack schools and their fishing qualities. Bull. Jap. Soc. Sci. Fish. 2(3):107-111. (Translation, Van Campen, W.G., 1952. Five Japanese papers on skipjack. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 83, iii + 78 pp.)

Uda, M. and J. Tsukushi. 1934. Local variations in the composition of various shoals of "katuwo," *Euthynnus vagans* (Lesson) in several sea-districts of Japan. Bull. Jap. Soc. Sci. Fish. 3(4): 196-202. (Translation, Van Campen, W.G., 1952. Five Japanese papers on skipjack. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 83, iii + 78 pp.).

Yabe, H. and T. Mori. 1950. An observation on a school of skipjack and kimeji accompanying a drift log. Bull. Jap. Soc. Sci. Fish. 16(2): 35-39. (Translation, Van Campen, W.G., 1954, Bur. Comm. Fish. Biol. Lab. Honolulu, Hawaii).

Yamaguchi, Y. and K. Murabayashi. 1981. The fish-luring effect of flotsam. (In Japanese with English summary). Bull. Jap. Soc. Sci. Fish. 47(10):1295-1298.

Table 22. Independent variables used in the analysis of CSS of tunas, variable type, and number of levels for categorical variables.

Variable	Type	Levels
Bimonthly period	categorical	6 (Jan-Feb, Mar-Apr, May-Jun, Jul-Aug, Sep-Oct, Nov-Dec)
Time of day (rounded to nearest hour)	continuous	
Location		
Distance to coast	continuous	
Area	categorical	8 (Figure 2)
Environmental characteristics		
Temperature	continuous	
Cloud cover	continuous	
Water clarity	categorical	2 (clear, turbid)
Wind index	categorical	3 (1=Beaufort 0 or 1, 2=Beaufort 2 or 3, 3 = Beaufort > 4)
Current	categorical	2 (weak, strong)
Log characteristics		
Shape	categorical	4 (cylindrical, polygonal [includes spherical], irregular, aggregated)
Color	categorical	6 (red or orange, yellow, white, black, brown, other [blue, green, silver])
Percent submerged	continuous	
Time in water ("age")	categorical	3 (short, medium, long)
Longest dimension	continuous	
Surface area	continuous	
Volume	continuous	
Type/origin	categorical	6 (wood-natural, wood-artificial, other biological material, fishing gear, trash and other, FADs)
Angle	continuous	
No. of previous sets	continuous	

Table 23. Number of observations and proportions of successful sets, as grouped for the stepwise logistic regression analysis.

Variable		Frequency	Proportion
Bimonthly period	Jan-Apr	529	0.446
	May-Aug	629	0.491
	Sep-Dec	963	0.486
Area No.	4	593	0.604
	1	103	0.194
	2, 3, 5 (W of 97°)	223	0.368
	5 (E of 97°)	110	0.573
	6	916	0.468
	7,8	176	0.437
Sea-surface temperature (°F)	<78.5	291	0.344
	78.5-82.5	1,236	0.522
	>82.5	594	0.451
Cloud cover	<50%	453	0.408
	>50%	1,668	0.496
Shape of object	Cylindrical	942	0.417
	Polygonal	420	0.421
	Irregular	481	0.476
	Aggregated	278	0.770
Percent submerged	<50	603	0.360
	>50	1,518	0.524
Longest dimension (m)	<1	377	0.355
	1-3	1,016	0.515
	≥3	728	0.489
Type/origin	1,2,3	1,526	0.437
	4,5	372	0.449
	6	223	0.807
Number of previous sets	0	1,753	0.397
	>1	368	0.861
Time of day	<8	564	0.819
(1)	8-14	1,104	0.316
(2)	>14	453	0.212
Distance from coast (nm)	≤300	1,551	0.491
	301-600	401	0.454
	>600	169	0.414

Table 24. Number of successful sets and sightings used in the analyses of factors affecting catches on floating objects.

Number of Sightings and Successful Sets		
Successful sets	Sightings	Total
1,013	1,108	2,121

Number of successful sets (for all tuna) by the two dominant tuna species. Note that the 35 sets that were unsuccessful with respect to tunas of yellowfin and skipjack tunas were successful for other types of tunas (*e.g.*, bigeye tuna).

		Unsuccessful Sets	**Yellowfin Successful Sets**	**Total**
	Unsuccessful Sets	35	245	280
Skipjack	**Successful Sets**	87	646	733
	Total	122	891	1,013

Table 25. Results from the stepwise regression analysis of CSS of all tunas. Significance levels are presented for those independent variables not yet in the model for which the p-value of a test against the hypothesis H_0: coefficient(s) = 0 was less than 0.10. The significance level for the model at each step is given in parentheses after the model formula; model formulas shown in bold type. Because no independent variable dropped below the 0.01 removal criterion once entered into the model, F statistics for eliminating variables from the model at each step are not provided. P-values are based on student's t or F distributions. (For categorical variables, the numerator degrees of freedom (df) are equal to the number of levels (Table 1) less 1; denominator df can be computed from the denominator df given at each step after the model formula (for step 1, denominator df =1,012).) "E" denotes statistical expectation. See Appendix A for details of the statistical methodology.

Variable	p-value	
Model - step 1: **E[ln(CSS)] = "intercept"**		
Bimonthly period	0.0338	
Area	<0.00005	(F = 8.64, df: 7, 1005)
Temperature	0.0604	
Water clarity	0.0353	
Percent submerged	0.0120	
Type/origin	0.0772	
Time of day	0.0128	
Distance to coast	0.0005	
Model - step 2: **E[ln(CSS)] = "intercept" + area (p<0.00005, F = 8.64, df: 7,1005)**		
Bimonthly period	0.01<p<0.05	(F = 2.39, df: 5, 1000)
Temperature	0.098	
Water clarity	0.069	
Percent submerged	0.005	
Type/origin	0.01<p<0.05	(F = 2.24, df: 5, 1000)
Time of day	0.014	
Distance to coast	0.001	

Model - step 3:
$E[\ln(CSS)]$ = "intercept" + area + distance to coast
($p<0.00005$, F = 9.11, df: 8,1004)

Bimonthly period	$0.01<p<0.05$	(F = 2.36, df: 5, 999)
Percent submerged	0.003	
Type/origin	$0.01<p<0.05$	(F = 2.42, df: 5, 999)
Time of day	0.032	

Model - step 4:
$E[\ln(CSS)]$ = "intercept" + area + distance to coast + percent submerged
($p<0.00005$, F = 9.11, df: 9, 1003)

Bimonthly period	$0.01<p<0.05$	(F = 2.32, df: 5, 998)
Type/origin	$0.05<p<0.10$	(F = 2.06, df: 5, 998)
Time of day	0.038	

Model - step 5:
$E[\ln(CSS)]$ = "intercept" + area + distance to coast + percent submerged + time of day ($p<0.00005$, F = 8.66, df: 10,1002)

Bimonthly period	$0.01<p<0.05$	(F = 2.30, df: 5, 997)
Type/origin	$0.01<p<0.05$	(F = 2.27, df: 5, 997)

Model - step 6:
$E[\ln(CSS)]$ = "intercept" + area + distance to coast + percent submerged + time of day + bimonthly period ($p<0.00005$, F = 6.58, df: 15, 997)

Type/origin	$0.01<p<0.05$	(F = 2.53, df: 5, 992)

Table 26. Estimated coefficients, standard errors, and significance levels (for a test against the hypothesis H_0: coefficient(s) = 0) for the "best" model describing catch per set of all tunas (*i.e.*, E[ln(CSS)] = "intercept" + area + distance to coast + percent submerged) from the stepwise regression analysis (Table 25). P-values are based on student's t or F distributions. Denominator degrees of freedom (df) are 1003; numerator df for categorical variables can be obtained from the number of levels for the factor (Table 1) less 1. Note that due to the parameterization of this model, the "intercept" corresponds to CSS in Area 4; estimated coefficients for "levels" of the categorical variable "Area" shown below represent deviations from the estimate of the "intercept". See Appendix A for details of the statistical methodology.

Variable	**Coefficient**	**Standard error**	**p-value**
"Intercept"	2.642	0.1477	<0.0005
Area			<0.0005 (F = 8.72, df=7, 1003)
1	-0.365	0.2547	0.152
2	-1.652	0.4326	<0.0005
3	-0.252	0.2093	0.229
5	-0.015	0.1629	0.927
6	-0.167	0.0831	0.044
7	-0.807	0.2612	0.002
8	0.660	0.1868	<0.0005
Distance to coast	0.00105	0.000297	<0.0005
Percent submerged	0.00458	0.001564	0.003

Table 27. Results from the stepwise regression analysis of CSS of yellowfin tuna. The initial model for this analysis was the "best" model for CSS of all tunas. Significance levels are presented for those independent variables not yet in the model for which the p-value of a test against the hypotheses H_o: coefficients(s) = 0 was less than 0.10. The significance level for the model selected is given in parentheses after the model formula; model formula are given in bold type. P-values are based on student's t or F distributions. (For categorical variables, the numerator degrees of freedom (df) are equal to the number of levels (Table1) less 1; denominator df can be computed from the denominator df given at each step after the model formula.) "E" denotes statistical expectation. See Appendix A for details of the statistical methodology.

Variable	**p-value**	
Model: E[ln(CSS of yf)] = "intercept" + area + percent submerged (p<0.00005, F =9.68, df=8, 882)		
Bimonthly period	<0.0005	(F = 7.387, df=5, 877)
Temperature	0.03	
Cloud cover	0.01	
Shape	0.05<p<0.10	(F = 2.44, df=3, 879)
Longest dimension	0.023	
Time of day	0.092	
Distance to coast	0.069	
Model: E[ln(CSS of yf)] = "intercept" + area + percent submerged + bimonthly period (p<0.00005, F = 9.01, df=13, 877)		
(Temperature)	(0.102)	
Cloud cover	0.077	
Shape	0.05<p<0.10	
Longest dimension	0.031	
Distance to coast	0.020	

Table 28. Estimated coefficients, standard errors, and p-values (of a test against the hypothesis H_0: coefficient(s) = 0) for the model: E[ln(CSS of yf)] = "intercept" + area + percent submerged + bimonthly period. Denominator degrees of freedom (df) are 877; numerator df for categorical variables can be obtained from the number of levels for the factor (Table 1) less 1. Note that due to the parameterization of this model, the "intercept" corresponds to CSS in Area 4 and bimonthly period November-December; estimated coefficients for "levels" of the categorical variables "Area" and "Bimonthly period" shown below represent deviations from the estimate of the "intercept". See Appendix A for details of the statistical methodology.

Variable	**Coefficient**	**Standard error**	**p-value**
"Intercept"	2.12	0.1558	<0.0005
Area			<0.0005 (F = 10.297,df=7,877)
1	-0.728	0.3036	0.017
2	-0.968	0.2881	0.001
3	0.391	0.1848	0.034
5	-0.427	0.1713	0.013
6	-0.43	0.0908	<0.0005
7	-0.87	0.3674	0.018
8	0.644	0.2195	0.003
Percent submerged	0.0051	0.00173	0.003
Bimonthly period			<0.0005 (F = 7.387, df=5,877)
Jan-Feb	-0.27	0.1458	0.064
Mar-Apr	-0.472	0.1399	0.001
May-Jun	0.203	0.1235	0.099
Jul-Aug	0.415	0.1299	0.001
Sep-Oct	-0.055	0.1191	0.643

Table 29. Results from the stepwise regression analysis of CSS of skipjack. The initial model for this analysis was the "best" model for CSS of all tunas. Significance levels are presented for those independent variables not yet included in the model for which the p-value of a test against the hypothesis H_0: coefficients(s)= 0 was less than 0.10. The significance level for the model selected is given in parentheses after the model formula; model formula are in bold type. P-values are based on student's t or F distributions. (For categorical variables, the numerator degrees of freedom (df) are equal to the number of levels (Table 1) less 1; denominator df can be computed from the denominator df given at each step after the model formula.) "E" denotes statistical expectation. See Appendix A for details of the statistical methodology.

Variable	**p-value**	
Model: E[ln(CSS of sj)] = "intercept" + area + distance to coast (p<0.00005, F =10.36, df= 8, 724)		
Bimonthly period	<0.0005	(F = 8.697, df= 5, 719)
Cloud cover	0.004	
Wind index	$0.01<p<0.05$	(F = 4.24, df= 2, 722)
Shape	$0.01<p<0.05$	(F = 3.41, df= 3, 721)
Longest dimension	0.055	
Type/origin	<0.0005	(F = 4.87, df= 5, 719)
Number of previous sets	0.042	
Percent submerged	0.637	
Model: E[ln(CSS of sj)] = "intercept" + area + distance to coast + bimonthly period (p<0.00005, F = 10.06, df=13, 719)		
Cloud cover	0.002	
Wind index	$0.01<p<0.05$	(F = 3.22, df=2, 717)
Shape	$0.05<p<0.10$	F = 2.48, df=3, 716)
Color	$0.05<p<0.10$	(F = 2.18, df=5, 714)
Longest dimension	0.076	
Type/origin	0.0035	
Number of previous sets	0.06	
Model: E[ln(CSS of sj)] = "intercept" + area + distance to coast + bimonthly period + cloud cover (p<0.00005, F = 10.18, df=14, 718)		
Type/origin	0.0044	
Shape	$0.05<p<0.10$	(F = 2.43, df=3, 715)
Color	$0.01<p<0.05$	(F = 2.37, df=5, 713)
Longest dimension	0.04	
Number of previous sets	0.033	

Model: E[ln(CSS of sj)] = "intercept" + area + distance to coast + bimonthly period + type/origin + cloud cover ($p<0.00005$, F = 8.54, df=19, 713)

Shape	$0.05<p<0.10$	(F = 2.56, df=3, 710)
Color	$0.01<p<0.05$	(F = 2.65, df=5, 708)
Number of previous sets	0.081	

Table 30. Estimated coefficients, standard errors, and significance levels (of a test against the hypothesis H_0: coefficient(s) = 0) for the model: E[ln(CSS of sj)] = "intercept" + area + distance to coast + bimonthly period + cloud cover + type/origin) for the stepwise regression analysis of CSS of skipjack. Denominator degrees of freedom (df) are 719; numerator df for categorical variables can be obtained from the number of levels for the factor (Table 1) less 1. Note that due to the parameterization of this model, the "intercept" corresponds to CSS in Area 4 and bimonthly period November-December; estimated coefficients for "levels" of the categorical variables "Area" and "Bimonthly period" shown below represent deviations from the estimate of the "intercept". See Appendix A for details of the statistical methodology.

Variable	**Coefficient**	**Standard error**	**p-value**
"Intercept"	1.68	0.1510	<0.0005
Area			<0.0005 (F = 8.928, df=7,719)
1	0.272	0.3249	0.402
2	-0.865	0.5751	0.133
3	-0.983	0.2961	0.001
5	0.563	0.2022	0.005
6	0.337	0.1209	0.005
7	0.280	0.4919	0.569
8	1.214	0.2527	<0.0005
Distance to coast	0.0012	0.0004	0.003
Bimonthly period			<0.0005 (F = 8.697, df=5,719)
Jan-Feb	0.040	0.1682	0.812
Mar-Apr	0.376	0.1553	0.016
May-Jun	-0.614	0.1648	<0.0005
Jul-Aug	0.255	0.1837	0.165
Sep-Oct	0.418	0.1367	0.002

Table 31. Results for the stepwise logistic regression analysis of the odds ratio for successful sets. (For p = probability that an observation will lead to a successful set, the odds ratio = p/(1-p). Model formulas at each step are shown in bold type. Significance levels are presented for those factors for which the p-value of a test against the hypothesis H_0: "factor improved fit of the model to the data" was less than 0.10 (test is based on the change in "deviance"). The change in deviance (D; a measure of how much a particular factor improves the fit of the model to the data) and degrees of freedom (df) are also given (the change in deviance has an approximate chi-square distribution). P-values presented should not be taken literally as they do not represent tests corrected for over-dispersion; the purpose of this table is merely to show the order in which variables were selected to build the "best" subset model. See Appendix A for details of the statistical methodology.

Variable	**p-value**	**D**	**df**
Model - step 1: ln[p/(1-p)] = "constant"			
Area	<0.00005	101.49	5
Temperature	<0.00005	32.73	2
Cloud cover	0.0009	11.12	1
Shape	<0.00005	118.61	3
Percent submerged	<0.00005	47.37	1
Longest dimension	<0.00005	28.98	2
Type/origin	<0.00005	11.50	2
Number of previous sets	<0.00005	284.63	1
Time of day	<0.00005	438.77	2
Distance to coast	0.094	4.71	2
Model - step 2: ln[p/(1-p)] = "constant" + time of day			
Area	<0.00005	88.91	5
Temperature	<0.00005	26.19	2
Cloud cover	0.0177	5.62	1
Shape	<0.00005	58.97	3
Percent submerged	<0.00005	37.23	1
Longest dimension	0.0001	18.69	2
Type/origin	<0.00005	51.18	2
Number of previous sets	<0.00005	120.31	1
Distance to coast	0.0042	10.96	2

Model - step 3: ln[p/(1-p)] = "constant" + time of day + number of previous sets

Area	<0.00005	68.72	5
Temperature	<0.00005	20.30	2
Cloud cover	0.0463	3.97	1
Shape	0.0001	21.88	3
Percent submerged	<0.00005	32.99	1
Longest dimension	0.0007	14.52	2
Type/origin	0.0007	14.54	2
Distance to coast	0.0050	10.60	2

Model - step 4: ln[p/(1-p)] = "constant" + time of day + number of previous sets+ area

Shape	0.0003	19.15	3
Percent submerged	<0.00005	27.66	1
Longest dimension	0.0003	16.16	2
Type/origin	0.0093	9.36	2

Table 32. Estimated coefficients, standard errors (SE), estimated coefficients divided by their standard errors and "F to remove" values for each factor included in the "best" subset of explanatory variables describing variability in the logarithm of the odds of the probability of a successful set (based on entry/removal alpha levels set at 0.01). The estimated coefficient divided by its standard error can be regarded as a rough approximate to a student's t statistic for a test against the hypothesis Ho: coefficient = 0. Standard errors and significance levels for removal (and approximate t statistics) have been corrected for over-dispersion (with respect to the assumption of binomial variation). The correction estimate of the over-dispersion parameters used was 5.1755.

				"F to remove"		
Term	**Coefficient**	**SE**	**Coeff./SE**	**(F**	**d.f.**	**p-value)**
Model: ln(p/(1-p)) = "constant" + time of day + number of previous sets						
Number of previous sets	1.718	0.389	4.42	23.25	1, 1307	<0.0005
Time of day						
(1)	-1.487	0.298	-4.99	26.51	2, 1307	<0.0005
(2)	-2.485	0.373	-6.66			
"Constant"	0.9946	0.268	3.71	15.46	1, 1307	<0.0005

Goodness-of-fit test (C.C.Brown): 3.36; d.f. = 2, p = 0.186

Table 33. Two-way frequency tables for the number of successful sets for all tunas by area and shape, type/origin and shape, color and shape, and area and month.

	SHAPE				
	Cylindrical	**Polygonal**	**Irregular**	**Aggregated**	**Total**
AREA					
1	3	3	12	2	20
2	9	7	4	0	20
3	22	12	14	5	53
4	139	56	69	94	358
5	16	19	15	22	72
6	197	63	87	82	429
7	1	5	11	2	19
8	6	12	17	7	42
Total	393	175	229	214	1,013
TYPE/ORIGIN					
Wood (natural)	207	3	51	9	270
Wood (artificial)	130	152	52	12	346
Other biological material	2	1	46	2	51
Fishing gear	21	1	65	16	103
Trash/other	31	20	11	2	64
FADs	2	0	4	173	179
Total	393	175	229	214	1,013
COLOR					
Red	13	8	11	7	39
Green	20	2	2	6	
Orange	73	11	16	37	
Blue	13	4	0	7	24
Yellow	34	14	37	30	115
Black	23	2	12	28	65
White	10	13	49	9	81
Brown	284	132	104	113	633
Silver	71	3	2	13	
Total	393	175	229	214	1,013

Table 34. Two-way frequency tables of the number of successful sets for all tunas by area and month.

	Area								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
January	0	0	0	6	10	23	5	8	52
February	2	0	7	31	4	5	1	2	52
March	7	0	12	1	1	48	1	15	85
April	0	0	3	2	3	27	0	12	47
May	2	1	0	19	1	64	0	0	87
June	0	6	0	65	0	6	0	0	77
July	0	11	0	45	0	18	1	0	75
August	3	2	2	36	2	22	3	0	64
September	5	0	9	16	8	16	3	0	57
October	0	0	15	58	6	50	2	0	131
November	1	0	3	50	25	88	1	0	168
December	0	0	2	29	12	62	2	5	112
TOTAL	20	20	53	358	72	429	19	42	1,013

Table 35. Average number of previous sets and longest dimensions of floating objects, by object shape, for all tunas (successful sets; n = 1013).

	Frequency	Average	Standard error
Number of previous sets			
Cylindrical	393	0.28244	0.03490
Polygonal	177	0.44633	0.82830
Irregular	229	0.43231	0.05219
Aggregated	214	1.14490	0.09161
Longest dimension			
Cylindrical	393	3.8598	0.16243
Polygonal	177	1.7422	0.08244
Irregular	229	4.3826	0.26294
Aggregated	214	3.3370	0.17704

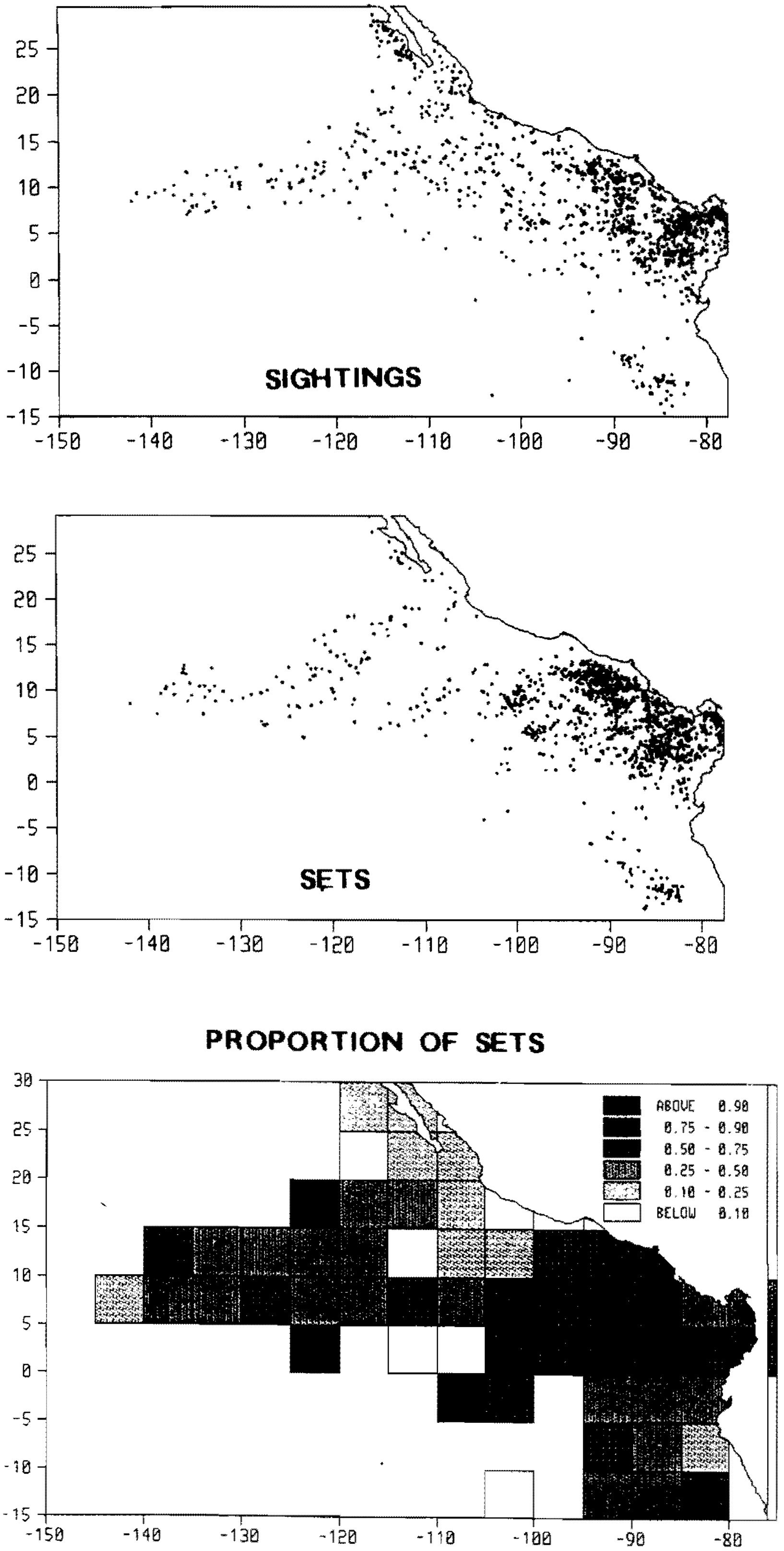

Figure 1. Distribution of sightings, sets and the proportion of observations that were sets by 5° square areas.

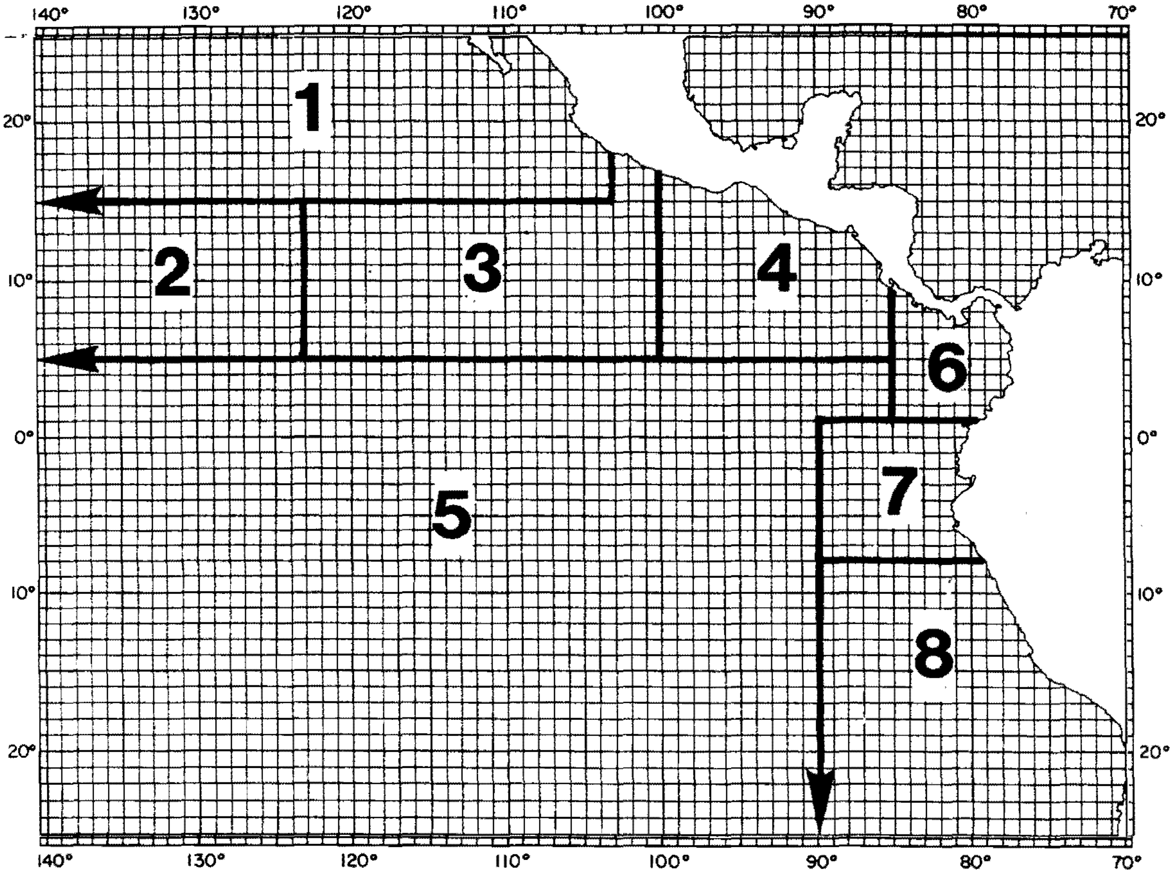

Figure 2. Location of areas used in the analyses of factors affecting catch of tunas on floating objects.

APPENDIX A

Statistical Methods

Because sightings (see Data Summary section for a description of the data used in this analysis) made up such a large fraction of the observations used in this analysis (Table 24), zero-tonnage observations (sightings) dominated the polled sighting and catch per successful set data, producing a large spike at zero catch. To address this aspect of the data, we assumed that the data could be modeled as a sample from a distribution of the form

$C = 0$ with probability $(1\text{-}p)$ and

$C \sim F_C(c;\theta)$ with probability p,

where C = catch per set (sightings are zero-tonnage sets, catch per successful set corresponds to positive values), p = probability of making a successful set, and $F_C(c;\theta)$ is the cumulative distribution function of C specified by parameters θ (*i.e.*, $\text{Prob}(C < c) = (1\text{-}p)+pF_C(c;\theta)$). For this analysis we took $F_C(c;\theta)$ to be the lognormal distribution with $\theta = (\mu,\sigma^2)$. (In other words, we assumed that the natural logarithm (ln) of CSS followed a lognormal distribution with mean μ and variance σ^2.) Given a vector of independent variables X, we assumed that $E[\ln(C)]=X'\beta$ (for $C>0$) and $\ln[(p/(1\text{-}p)]=X'\alpha$, where the quantity $p/(1\text{-}p)$ corresponds to the "odds ratio" for successful sets (*i.e.*, the probability of the occurrence of a successful set divided by the probability of occurrence of an unsuccessful set), and β, and α are vectors of coefficients (to be estimated). Under the further assumption that p and θ are unrelated, estimates of α and β can be obtained using standard generalized linear model techniques (e.g, see McCullagh and Nelder, 1989) (*i.e.*, the log-likelihood $l(c;p,\theta)$ can be reparametrized in terms of α and β and can be maximized separately for estimates for α and β; for examples of related models see Lo *et al.*, 1992; Lambert, 1992; Stefánsson, 1991; Coe and Stern, 1984). The investigation of factors affecting catch-per-set of tunas was therefore undertaken in two parts: 1) an analysis of factors affecting CSS of tunas, and 2) an analysis of factors affecting the likelihood (or probability) that an observation will lead to a successful set. Not all the independent variables listed above could be used in these analyses, due to missing data. In addition, due to the sparsity of the data for certain combinations of independent variables, strata for some of the categorical variables were collapsed to increase the sample size within the revised strata.

1) Study of factors affecting catch of all tunas in successful sets

A test of the effect of the independent variables on CSS of tunas was formulated as a multiple regression problem. Independent variables considered to potentially affect CSS of tunas are presented in Table 22 and Figure 2. In all, 19 independent variables (9 categorical and 10 "continuous") were considered. Independent variables were added to (or removed from) the model, based on a stepwise selection procedure where the alpha levels for entry (and removal) were both set at 0.01. Independent variables were believed to be more likely to influence CSS in a multiplicative rather than an additive manner, motivating the natural logarithmic transformation of the data. In addition, because of the nature of these data, it was hoped the natural logarithmic transformation would help to stabilize the variance and make the distribution of the data more nearly normal. The initial model fit to the data consisted solely of a constant (or "intercept" term). Independent variables were then entered into (or removed from) the model individually until no variables passed the entry (or removal) criteria. The general model fit was of the form

$$\mu_j = X'_j \beta,$$

where

μ_j = mean of the natural logarithm of CSS for the *j*th set (*i.e.*, C_j = CSS for the *j*th set, μ_j = E(ln(CSS$_j$)), (ln(CSS$_j$) ~ *indep.* $N(\mu_j,\sigma^2)$),

X'_j = vector of independent variables for the *j*th set, and

β = vector of coefficients (to be estimated).

In modeling catch of all tunas, we assumed that regardless of the species of tuna caught, the response to the independent variables measured would be the same, or at least in the same direction. To investigate this hypothesis, successful sets for yellowfin and skipjack were analyzed separately using a similar procedure to that described for catch of all tunas. The initial model for this stepwise procedure for each of these two species was the best subset of variables selected for all tunas.

2) Study of factors affecting the probability of making a successful set

To evaluate the odds ratio, observations were grouped into two categories: zero-catch observations (sightings) and observations with catch (successful sets). Because of the sparsity of the data, only 11 independent variables were included in this analysis (Table 2). All independent variables were treated as categorical. The 11 factors were selected based on the results of the stepwise regression analysis of CSS, and crude comparison of the proportion of successful sets across levels of each independent variable. Levels for each factor were selected so as to minimize the number of cells with no observations, yet hopefully still capture any potential affect of the factor on the probability of making a successful set. We assumed the total number of observations in each cell was fixed. This assumption was believed to be reasonable, given the purpose of this analysis, namely to determine if any the available factors affect the probability of an observation leading to a successful set.

A best subset of predictor variables was selected, using a stepwise logistic regression procedure where alpha levels for entry and removal were set at 0.01. The general model fit was of the form

$$\ln[p_k/(1-p_k)] = Z'_k \alpha,$$

where

p_k = probability of a successful set for the *k*th cell (*i.e.*, the number of successful sets in the *k*th cell ~ Binomial (p_k,n_k) and $p_k = \exp(Z'_k \alpha)/(1+\exp(Z'_k \alpha))$),

Z'_k = vector representing the factors describing the *k*th cell, and

α = vector of parameters (to be estimated).

Parameters were estimated using the technique of iteratively reweighted least squares (McCullagh and Nelder, 1989). The factor with the greatest change in deviance (a measure of the fit of the model to the data) at each step was added to the model. To investigate the possibility of over-dispersion with respect to the assumption of binomial variation, an estimate of the dispersion parameter based on Pearson's chi-square statistic was obtained for the last step in the stepwise model building procedure. Significance levels for the "best" subset of predictors were then re-evaluated based on an F distribution (with the appropriate degrees of freedom) so that over-dispersion could be taken into account when selecting the most influential factors (McCullagh and Nelder, 1989).

Discussion of statistical analyses

1) Study of factors affecting catch of all tunas in successful sets.

Based on the stepwise regression analysis, the following "best" model for ln(CSS) was selected:

$$E[\ln(C_j)] = u + a_i X_{ij} + b\,Y_j + c\,Z_j, \; (j = 1,.., 1013;\; i = 1,2,3,5,...,8),$$

where

C_j = CSS for set j,

X_{ij} = categorical variable indicating an areal effect (X_{ij} = 1 if the jth set occurred in area i, X_{ij} = 0 otherwise),

Y_j = distance to the coast for set j,

Z_j = percentage of the floating object underwater for set j, and

u, a_i, b, and c = estimated coefficients (as a result of the parameterization of the model, u represents CSS in Area 4; in the notation of the tables, u ="intercept").

This model was highly significant ($p<0.00005$, F = 9.11, d.f. = 9, 1003); however, the regression explained only a small proportion of the variation in the data ($R^2 = 0.076$). A normal probability plot of the residuals showed tails slightly heavier than would be expected for a normal distribution, with some evidence of skewness; however, there was evidence that the natural logarithmic transformation helped to stabilize the variance and make the data more nearly normal. Because no variables, once entered, passed below the 0.01 level for removal, the stepwise procedure in this case was equivalent to a forward selection procedure.

Selection of the alpha levels for entry and removal in a stepwise regression analysis is rather arbitrary. Entry and removal alpha levels of 0.01 were used in this analysis in an attempt to offset departures from normality. However, it is worth noting the "best" model that would have been selected had alpha levels for entry and removal been set at 0.05. Beyond the inclusion of time of day, bimonthly period, and type/origin, no other variables could be entered, and no variables previously included could be removed at the 5% level (Table 25). Significance levels for inclusion for all other independent variables exceeded 0.20. The increased complexity of this full model, especially in view of the sparsity of the data, tends to offset the minimal increase in explanatory power gained. Improvement to the R^2 value was only minimal (0.1015 versus 0.076).

The sparsity of these data resulted in some degree of confounding between several explanatory variables, which complicates interpretation of the results of this analysis. For example, floating objects made of particular materials tended to be predominantly of the same shape (Table 33). Several colors were under-represented in the data, brown being by far the most prevalent (Table 33). The greatest dimension of polygonal objects was, on average, much less than that for any of the other shapes (Table 35). The number of previous sets showed a marked increase for aggregated objects over other shapes (Table 35). For some explanatory variables, interactions may be as important for describing catch per set as the independent variables themselves. As well as increasing power, additional data might reduce the degree of confounding, in addition to allowing the possibility of testing for interactions. On the other hand, because these data were collected on an opportunistic basis, confounding of factors may remain a problem.

2) Study of the probability of a successful set for all tunas

Based on a stepwise selection procedure, the following model of the logarithm of the odds of a successful set was selected:

$$\ln[p_{jk}/(1-p_{jk})] = u + a_iX_i + b\,Y, \; (i=1, 2; j=1, 2, 3; k=1, 2)$$

where

p_{jk} = probability of a successful set for the jkth cell
(= $\exp(u + a_iX_l + bY))/(1 + (\exp(u + a_iX_i + bY))$,

X_i = categorical variable representing a time of day effect (X_l = 1 if time period is between 8 and 14 hours, 0 otherwise; $X_2 = 1$ if time period is greater than 15 hours, 0 otherwise),

Y = categorical variable representing an effect due to the previous number of sets (Y = 1 if the previous number of sets was one or more, 0 otherwise), and

u, a_i, b = estimated coefficients (for the parametrization of the model used, u represents p for observations on floating objects with no previous sets, occurring at or before 7 a.m. (in the notation of Tables 31 and 32, $u \equiv$ "constant").

The data were found to be over-dispersed with respect to binomial variation (the over-dispersion parameter was estimated as 5.5--true binomial variation has a dispersion parameter of 1.0 (McCullagh and Nelder, 1989)). As with the stepwise linear regression analysis, no variable, once entered, decreased below the F value for removal. The fit of the logistic model to the proportion of successful sets for all tunas was not outstanding; a test of the fit to the logistic model against an alternative family of models (C.C. Brown statistic yielded a p-value of 0.186). The usual chi-squared goodness-of-fit test was not deemed appropriate in this case due to the large percentage of cells with few observations.

As mentioned above, selection of alpha levels for entry and removal in a stepwise procedure tend to be arbitrary. Had the alpha levels for entry and removal been set at the 5% level, percent submerged and area would have entered the logistic model. However, there appears to be no improvement to the fit (p-value = 0.165, C.C. Brown statistic), and improvement in the explanatory power of the model is questionable given the sparsity of the data. The fit of the logistic model to the data would seem to be poor, regardless of the number of parameters included. However, measuring goodness of fit for an entire sample in terms of a single number is not necessarily the most appropriate means of assessing goodness of fit, especially when many cells contain very few observations (Landwehr *et al.*, 1984). In as much as the proportion of successful sets was shown to be over-dispersed with respect to binomial variation, it may be that binomial-like variation is not appropriate and that an entirely different error distribution should be considered. The lack of significance of some of the explanatory variables may be due in part to the grouping of the data into rather arbitrary levels. As mentioned above, the sparsity of these data further complicates interpretation of the results. In addition, some variables not included in the stepwise analysis may significantly affect the likelihood of a successful set. This provides additional impetus to explore other means of analyzing these data.

General comments

It should be noted that we have treated these data as though they represent independent observations on catch per set, when in fact sets and sightings within a trip are not truly independent. Correlations between records within a trip were not accounted for in the error structure of either model. Such correlations, if they exist, may have affected the significance levels of our results.

PELAGIC FISH COMMUNITIES AROUND FLOATING OBJECTS IN THE OPEN OCEAN

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INTRODUCTION

Floating objects, in the sense assumed here, are any comparatively large inert objects having positive or nearly neutral buoyancy and constantly drifting at or near the water surface. The floating objects may be classified as either 1) natural or artificial (=anthropogenous), 2) terrigenous or indigenous, or 3) living or dead. The main types of the open sea floating objects are 1) pelagic seaweeds (*Sargassum*, *Macrocystis*, *etc.*), 2) drifting flotsam of terrestrial origin, and 3) living neustonic invertebrates (*Physalia*, *Velella*, etc.). Only the first two types are considered in this paper.

Fishes associated with floating objects in inshore and neritic zones were intensively studied in such areas as Japan (Ushida and Shojima, 1958; Kojima, 1960; Shojima and Ueki, 1964; Anraku and Azeta, 1965; Senta, 1966; Ida *et al.*, 1967; Inoue *et al.*, 1968; Ikehara, 1977), Hawaii (Gooding and Magnuson, 1967), California and Central America (Hunter and Mitchell, 1967; Mitchell and Hunter, 1970), and western Atlantic Ocean (Bohlke and Chaplin, 1968; Fine, 1970; Dooley, 1972). However, the fish communities around floating objects in the open ocean are much less known and the literature on the matter is very limited (Parin, 1958, 1963, 1968; Besednov, 1960; Hunter and Mitchell, 1967; Fedoryako, 1980, 1982a, 1982b, 1988; Gorelova and Fedoryako, 1986).

METHODS

This report is based mainly on results of observations made during the oceanographic expeditions of the P.P. Shirshov Institute of Oceanology (Moscow) since the mid-1950's. Material was collected on cruises of the research vessels Vityaz, Akademik Kurchatov and Dmitry Mendeleev in all oceans, mainly from the open sea above oceanic depths, during both day and night and during different seasons. Samples were collected by dip-netting and using a small neuston trawl. Also, fishes were observed from both shipboard and life boats, in shipboard aquaria and visually while diving.

RESULTS AND DISCUSSION

Floating objects are widely but not evenly distributed in the tropical open sea. Over most of the water surface, they are very scattered but there are a few well-known regions of constant and abundant concentrations of drifting objects, mainly seaweeds - the Caribbean Sea, Gulf of

Mexico, Gulf Stream and Sargasso Sea in the Atlantic, the southern Red Sea, Gulf of Aden and the Bay of Bengal in the Indian Ocean, and the seas around the Indo- Australian archipelago, Philippines, New Guinea, and southern Japan, as well as Kuroshio Current zone in the Pacific Ocean (Fig. 1). The abundance of floating objects in the open sea depends on the intensity of their replenishment and duration of their existence, and their distribution is greatly affected by ocean currents. It is well known that drifting seaweeds and flotsam often accumulate along surface convergence zones.

Fish fauna of drifting algae and other flotsam. The number of fish species observed in association with floating objects in the neritic zone totaled 209 species belonging to 60 families and in the oceanic zone totaled 111 species belonging to 35 families (Tables 1 and 2).

Of the fishes associated with floating sea weeds, we found 31 species of 15 families in the open waters of the western tropical Atlantic, 39 species of 19 families in the Indian Ocean and 48 species of 25 families in the Pacific Ocean of which 11 species are distributed circumtropically. Overall, 82 species are associated with floating seaweeds in the open ocean and the most characteristic of the 29 families are the Carangidae and Exocoetidae, each with more than 10 species. The majority of species (55%) are also associated with seaweeds in neritic waters.

The species occurring under flotsam in the open sea, however, are less numerous. There are 19 species in the Atlantic, 21 species in the Indian Ocean and 29 species in the Pacific, for a total of 47 species of 20 families, of which the Carangidae and Balistidae are best represented. Fish faunas of drifting seaweeds and flotsam are rather similar in species composition, with almost 78% of the associated species being in common. Among the most typical fishes are *Hemiramphus lutkei* (Hemiramphidae), *Cheilopogon furcatus* (Exocoetidae), *Histrio histrio* (Pomacentridae), *Terapon theraps* (Teraponidae), *Kyphosus cinerascens* (Kyphosidae), *Lobotes* surinamensis (Lobotidae), *Canthidermis maculatus* and *C. rotundatus* (Balistidae), all of them typical nearshore species. Each of these is among the most widely distributed members of its family, probably a result of prolonged travelling with floating objects.

Fish communities around floating objects

A peculiar environment of the biotope of floating objects arises as a result of boundary conditions existing between the solid and liquid media. Three spatial groups of fishes are combined in the assemblage of floating objects (Fig. 2, Table 3). [In the terminology of spatial groups proposed here we take as a basis the Latin word natant (floating on water surface) and use the prefixes intra (within), extra (outside) and circum (around) to show the spatial relationship to the floating object]. The intranatant group comprises small fishes (up to 10-12 cm SL) of demersal origin. They dwell inside the seaweed bunches or very close to the flotsam surface - not more than 50 cm above the submerged upper edge of the object and as near as 5-10 cm at its sides or bottom. These fishes are sluggish, inactive and domestic in behavior, and are able to fasten to the objects and hide there using their protective coloration. All ontogenetic stages of fishes are represented - from demersal eggs of flying fishes and sauries, to adults of sargassumfish, *H. histrio*, and pipefish, *Syngnathus pelagicus* obligatorily living there. However, the majority of specimens are juveniles of near-bottom species, such as *L. surinamensis*, *Abudefduf saxatilis*, *Plotosus anguillaris* or pelagic dolphinfish *Coryphaena* *hippurus*. This portion of the community is the most diverse - it contains about 75% of all species associated with floating objects.

Fishes of the extranatant group swim during the day at a distance of 0.5 m to 2.0 m beneath the lower surface of floating objects, but come closer to the object at night, or when frightened. These fishes are rather agile and able to make sharp rushes and rapid vertical shifts. With the exception of the monocanthids, *Alutera scripta* and *A. monoceros*, that reach 22 -28 cm SL, juveniles ranging from 3-5 to 10-12 cm predominate in this spatial group, and are exemplified by *K. cinerascens*, *T. theraps*, *Caranx* spp., and *Psenes cyanophrys*. About 40% of the community species, half of them being intranatant at smaller sizes, are in the extranatant group.

The circumnatant group is composed mainly of large, and active predatory fishes (reaching in size to over 1 m SL), like dolphinfish, *C. hippurus*, rainbow runner *Elagatis bipinnulatus*, yellowtails, *Seriola* spp., skipjack, *Katsuwonus pelamis*, and juvenile yellowfin tuna, *Thunnus albacares*. The smallest members are balistids, *C. maculatus*, *C. rotundatus, and Balistes capriscus*, reaching 30-50 cm SL. They cruise in their search for prey around floating objects approaching the object and then moving away, far out of the field of vision. This group contains few species (about 15% of the total amount), mostly represented in the intra- and extranatant groups at earlier stages of life. The best example of this kind is the dolphinfish, *C. hippurus*, which passes through all three divisions during its life history.

Communities of seaweeds and flotsam significantly differ in the ratio of spatial groups in their species composition. Intra- and extranatant fishes sharply predominate around the drifting algae (66 species comprising 30% of the total species and 96% of the individuals) while more than half of the species around terrestrial floating objects are either extra- or circumnatant ones.

The trophic relationships of fishes associated with floating objects are determined mainly by their size and distribution in the biotope. Three trophic levels (Fig. 3) are recognized in the community of drifting algae (Gorelova and Fedoryako, 1986). Small intra- and extranatant fishes forming the first level feed on the vast variety of forage organisms, including pieces of seaweed thalli, epibiotic invertebrates and oceanic plankton. Depending on their microhabitats, these fishes differ significantly in their diet, but not a single species proved to be purely herbivorous. The second trophic level, that of facultative predators, are those fishes which consume the plankton and neuston invertebrates around the floating objects and small inhabitants of seaweed bunches, including smaller specimens of their own species. Here belong all members of the extranatant group and a few intranatant fishes, such as *H. histrio* and *C. hippurus*. The third level is formed by circumnatant fishes which may feed on any appropriately sized prey in the drifting community, but mainly upon purely pelagic species: gempylids, scombrids, nomeids, exocoetids, squids, *etc*.

It is essential to note that all three trophic levels are not limited to the food resources associated with floating objects. Sargasso weeds and their epibionts are of importance in feeding of the larger Balistidae and Monocanthidae, Diodontidae, Antennaridae, Platacidae, *etc*., of which only big triggerfishes are rather numerous in the community. On the other hand, the most abundant fishes, such as *K. cinereus*, *T. theraps*, *A. saxatilis*, *P. cyanophrys*, live mainly upon epipelagic plankton and neuston. Thus, the primary and secondary production of the entire floating community cannot maintain production of the higher-level consumers and a considerable part of their energy requirements is provided by the production of the surrounding pelagic realm. As a result, the species composition in the diets of fishes associated with floating objects and true pelagic fishes, both planktophagous and predatory, overlap each other, and these fishes have to be considered as direct trophic competitors.

A quantitative assessment of fishes associated with floating objects has not been done on the high seas. It is quite evident, however, that the total biomass of fishes increases where drifting algae and other flotsam are more abundant. In this way the food resources for large predatory animals, including tunas, also can increase in such areas. However, these additional resources are by no means important. Being easily exhaustible and not able to be rapidly replenished, these drifting communities cannot feed numerous guest predators, especially the schooling fishes like tunas. It seems most probable that tunas encounter a floating object during their wanderings, associate with it temporarily and then leave.

One may speculate that both floating objects and schools of tuna are concentrated along the zones of convergences and their coincidence in space which is frequently observed is not accidental. This point of view seems very likely, but has never been confirmed by reliable facts.

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LITERATURE CITED

Anraku, M., and Azeta, M. 1965. The feeding habits of larvae and juveniles of the yellowtail, *Seriola quinqueradiata* Temminck et Schlegel, associated with floating seaweeds. Bull. Seikai Reg. Fish. Res. Lab. 33:13-45.

Besednov, L.N. 1960. Data on fish fauna of the Pacific flotsam. Trudy Inst. Okeanol. 41:192-197 (in Russian).

Bohlke, J.E. and Chaplin, C.C.C. 1968. Fishes of the Bahamas and Adjacent Tropical Waters. Livingston Publ., Wynnewood PA, 771 pp.

Dooley, J.K. 1972. Fishes associated with the pelagic Sargassum complex, with discussion of the Sargassum community. Contr. Mar. Sci. 16:1-32.

Fedoryako, B.I. 1980. Ichthyofauna of surface waters of the Sargasso Sea south-west of Bermuda Islands. Voprosy Ikhtiol. 20(4):579-589 (in Russian).

Fedoryako, B.I. 1982a. Langmuir circulations as possible mechanism of fish aggregations near flotsam. Okeanologya 22(2):314-320 (in Russian).

Fedoryako, B.I. 1982b. Annotated list of fishes associated with drifting flotsam. In: Poorly Known Fishes of the Open Ocean. Moscow: Inst. Okeanol. p. 110-118.

Fedoryako, B.I. 1988. Fish accumulations in the open ocean near stationary buoys. Okeanologiya 28(4):667-669 (in Russian).

Fine, M.L. 1970. Faunal variation on pelagic sargassum. Mar. Biol. 7(2):112-122.

Gooding, R.M. and Magnuson, J.J. 1967. Ecological significance of a drifting object to pelagic fishes. Pacif. Sci. 21(4):486-497.

Gorelova, T.A. and Fedoryako, B.I. 1986. Topic and trophic interconnections of fishes associated with sargasso weeds. Voprosy Ikhtiol., 26(1):94-102 (in Russian).

Hunter, J.R. and Mitchell, C.T. 1967. Association of fishes with flotsam in offshore waters of central America. Fish. Bull. U.S. 66(1):13-29.

Ida, H., Hiyma, Y. and Kusaka, T. 1967. Study on fishes gathering around floating seaweeds. - 1. Abundance and species composition. - 2. Behavior and feeding habit. Bull. Jap. Soc. Sci. Fish. 33(10):923-926

Ikehara, K. 1977. Studies on fish eggs and larvae accompanied with drifting seaweeds in the Sado Strait and its vicinity. Bull. Jap. Sea Reg. Fish. Res. Lab. (28):17-28.

Inoue, M., Amano, R. and Iwasaki, Y. 1968. Studies environmental alluring skipjack and other tunas. - Pt. II. On the driftwoods accompanied by skipjack and tunas. - Pt. III. Tagging experiments on the experimental driftwoods as part of ecological study of tunas. Bull. Jap. Soc. Sci. Fish. 34(4):91-105.

Kojima, S. 1960. Fishing for dolphins in the western part of the Japan Sea. V. Species of fish attracted to bamboo rafts. VI. Behavior of fish gathering around bamboo rafts. Bull. Jap. Soc. Sci. Fish. 26(4):379-388.

Mitchell, G.T. and Hunter, J.R. 1970. Fishes associated with drifting kelp, *Macrocystis pyrifera*, off the coast of southern California and northern Baja California. Calif. Fish. Game 56(4):288-297.

Parin, N.V. 1958. Pelagic ichthyofauna of the northwestern Pacific. Priroda (5):60-66 (in Russian).

Parin, N.V. 1963. Some results of studies of pelagic fishes of the Pacific and Indian Ocean attracted by electric light. Trudy Inst. Oceanol. 62:128-144 (in Russian).

Parin, N.V. 1968. Ichthyofauna of the Oceanic Epipelagial. Moscow: Nauka, 184 pp. (in Russian).

Senta, T. 1966. Experimental studies on the significance of drifting seaweeds for juvenile fishes. - I. Experiments with artificial drifting seaweeds. - II. Experiments on the effect of light intensity. - III. Experiments on visual stimulations. Bull. Jap. Soc. Sci. Fish. 32(8):639-697.

Shojima, Y. and Ueki, K. 1964. Studies on the larvae and juveniles of fishes accompanying floating algae. - II. Research in the vicinity of Tsuazaki, during April, 1958 - Mar., 1959. Bull. Jap. Soc. Sci. Fish. 31(3):248-254.

Ushida, K. and Shojima, Y. 1958. Studies on larvae and juveniles of fishes accompanying floating larvae. - I. Research in the vicinity of Tsuazaki, during Mar., 1957 - Mar., 1958. Bull. Jap. Soc. Sci. Fish. 24(6-7):411-416.

Table 1. Systematic composition of fish community associated with floating objects.

Order	**Neritic zone**		**Oceanic zone**		**Total**	
(Suborder)	**Family**	**Species**	**Family**	**Species**	**Family**	**Species**
Anguilliformes	+	+	-	-	+	+
Clupeiformes	4	4	-	-	4	4
Siluriformes	1	1	1	1	1	1
Lophiiformes	2	2	1	1	2	2
Gobiesociformes	1	1	-	-	1	1
Beloniformes	4	15	4	24	4	28
Beryciformes	1	1	1	2	1	2
Gasterosteiformes	1	1	-	-	1	1
Syngnathiformes	4	12	1	3	4	14
Scorpaeniformes	4	13	1	1	5	14
Perciformes	32	130	20	57	36	146
(Percoidei)	(26)	(79)	(15)	(35)	(30)	(92)
(Carangoidei)	(3)	(45)	(3)	(20)	(3)	(47)
(Mugiloidei)	(2)	(4)	(2)	(2)	(2)	(5)
(Polynemoidei)	(1)	(2)	(-)	(-)	(1)	(2)
Pleuronectiformes	-	-	1	1	1	1
Tetraodontiformes	5	27	4	21	5	33
Total	59+	207+	34	111	65+	247+

Table 2. Taxonomic diversity of the Perciformes associated with floating objects in neritic and oceanic zones.

Number of Species

Families	Neritic zone	Oceanic zone	Total
Carangidae	42	17	42
Centrolophidae	20	2	20
Nomeidae	8	9	10
Kyphosidae	8	3	8
Scombridae	7	3	7
Pomacentridae	5	1	5
Blenniidae	4	4	8
Mullidae	4	2	6
Coryphaenidae	2	2	2
Lobotidae	2	1	2
Girellidae	2	1	2
Oplegnathidae	2	2	2
Platacidae	1	1	1
Teraponidae	-	1	1
Tetragonuridae	-	3	3
Scaridae	-	1	1
Gobiidae	-	1	1

Table 3. Typical fishes associated with floating objects.

INTRANATANT	
Histrio histrio	juveniles to adults
Syngnathus pelagicus	juveniles to adults
Lobotes surinamensis	juveniles
Abudefduf saxatilis	juveniles
Coryphaena hippurus	small juveniles
Canthidermis maculatus	small juveniles
Cheilopogon furcatus	eggs to juveniles
EXTRANATANT	
Alutera scripta	adolescents
Kyphosus cinerascen	sjuveniles
Terapon theraps	juveniles
Psenes cyanophris	juveniles
Elagatis bipinnulatus	juveniles
Coryphaena hippurus	juveniles
Canthidermis maculatus	juveniles
CIRCUMNATANT	
Katsuwonus pelamis	adolescents
Thunnus albacares	adolescents
Canthidermis maculatus	adults
Balistes capriscus	adults
Coryphaena hippurus	adults
Elagatis bipinnulatus	adults
Seriola spp.	Adult

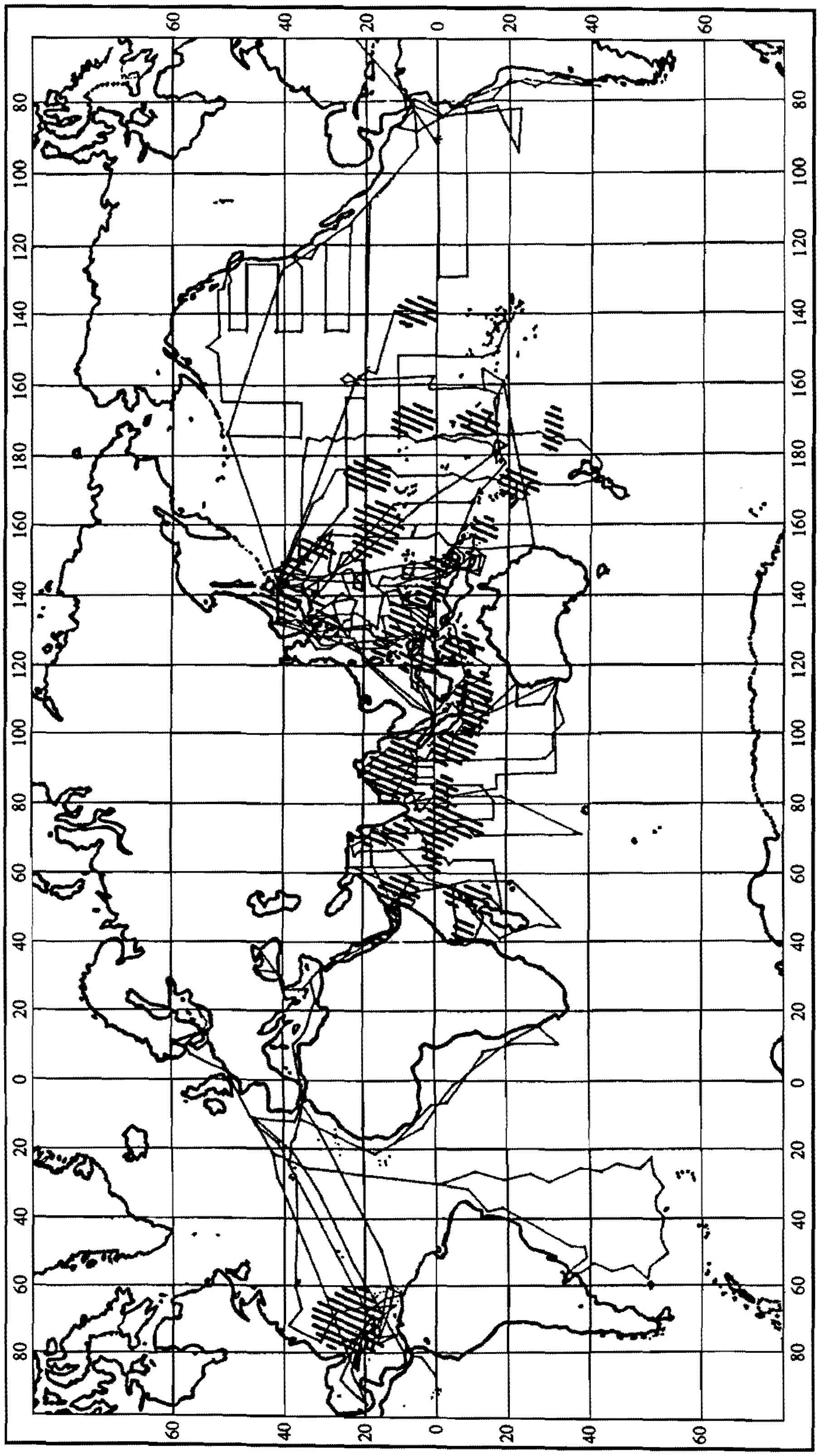

Figure 1. Routes of the P.P. Shirshov Institute of Oceanology research vessels (narrow lines) and distribution of floating weed aggregations (cross-hatched areas).

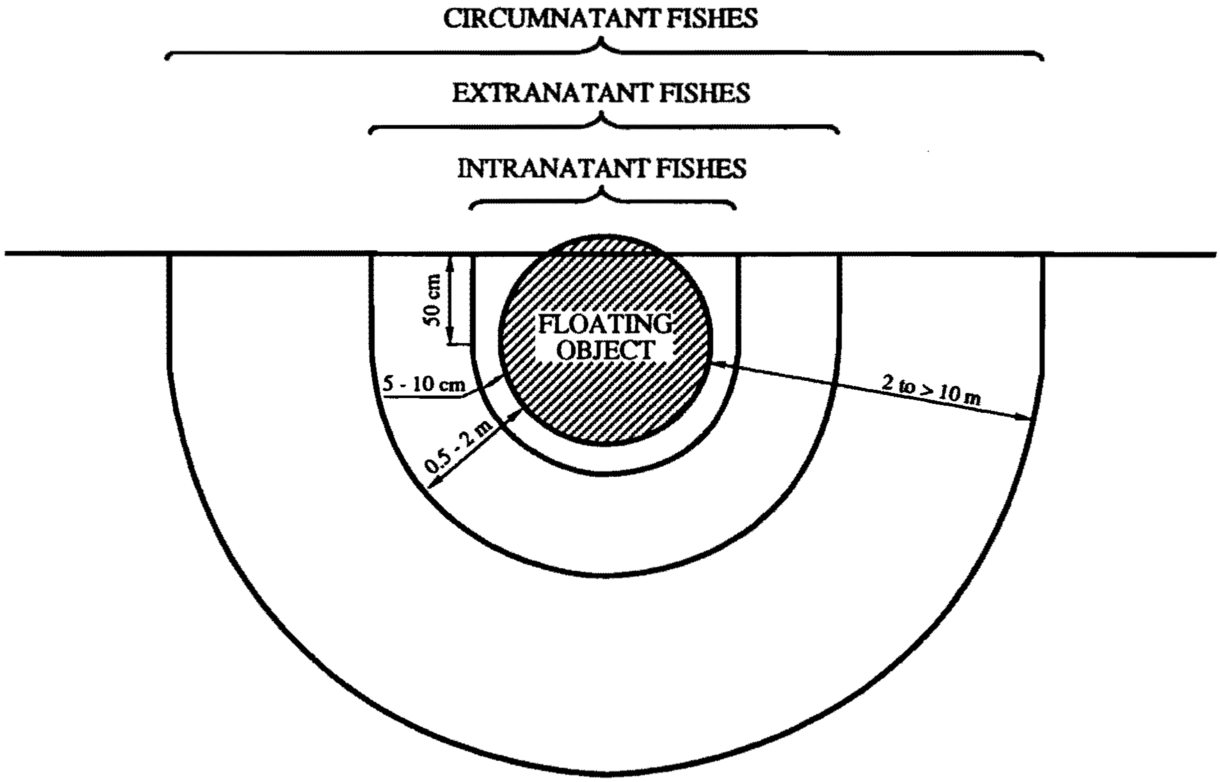

Figure 2. Spatial groups of fishes around a floating object.

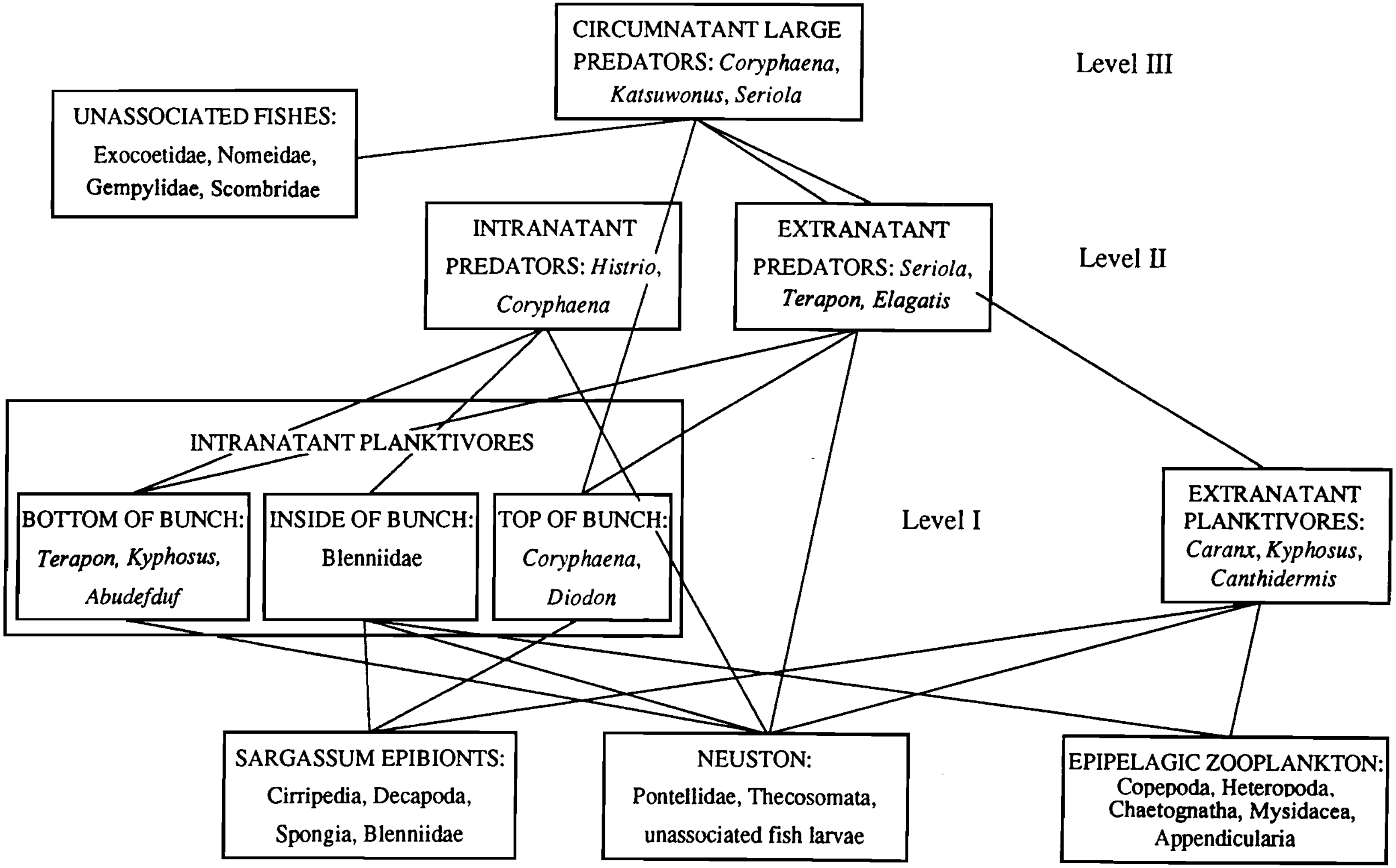

Figure 3. Trophic relationships in a drifting Sargassum community.

DISTRIBUTION OF FLOATING LOGS IN THE PACIFIC AND PURSE-SEINE-SETS ON TUNAS ASSOCIATED WITH LOGS BY JAPANESE BOATS IN THE TROPICAL WESTERN AND CENTRAL PACIFIC

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INTRODUCTION

Knowledge of the association of tunas with floating objects can not be overstated if one understands how the present purse-seine fishery in the western and central tropical Pacific has evolved from almost none to the largest tuna fishery in the world, consisting with international fleets and producing about 0.8 million tons per year after 1990 (Lawson 1994). The remarkable development of the purse-seine fishery was made possible by discoveries of Japanese boats in the mid 1960s that tuna schools, mostly consisting of juveniles, associate with floating logs and that they could be harvested successfully under certain conditions (*e.g.*, JAMARC 1976). After those discoveries, industrial purse seiners not only from Japan but also from several other countries such as the USA, the Republic of Korea and the Republic of China joined in exploitation of the tuna resources in this region. However, little is known about how and why tuna schools associate with floating objects and the role floating objects play in distribution and ecology of tunas. The present paper was prepared to present information which may help to understand some aspects of the association of tunas and floating objects through sighting survey data on marine debris and fisheries data of the Japanese tuna purse-seine boats operating in the western and central tropical Pacific.

BRIEF HISTORY OF THE JAPANESE TUNA PURSE-SEINE FISHERY IN THE WESTERN AND CENTRAL PACIFIC

Traditional Japanese purse seining has a long history in the Sanriku area off northeast waters of Japan. Two net boats along with several support boats form a unit, commonly referred to as group seiner, target mainly bluefin tuna in summer. Before World War II, fishing was confined to coastal areas of the northwest Pacific. Although the northwest Pacific fishing ground has expanded substantially to offshore waters after World War II, the main fishing ground still remains in the coastal and offshore waters around Japan. Some boats started in the 1960s to try to operate in the tropical waters of the western Pacific to establish year round operations because it was not possible to fish for tuna by purse-seiners in the winter season in Japanese waters. After several years of failure in experimental operations in tropical waters, stable year round operations were made possible mainly by catching tunas associated with logs in the mid-1970s (Honma and Suzuki 1978). Figure 1 shows the fishing grounds of the Japanese tuna purse-seine fishery in terms of number of sets during 1987-1991.

There are several differences in boat types, operational aspects and the species composition of the catches between the northwest Pacific and tropical fisheries of the Japanese purse-seine fishery (Honma and Suzuki 1978). In general, the purse-seine boats currently operating in the northwest Pacific are the group seiners evolved from traditional two-net-boat seiner, consisting of a net purse seiner (100 to 200 GT) and several supporting boats such as reefers and searching boats. They catch tropical species such as skipjack and yellowfin as well as temperate species such as bluefin. Minor amounts of bigeye and albacore are also caught. The number of group seiners has decreased to about 40 in recent years and at present no two-net-boat seiners are operating. Most of the Japanese seiners operating in the tropical waters are single purse seiners (300 to 500 GT) without any support boats. The number of purse seiners has been limited to 32 and they operate in the tropical waters along with a fraction of the group purse seiners, five to seven groups, which are allowed to operate seasonally in the tropical waters.

DATA AND ANALYSES

Data

Purse-seine and baitboat fisheries extensively depend on floating objects for catching tunas. However, there is no information available on school types fished for the Japanese baitboat fishery except historical data of the Japanese boats chartered by the South Pacific Commission for tuna tagging. Therefore, the baitboat fisheries were not analyzed in this paper. As for the Japanese purse-seine fishery in the northwest Pacific, the quality of the data is lower than that available for tropical waters. In addition, the tropical purse-seine fishery is far larger both in total catch and in dependency on floating logs than that in the northwestern Pacific. Therefore, only the purse-seine data from tropical waters are analyzed in this paper.

Another set of data used in this study is the sightings of floating objects made by various types of vessels. The sighting information of the floating objects comes from vessels which belong to the Fisheries Agency of Japan, fisheries high schools, and universities as well as from commercial fishing boats and merchant ships. The number of boats which provided the data was about 60 and the survey started in 1986 mainly for the northwest Pacific, but it also covered some areas of the tropical Pacific. The 1986 survey data were not used since very few observations were available for that year.

The data recorded during the survey were all the floating objects larger than 5 cm in length and were available for the years 1987-1991. The types of information recorded are, for each sighting, angle of the floating object from the ship's course and its estimated distance, the type of floating objects such as artificial ones (*e.g.*, fishing gear, wood chip, styrofoam, glasses, petrochemical products), or natural ones (*e.g.*, seaweeds, logs). If multiple numbers of the same object were found, the numbers are entered up to as much as 99 and the size of the floating objects are classified as S, M and L which denote maximum length of objects less than 50 cm, from 50 to 200 cm and larger than 200 cm.

General meteorological and oceanographic observations were also recorded during the sighting survey. In addition to the sighting information, environmental information was collected every hour. A summary of these data has been reported to the International North Pacific Fisheries Commission (*e.g.*, Nasu and Hiramatsu 1991). The 1991 survey results are not yet published but used in this study. For a minor part of the 1987 data, floating log (natural origin) and wood chip (artificially processed) were combined in original record. However, the present analysis treated those data as the floating log data. In summary, the data from 1987 through 1991 were analyzed for the floating log information.

Other information used were the catch and effort statistics of the Japanese purse-seine boats which were operating during this period in the tropical Pacific. The purse-seine logbook data cover time and location of the set by day and by minutes, catch by species recorded to 0.1 tons and by size categories (equal to or larger than 10 kg and smaller than 10 Kg) for yellowfin tuna, school types and sea surface temperature. The purse-seine statistics have been compiled by the National Research Institute of Far Seas Fisheries . The data coverage is near 100 % for the tropical fleet.

Analyses

The current systems, primarily flowing east-west or west-east in direction in the western and central tropical Pacific, is a major factor in determining the time and space distributions of the floating objects. In most cases, the data were stratified by 2°-latitude and 5°-longitude quadrates and 2-month time intervals, taking into account the time and space availability of the data.

Estimation of the density of floating objects was made employing the line transect method (Seber, 1982) described by Nasu and Hiramatsu (1991). Density of floating objects (N) in a unit area is defined as follows:

$$N = \frac{n}{2(W/1852)L}$$

where

n = number of the floating objects found
W = effective perpendicular distance in nautical miles
(W was measured originally in meters)
L = miles surveyed

Effective perpendicular distance was calculated by the type of floating objects by year. It ranged from 36 to 49 meters for wood chips and the floating logs (Nasu and Hiramatsu 1991). The annual estimates of W were revised later (Hiramatsu, personal communication) and those are 47.2, 36.3, 45.5, 46.5, 46.6 meters for 1987, 1988, 1989, 1990 and 1991, respectively.

RESULTS

Time and Space Distribution of the Floating Logs

Sets on tuna associated with floating logs are, in general, the most important among various set types for which the Japanese tuna purse seiners operate in the western and central tropical Pacific.

Figures 2 and 3 show the distribution of surveyed distance (nautical miles) and average density of the logs (frequency of occurrences per square miles x 103) for all data combined during 1987-1991 period. The survey data are poor for the areas south of 10°N where the major purse-seine fishing ground is formed. Also, though not shown here, the data from the first half of the years are much smaller than those from the latter half of the years for the tropical waters. As is already pointed out (Nasu and Hiramatsu 1991), areas with high density of floating logs are mainly in the coastal areas with somewhat low density zone between 10°N to 30°N in the western Pacific. In the tropical areas, the waters around the Philippines, Indonesia, Papua New Guinea and Solomon Islands as well as southern Mexico and Central America are predominantly abundant with floating logs. Also, a high-density band is seen ranging between 5°N and 10°N and between 130°E and 160°E. Incidentally, although not shown in this paper, analysis by size of the floating logs indicates that large logs (L) tend to be more abundant in the western tropical Pacific.

Preliminary analysis of seasonal variation of the spatial distribution pattern by quarter of the year did not give a clear picture due to a lack of data especially in tropical areas. Four specific areas were selected where the data are relatively abundant and the density of the logs appears high (Fig. 4). The time trend of the density by areas and by two-month intervals are shown in Figure 5. In general, the data coverage appears inadequate to elucidate any seasonal change or annual variation of log density, especially for area 3. However, it is suggested that 1) for area 2, the density tend to increase in the latter half of the years, except in 1990., 2) for area 4, the density in 1987 and 1990 is lower than other years.

To see if there is significant annual variation among the areas, annual mean densities were calculated for areas 1, 2 and 4 for the years with more than 100 observations. Criterion using the data sets with more than 100 observations for estimation of mean density was used by the reason that if the number of observations is large, approximately over 100, the estimate could be regarded as sampled from a normal population even if the distribution of densities was skewed and population variances were unknown as in the case of the present study (Kunisawa and Iwasaki 1966). The result is shown in Figure 6 and Table 1 with a 95 % confidence interval. Table 2 shows the result of two sample t test of difference in mean. For area 1, only means between 1988 and 1989 was significantly different. The mean value in 1989 in area 2 was significantly higher than other years while it was significantly lower in 1991. The 1987 mean for area 4 was statistically low compared to those in 1988 and 1989.

Log-Associated Sets of Japanese Tuna Purse-Seine Boats in the Western and Central Pacific

Figure 7 shows distribution of the number of sets on floating logs by the Japanese purse-seine boats during 1987-1991. The pattern of distribution is similar to that shown in Figure 1, but the relative importance of sets on floating logs is reduced in the northwest Pacific. This indicates that the Japanese purse-seine boats depend on floating logs in the tropical waters. Since the ratio in terms of percentage of the log-associated sets over all types of sets combined shows relatively even distribution for the same year period (Fig. 8), school fish, another important mode of school types, occurs in the same areas where the log-associated fish are found frequently. Seasonality of the log-associated sets seem to indicate an increased number of sets in the latter half of the years with the lowest log-associated sets in the first quarter (Fig. 9).

DISCUSSION

The major areas where the Japanese purse-seine fishery operates in the western and central tropical Pacific correspond in part to the high-density areas of floating logs inferred from the sighting survey data. These analyses also indicate other high-density areas in the western and central tropical Pacific such as near shore areas of Indonesia and Papua New Guinea as well as areas around the Solomon Islands. Lack of Japanese purse-seine operations in those high-density areas of floating logs is because the Japanese operations are not permitted by those countries. Most of the high-density areas of floating logs are operated by the international purse-seine fleets (Lawson 1994).

It was mentioned previously that there is a zonal band of high density between 5° and 10°N in Figure 3. Since the North Equatorial Countercurrent occurs in this zone, the current probably plays an important role in the transportation of logs toward oceanic areas together with the New Guinea Coastal Current and South Equatorial Countercurrent which also flow east or southeast in the areas of high log density (Yamanaka 1973). Possible consequences of logs flowing eastward on distribution and transportation of juvenile tunas may be of interest for further studies since tunas associated with floating logs are mostly composed of juveniles.

Significant annual variations in the density of floating logs were observed in some areas although the sighting data are rather fragmentary. The floating logs found in the western and central tropical Pacific probably have their origins in tropical rain forests of Southeast Asia and Papua New Guinea. As a matter of consequence, it is inferred that the amount of logs drained into the ocean is related with amount of rainfall in those are as which is largely affected by the global climatic changes such as El Niño events (Nicolls 1987). Therefore, in the future study, it may be worth to explore possible relationships between changes in the density of floating logs and those of the global climates including oceanographic characteristics such as currents.

The annual variation of density (abundance) of the floating logs may affect the fishing operations and resultant fishing success. Catch and effort statistics of the Japanese purse-seine fishery in the tropical areas were compiled annually in terms of number of sets, combined catch of yellowfin and skipjack and CPUE (combined catch / number of sets) for the period of 1987-1991. Those three statistics were compiled by log-associated operations and other school types (mostly free school type). The result is shown in Figure 10. There appear to be no appreciable consistent correlations between those statistics and density of the floating logs. As for comparison between numbers of log sets and density of the floating logs, it can be stated that no apparent relationship between the two variables implies that there are more floating logs available than there are fish assembled around them. In fact, artificial logs or rafts are not used by purse seiners operating in the western and central Pacific by Japanese boats. However, it could also be stated that since log-associated sets are made only once a day in the very early morning, often selecting the best log among several pre-surveyed logs, the density of floating logs and the number of log sets may have a weak correlation if any. As the comparison made here is fairly crude, a more-detailed analysis should be conducted including additional fisheries data other than the Japanese purse-seine catch statistics and also oceanographic information.

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LITERATURE CITED

Honma, M. and Z. Suzuki. 1978: Japanese tuna purse seine fishery in the western Pacific. S Series 10, Far Seas Fisheries Research Laboratory, 66 pp.

JAMARC. 1976. Report of feasibility study of tuna purse seining in new fishing ground (Areas around Caroline Islands), Fiscal year 1975 (in Japanese). Japan Marine Resources Research Center (JAMARC), 50(2), 189 pp.

Kunisawa, K. and K. Iwasaki. 1966. Introduction to statistics. Hirokawa Publishing Co., Tokyo, 163 pp. [in Japanese]

Lawson, T. (editor). 1994: Tuna Fishery Yearbook 1993. South Pacific Commission, 81 pp.

Nasu, K. and K. Hiramatsu. 1991: Distribution and density of marine debris in the North Pacific based on sighting survey in 1990. National Research Institute of Far Seas Fishery, Fisheries Agency of Japan, 30 pp., document presented to the 38th Regular Meeting of the INPFC.

Nicolls, N. 1987. The El Niño/ Southern oscillation phenomenon (in Chapter 1 of The societal impacts associated with the 1982-83 worldwide climate anomalies, edited by Glantz, M., R. Katz and M. Krenz). UNEP, pp. 2-10.

Seber, G.A.F. 1982: The estimation of animal abundance and related parameters, 2nd edition. Griffin, London, 654 pp.

Yamanaka, H. 1973. Surface currents in the Western Pacific Ocean as seen from the drift of tuna longline gear. Bull. Far Seas Fish. Res. Lab., (9):19-43.

Table 1. Mean annual densities and their standard errors of floating logs in selected areas (See Fig. 4 for area divisions). Mean and 95 % confidence intervals are shown in Fig. 6.

Year	**Area 1**		**Area 2**		**Area 4**	
	Mean	**s_x**	**Mean**	**s_x**	**Mean**	**s_x**
1987	0.0276	0.0121			0.1779	0.0792
1988	0.0618	0.0160	0.0458	0.0135	0.7512	0.1394
1989	0.0195	0.0109	0.2389	0.0667	0.4924	0.1038
1990			0.0446	0.0167		
1991			0.0046	0.0037		

Table 2. Observed t value in two-sample t test of difference in mean with Welch's correction.*

Area 7	1987	1988	1989
1987			
1988	1.71		
1989	0.54	2.19**	

Area 8	1988	1989	1990	1991
1988				
1989	2.84**			
1990	0.06	2.83**		
1991	2.94**	3.51**	2.33**	

Area 10	1987	1988	1989
1987			
1988	35.75**		
1989	18.46**	1.49	

* For 1987 and 1989 mean values in Area 7, two set t test with equal variance was made since the variances in the two years were not significantly different at 5 % level in F test.

**Significant at 5% level in t test.

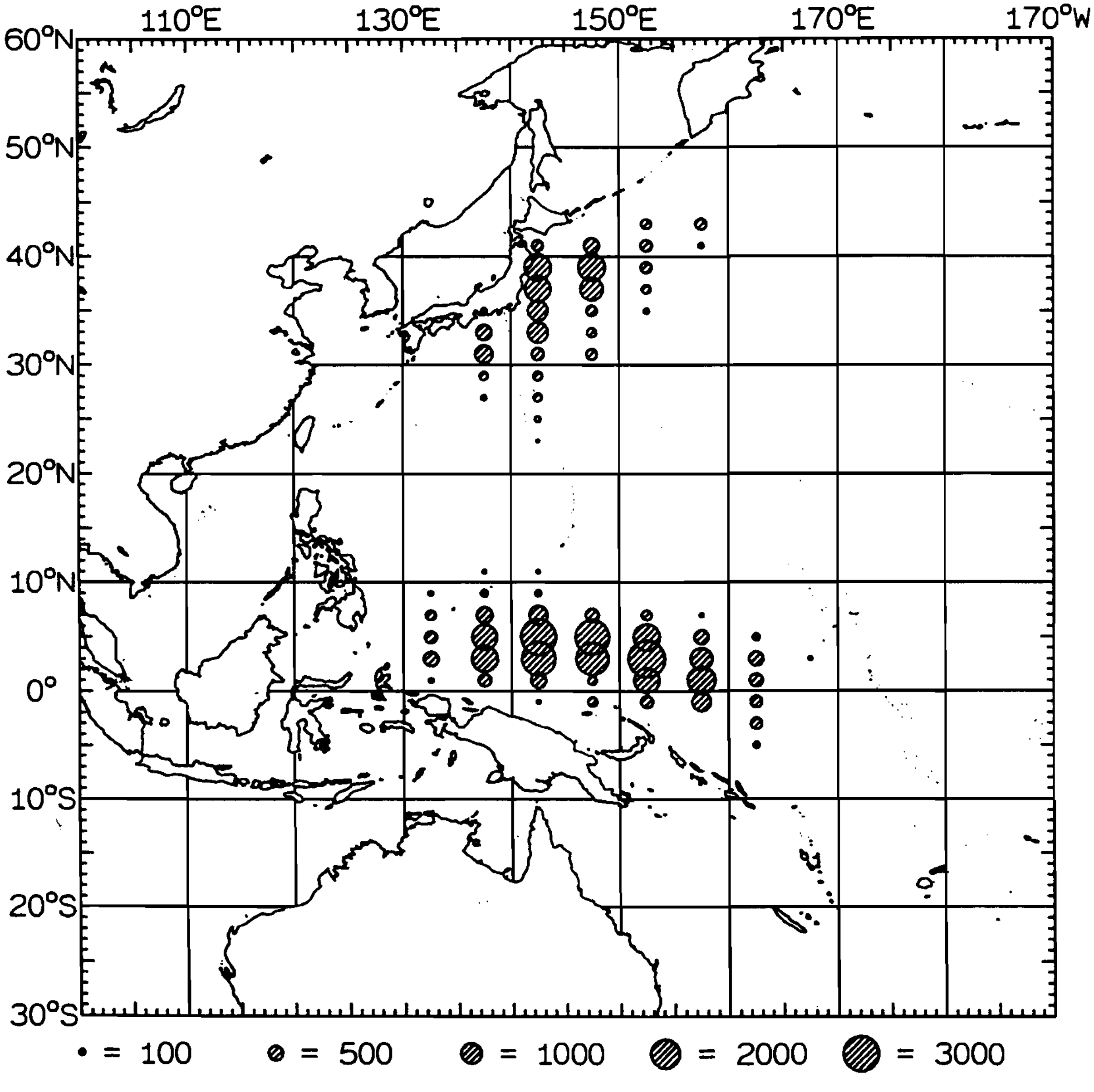

Figure 1. Fishing grounds of Japanese tuna purse-seine fishery shown in terms of number of sets during 1987-1991. Legends correspond to exact values in number of sets.

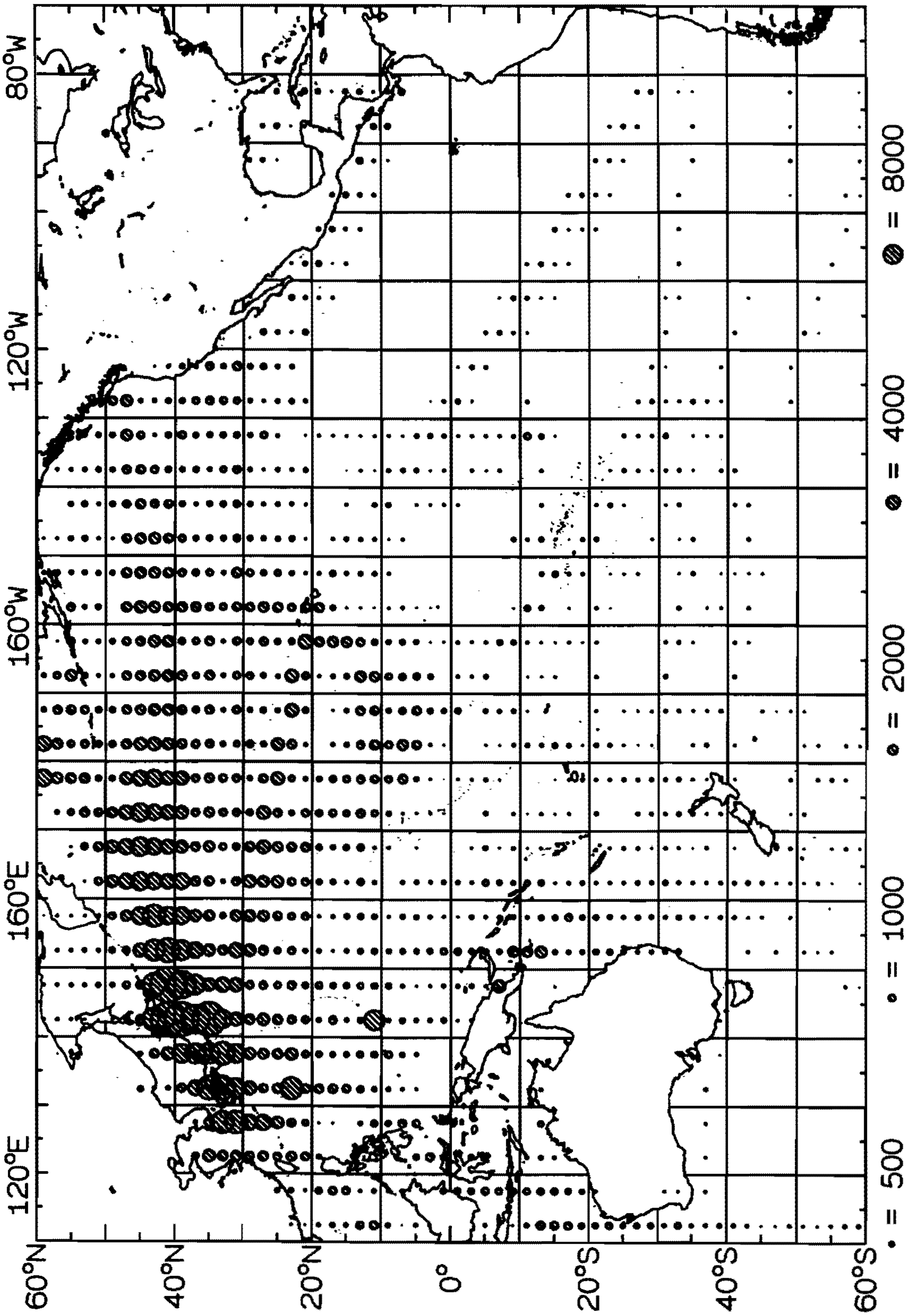

Figure 2. Distribution of surveyed distance (miles) covered by marine debris sighting program during 1987-1991. Sizes of circles correspond exact surveyed distance.

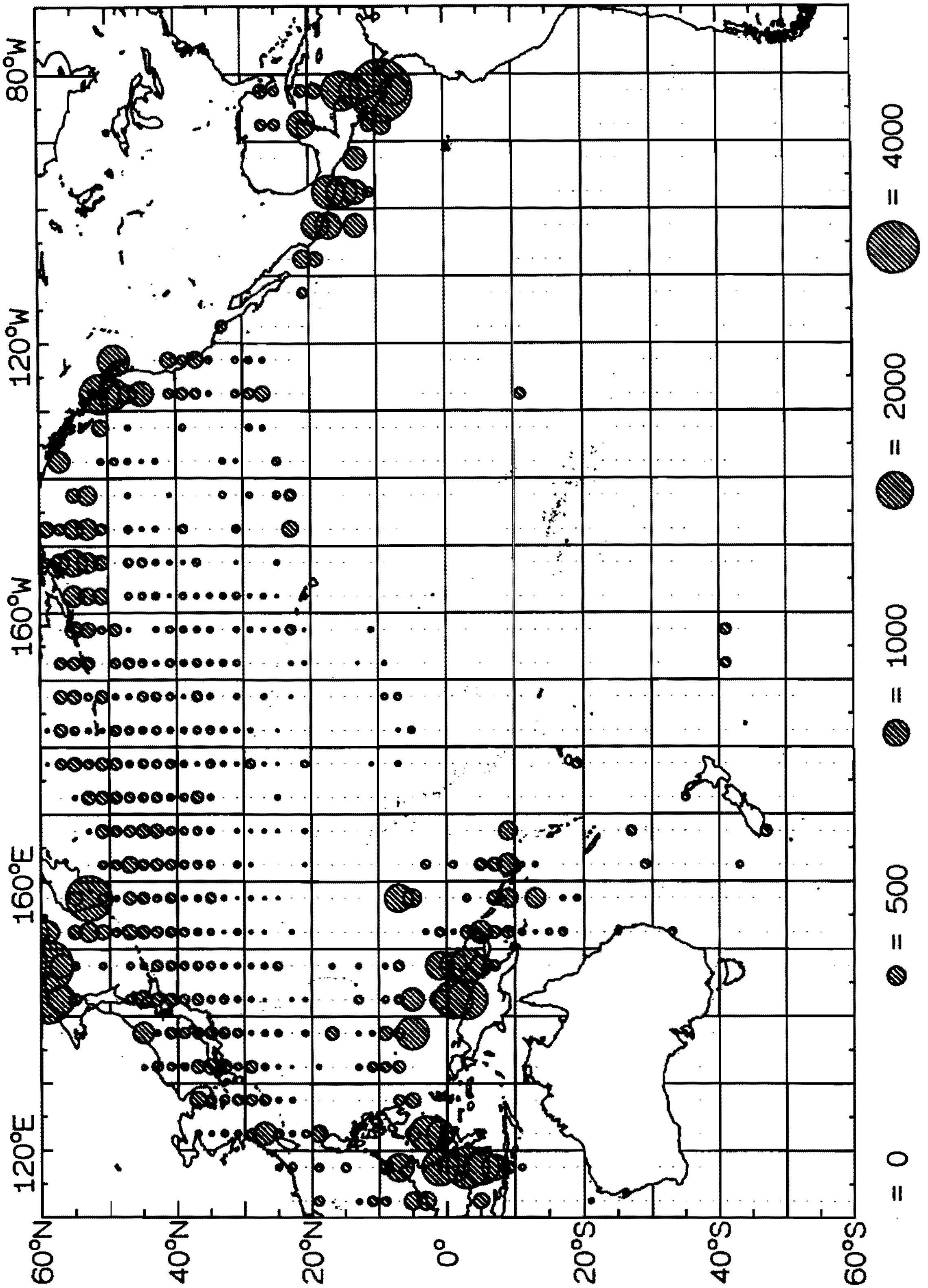

Figure 3. Distribution of density of floating logs (Number of floating logs x 103 /square miles) calculated from marine debris sighting program during 1987-1991. Sizes of circles correspond to exact values of density of floating logs.

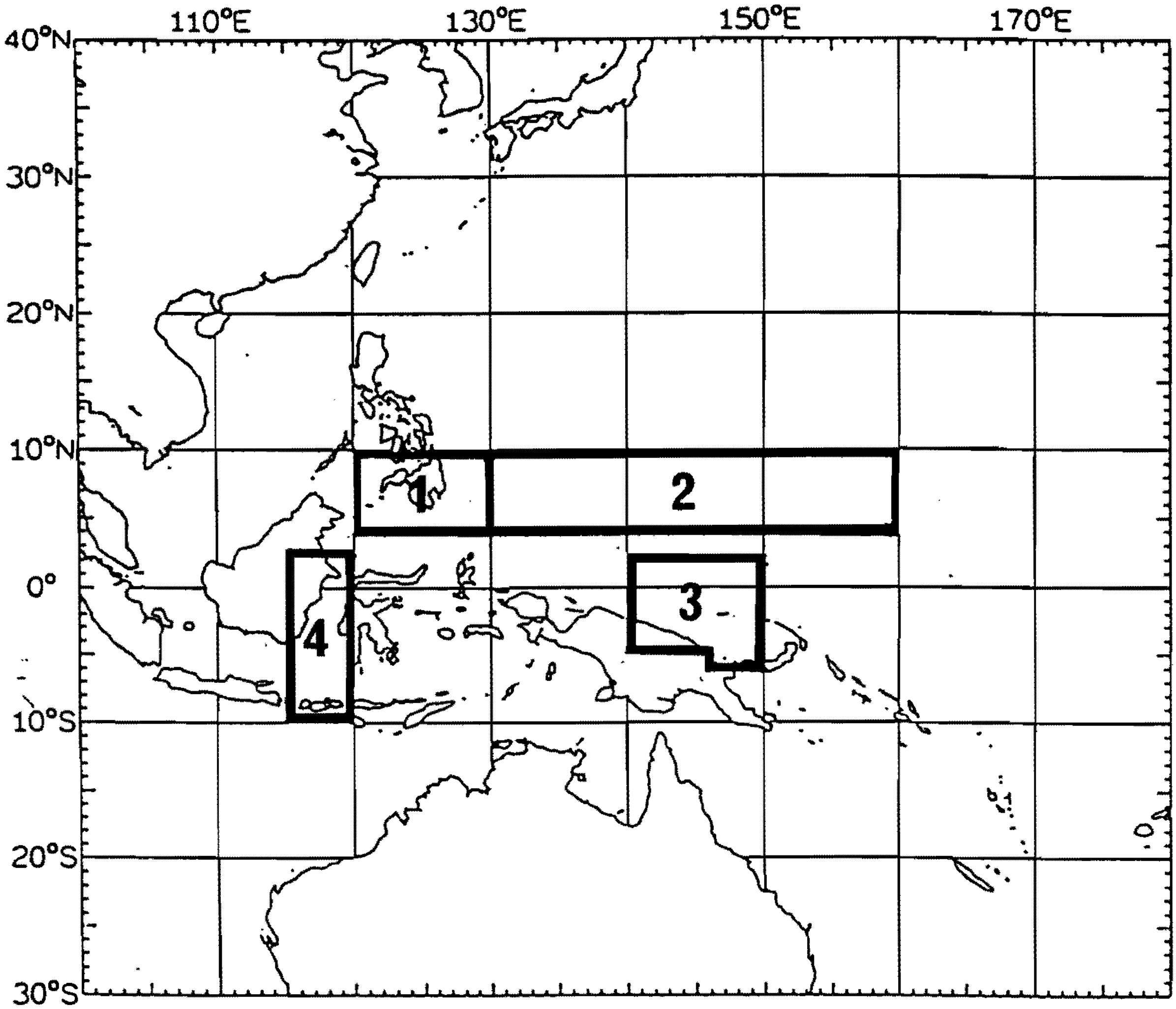

Figure 4. Areas for calculation of density of floating logs.

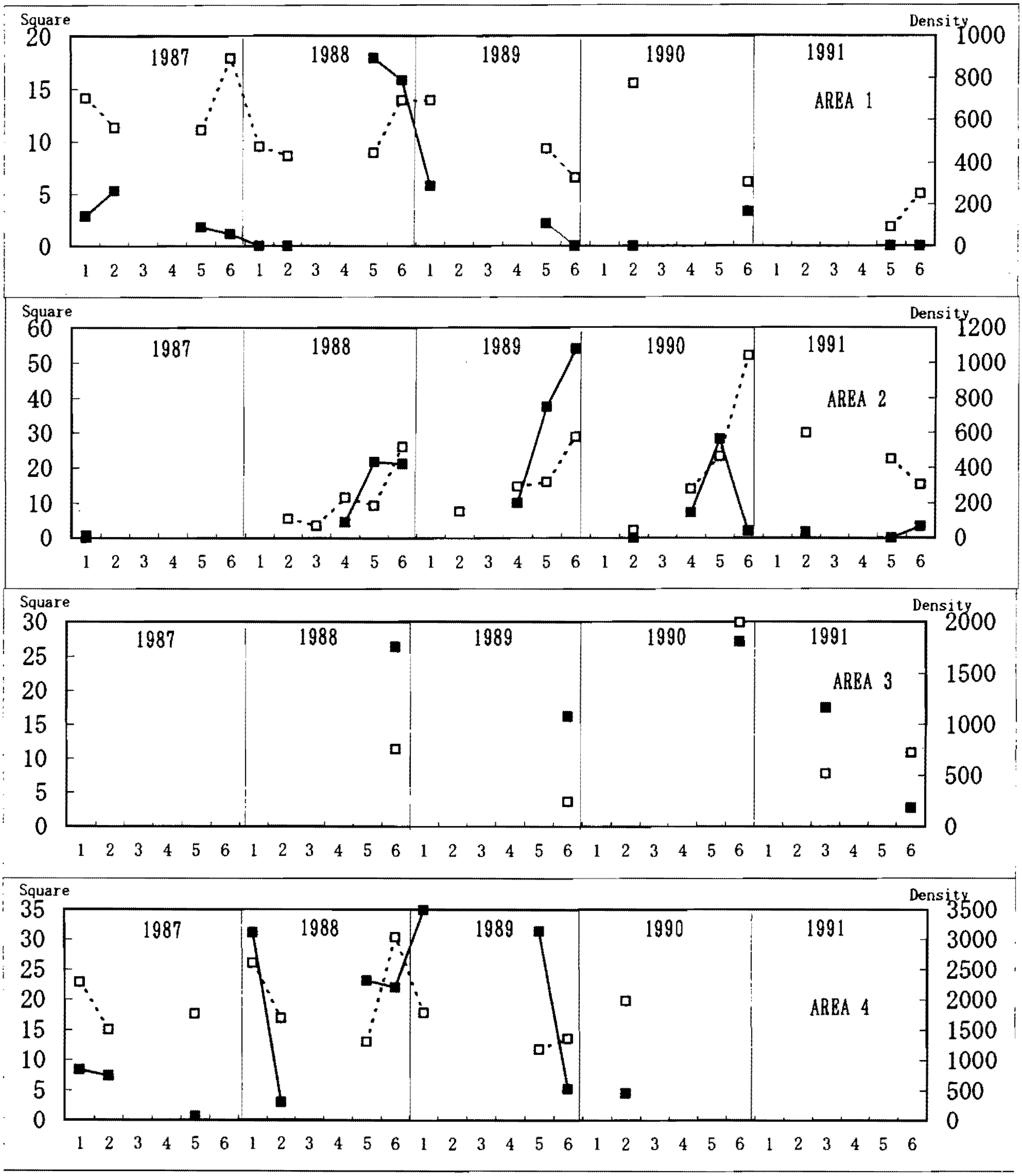

Figure 5. Trends of density (number of floating logs x 10^3 /square miles) of floating logs and area surveyed (square miles). Density and area surveyed are shown by solid squares with solid lines and open squares with dotted lines, respectively. See Fig. 4 for areas.

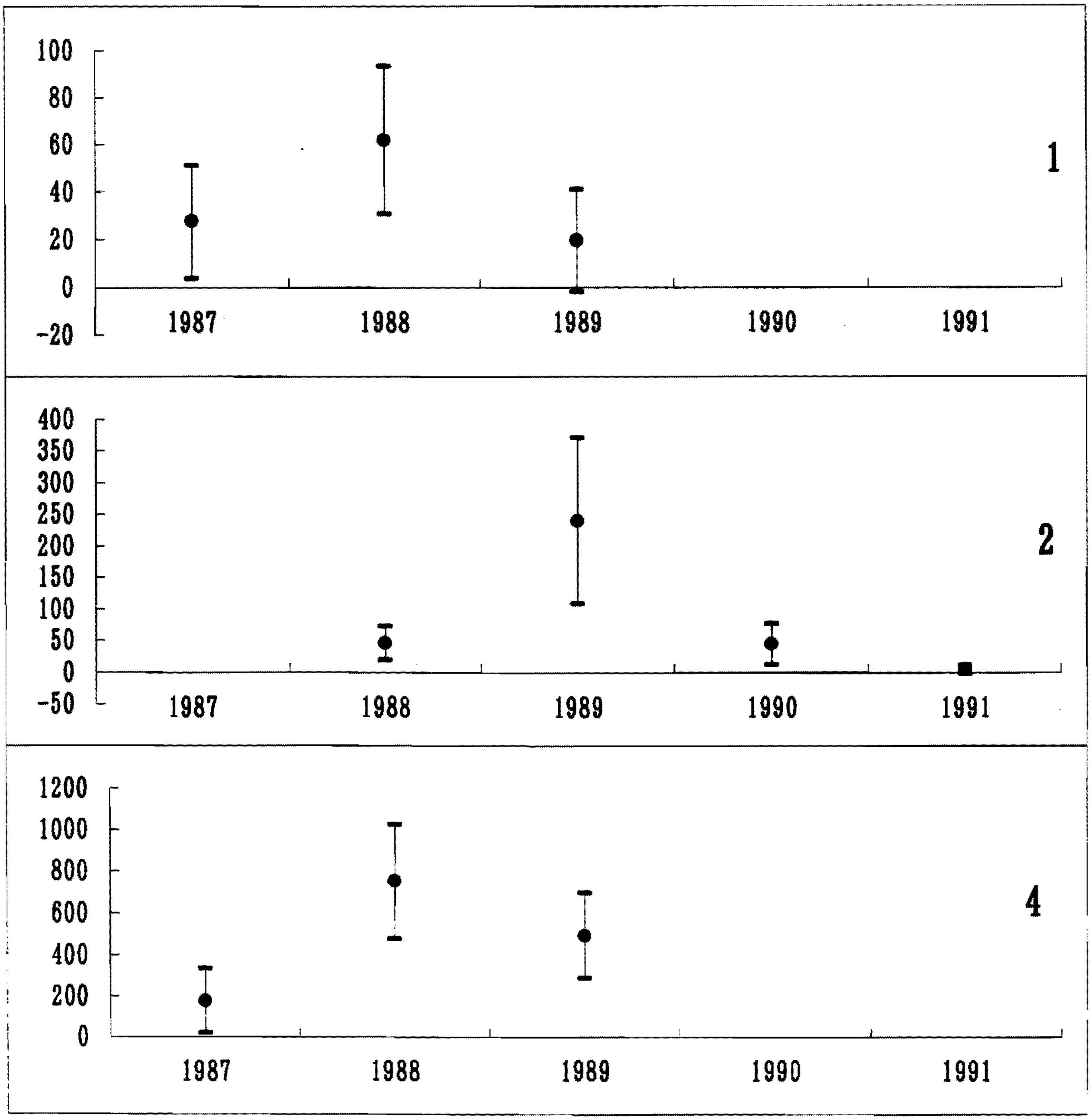

Figure 6. Annual mean density of floating log (number of floating logs x 10^6 /square miles) for selected areas. Solid circles and bars denote means and 95% confidence intervals, respectively.

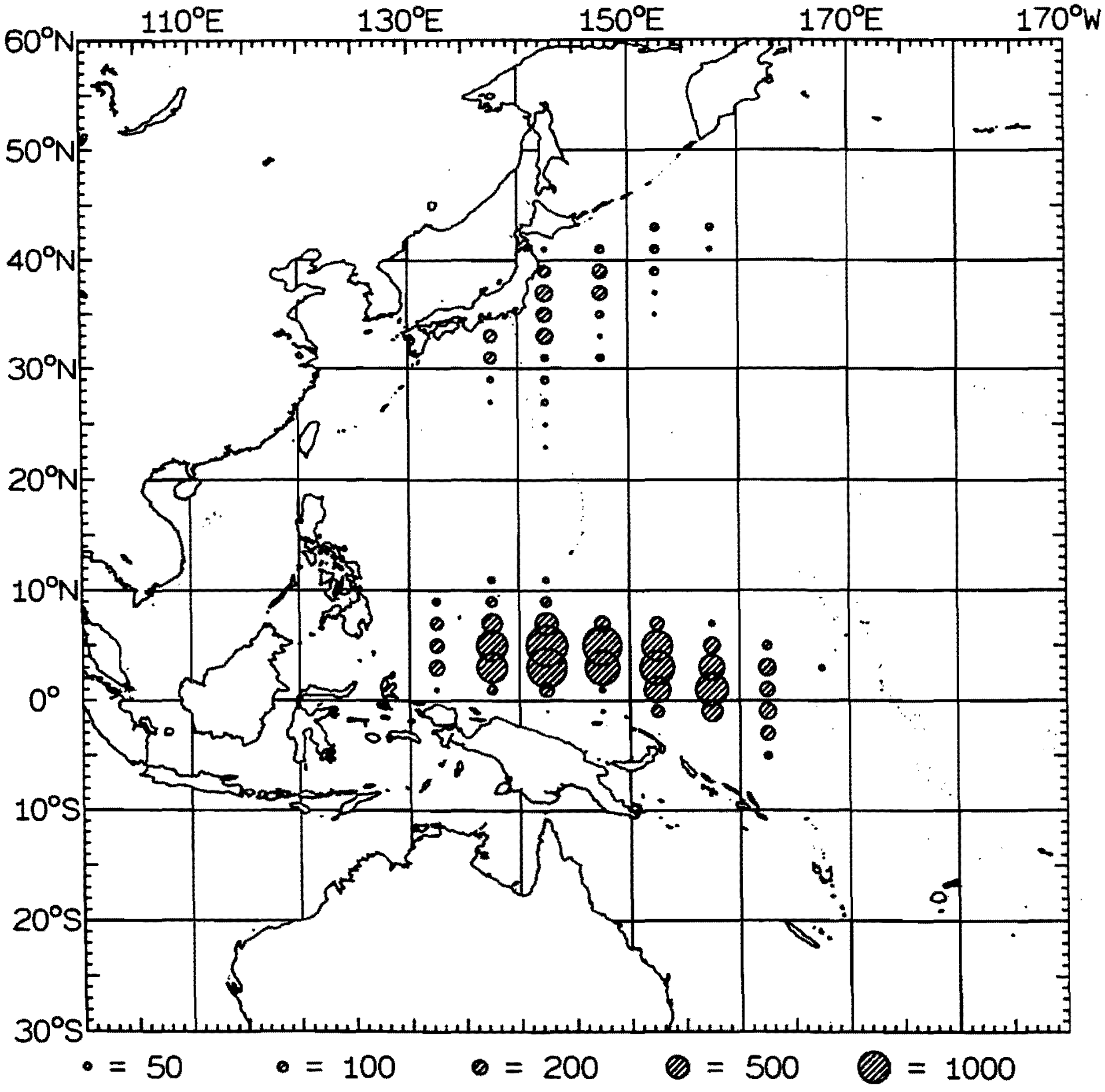

Figure 7. Distribution of number of sets associated with floating logs during the years 1987-1991. Legends correspond to exact number of sets on floating log-associated schools.

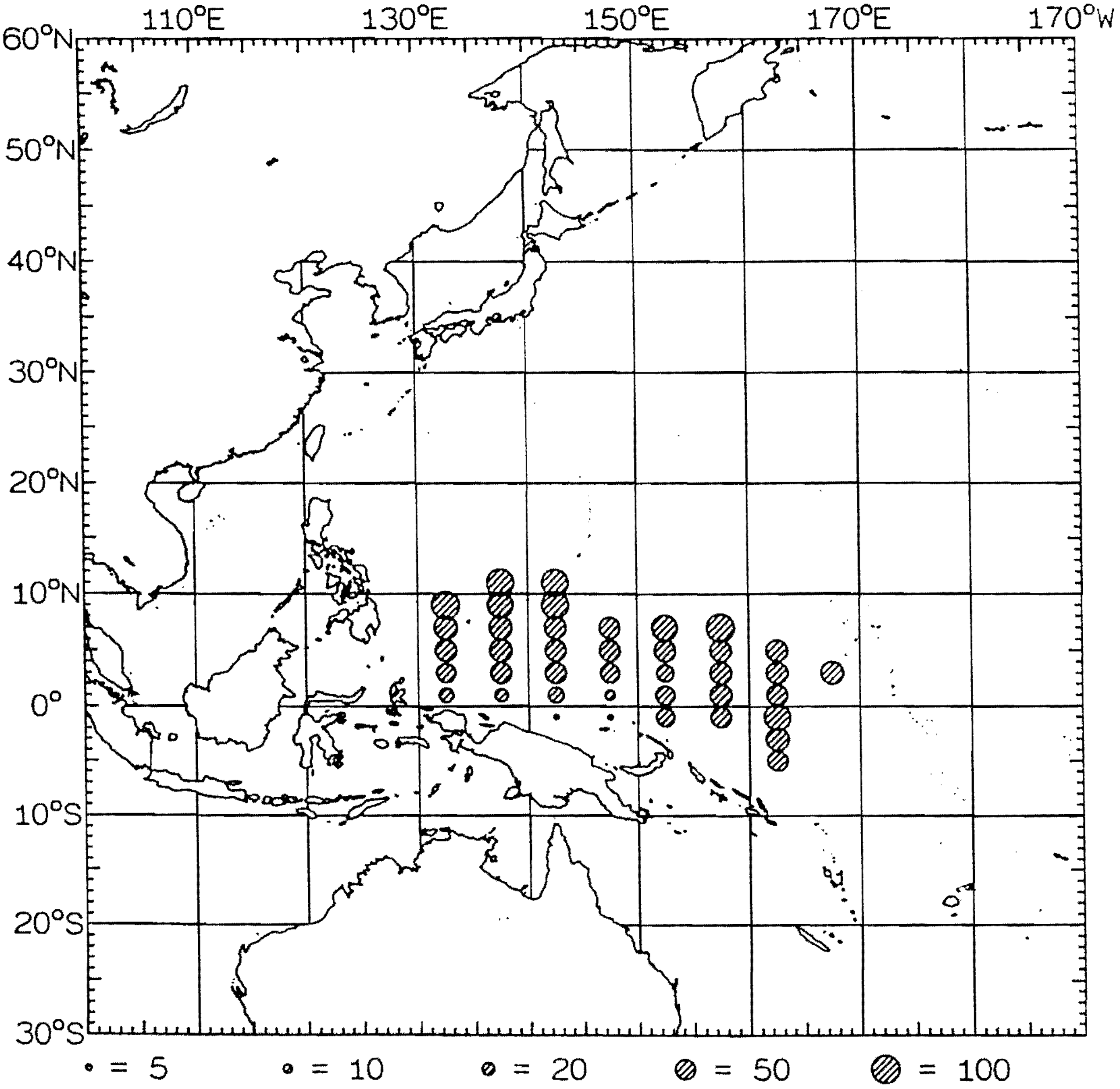

Figure 8. Distribution in percentage of number of log-associated sets over total sets. Legends correspond with exact percentage of number of sets on floating log-associated schools.

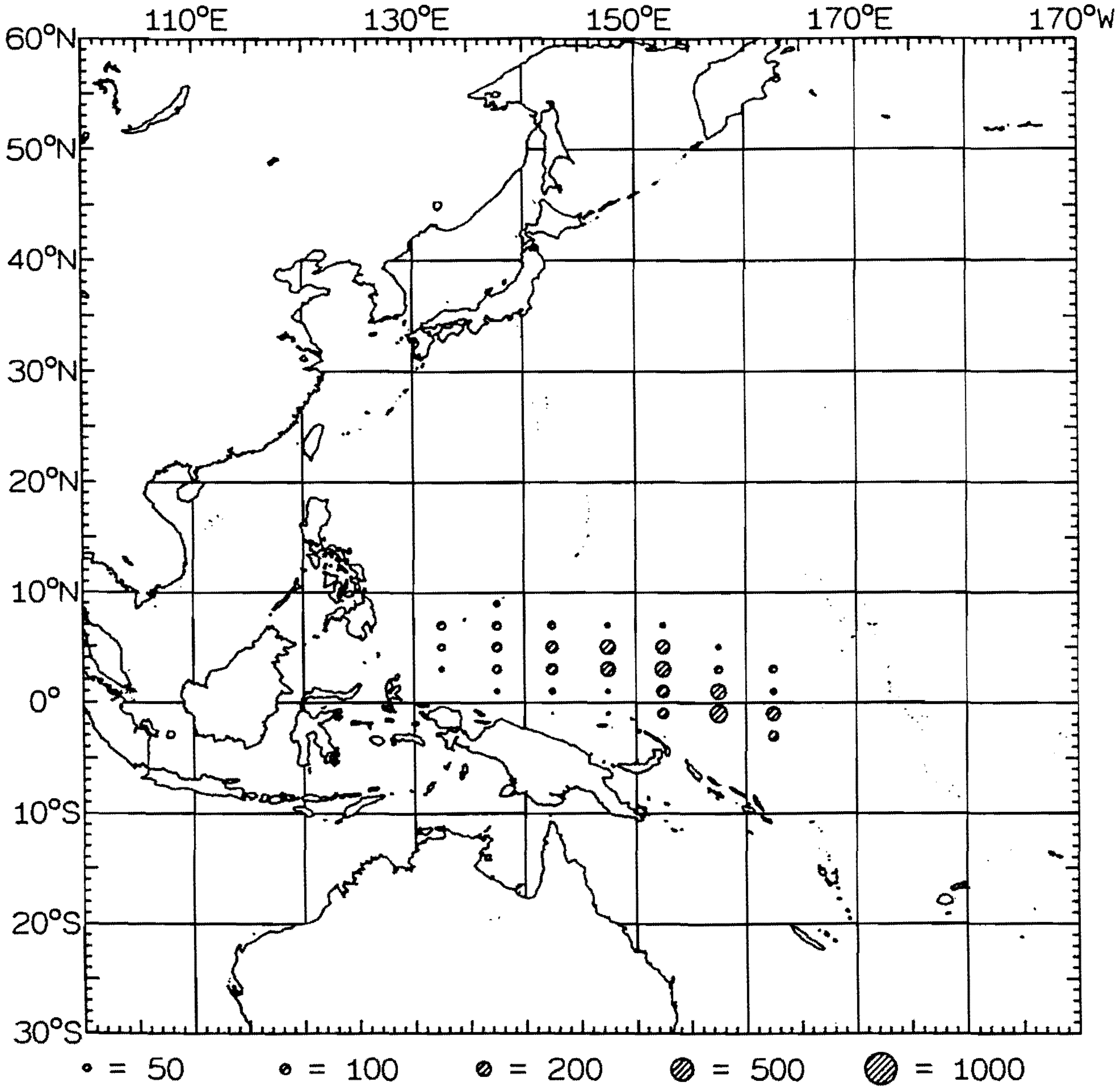

Figure 9-1. Quarterly distribution of the number of floating log-associated sets by the Japanese purse-seine boats during 1987 and 1991. First quarter (Jan.-Mar.). Legends correspond with exact percentage of number of sets on floating log-associated schools.

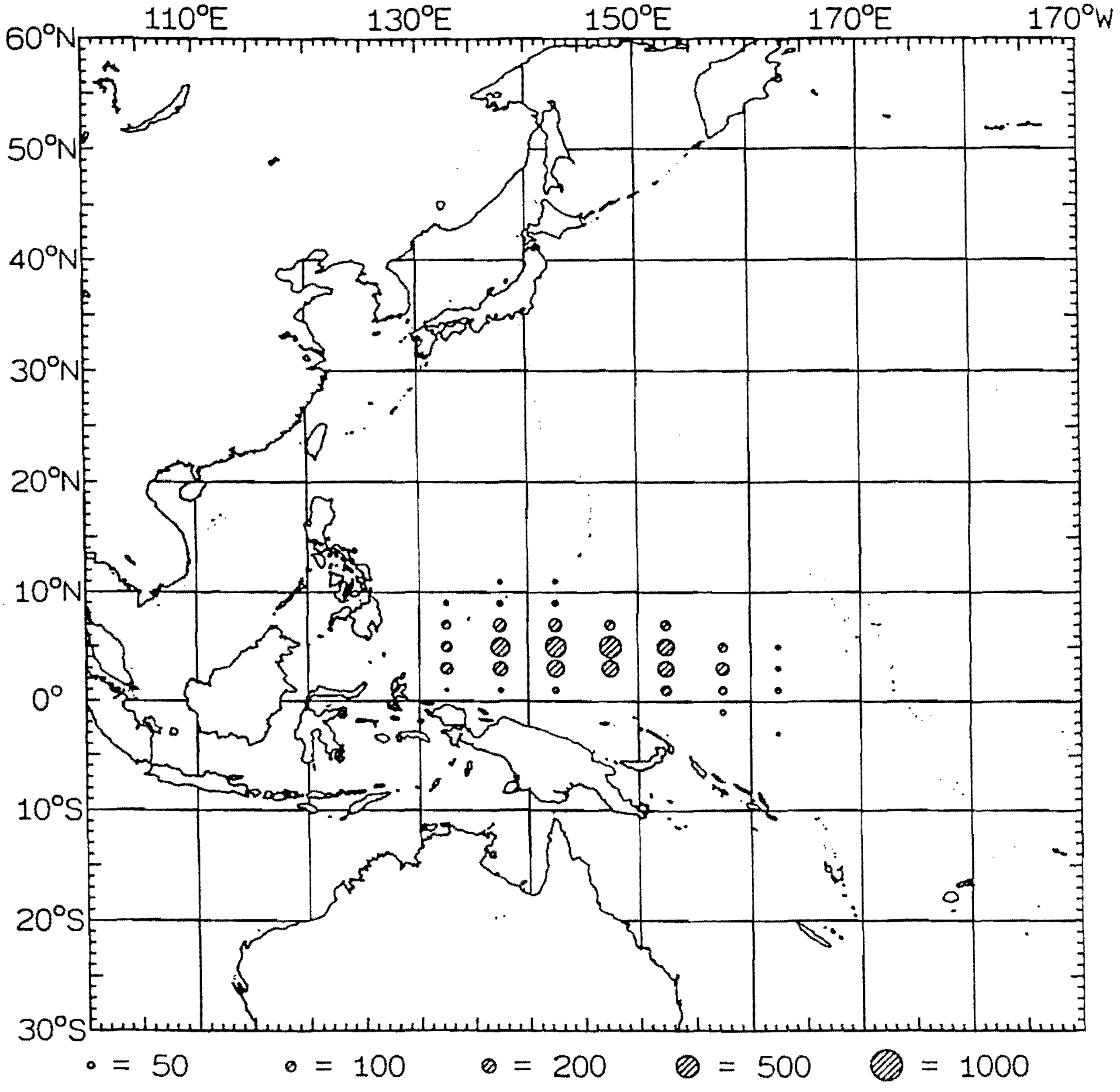

Figure 9-2. Quarterly distribution of the number of floating log-associated sets by the Japanese purse-seine boats during 1987 and 1991. Second quarter (Apr.-June). Legends correspond with exact percentage of number of sets on floating log-associated schools.

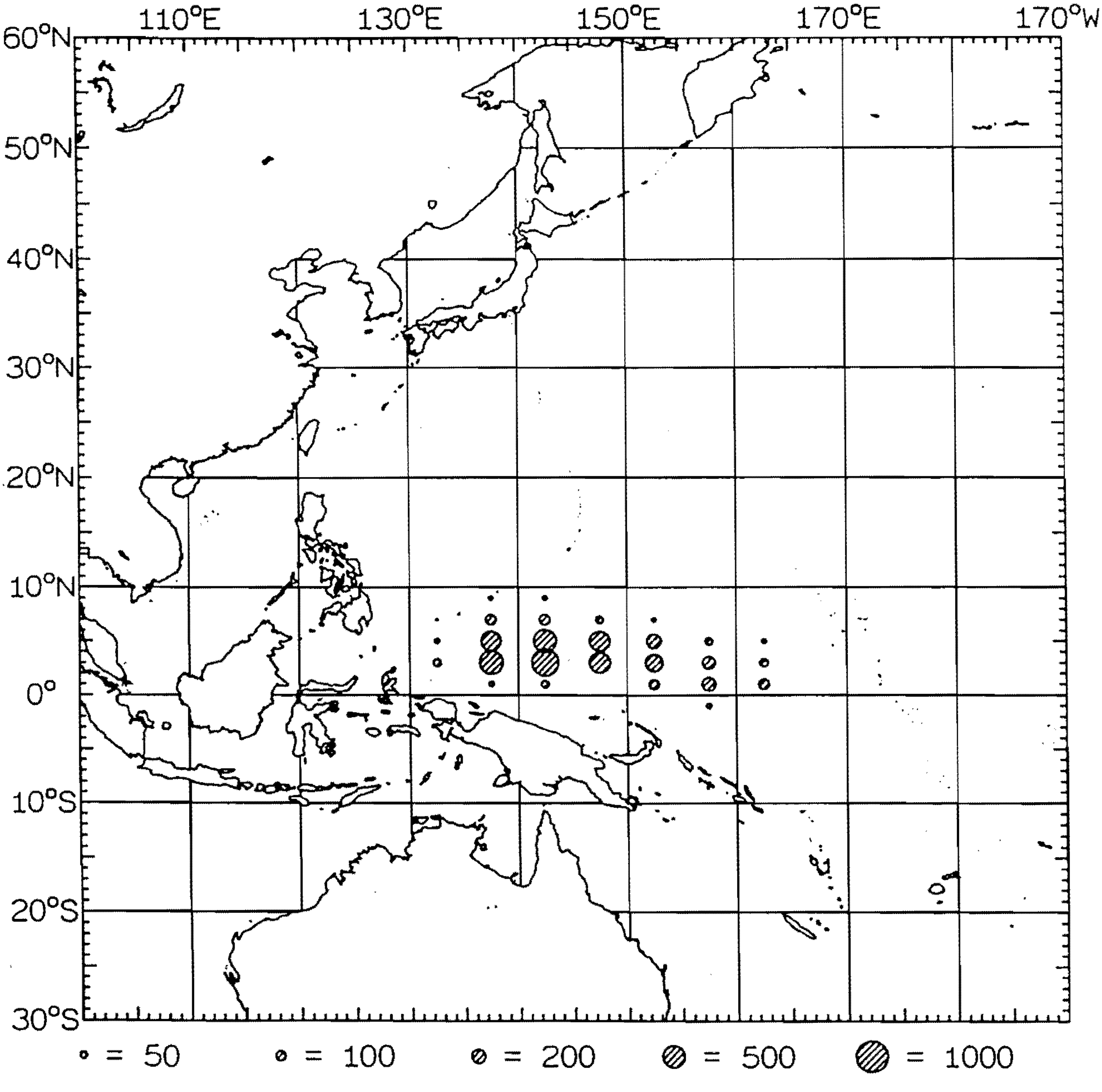

Figure 9-3. Quarterly distribution of the number of floating log-associated sets by the Japanese purse-seine boats during 1987 and 1991. Third quarter (July-Sept.). Legends correspond with exact percentage of number of sets on floating log-associated schools.

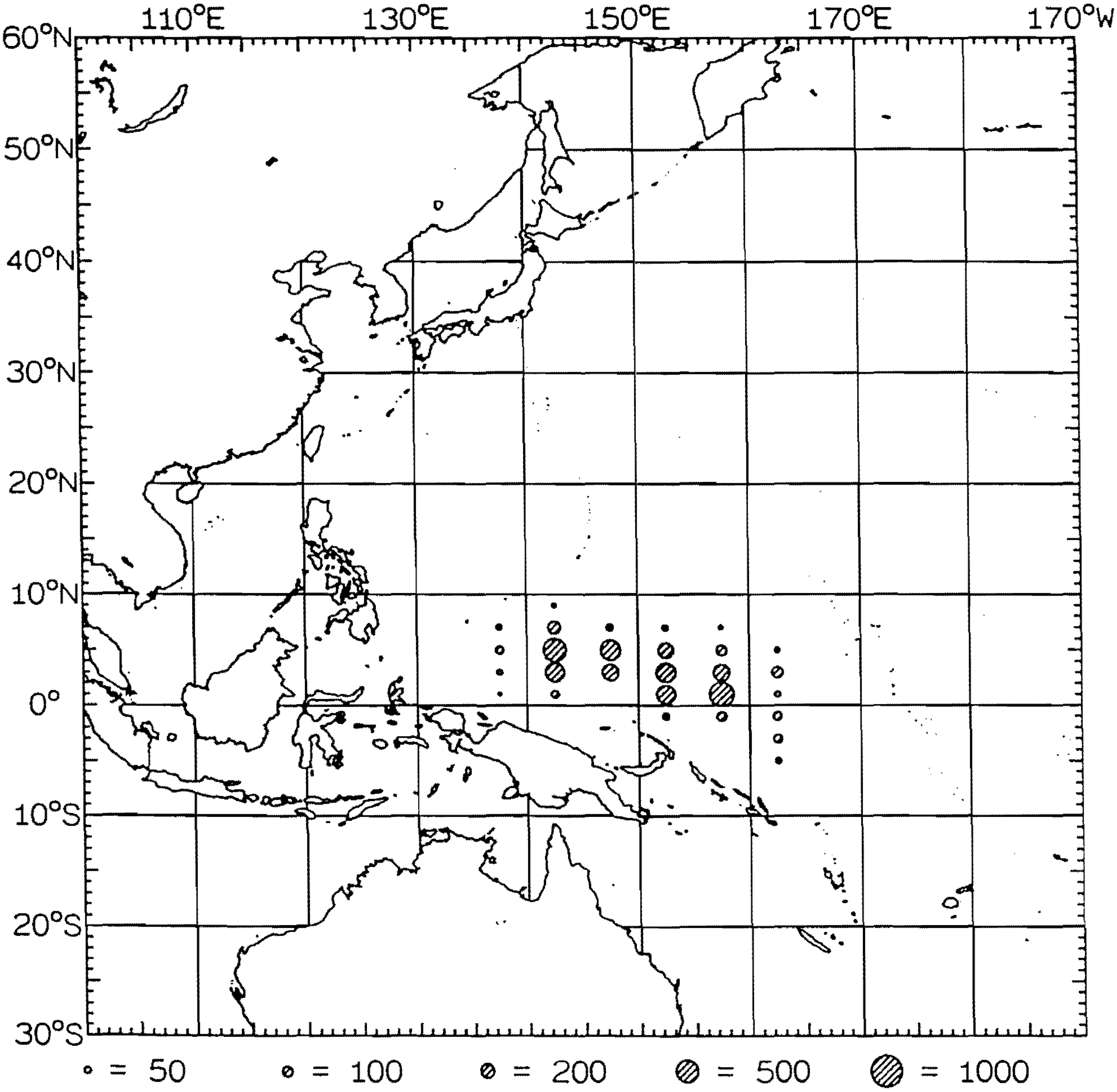

Figure 9-4. Quarterly distribution of the number of floating log-associated sets by the Japanese purse-seine boats during 1987 and 1991. Fourth quarter (Oct.-Dec.). Legends correspond with exact percentage of number of sets on floating log-associated schools.

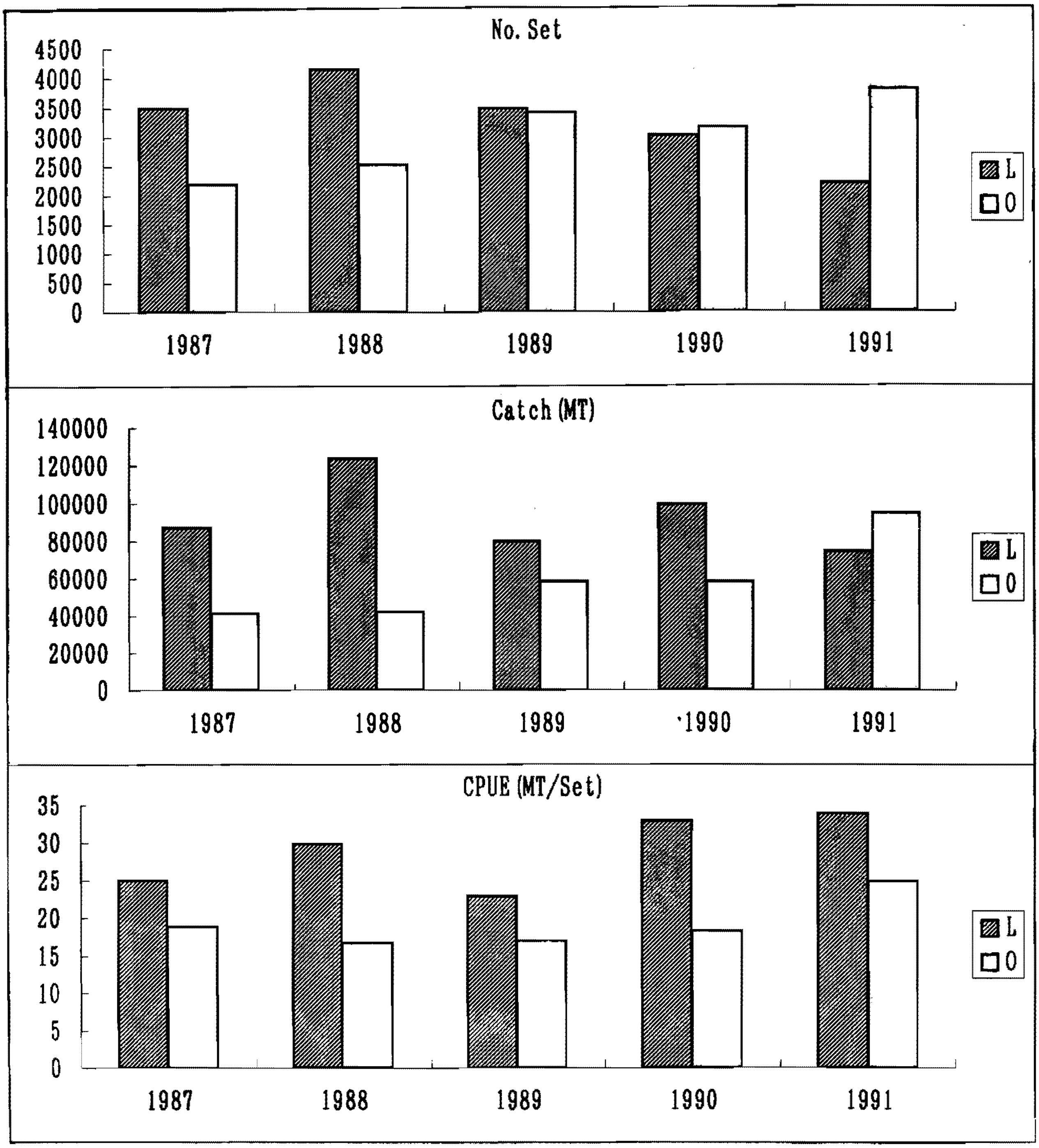

Figure 10. Numbers of sets, resultant catches (skipjack plus yellowfin) and CPUE by floating logs and other school types for the Japanese purse-seine fisheries in the western and central tropical Pacific during the years 1987 to 1991. L and O denote sets on floating logs and other school types respectively.

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