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FISHING FOR TUNAS ASSOCIATED WITH FLOATING OBJECTS: A 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, the 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 per cent 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 five per cent of their total sets.

The highest skipjack catches per set tend to come from log and school sets, whereas higher yellowfin catches 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 per cent of the quarterly US purse seine 'yellowfin' catch (by weight) from log sets is actually bigeye. In contrast, this percentage is less than two per cent 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. It commonly comprises such species as rainbow runner, mahimahi, ocean triggerfish and silky sharks. Blue marlin are 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 that 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 to the north of Papua New Guinea and Indonesia which flow eastward in the first half of the year and westwards in the second half of the year. The size of tuna aggregations associated with logs increases towards the east; this may be 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 of the year. This association may be influenced by the presence of a common prey species, the ocean anchovy.

Most sets on logs and FADs are made just before dawn, or 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 in 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.

Tuna aggregations associated with logs sometimes exceed 300 mt in size, but are more often less than 50 mt. Similar sized unassociated schools are caught. Frequently fished FADs probably support smaller aggregations because of 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

they are 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.

RESUME

La pêche thonière dans le Pacifique occidental et central, qui a permis de réaliser en 1990 des prises estimées à quelque 1,2 million de tonnes, est actuellement la plus importante du monde. Les prises de la flottille de senneurs, composée de navires de l'Australie, de l'Indonésie, du Japon, de la Corée, des Philippines, des Iles Salomon, de l'ancienne Union soviétique, de Taïwan et des Etats-Unis d'Amérique, ont atteint 700 000 tonnes en 1990. Les senneurs pêchent sur une variété d'objets flottants autour desquels les thonidés tendent à évoluer. Dans le Pacifique occidental, il s'agit essentiellement d'épaves, de dispositifs de concentration du poisson (DCP) dérivants ou ancrés et d'animaux marins (principalement de rorquals de Rudolphi et, parfois, de petits rorquals et de requins baleines). La pêche à la senne porte également sur des thonidés évoluant à proximité d'entités océanographiques ou géographiques telles que des courants et des monts sous-marins, ainsi que sur des mattes non associées. Les calées sur des bancs de dauphins sont pour ainsi dire inexistantes dans le Pacifique occidental. Les coups de senne sur épave et sur des thonidés non associés ou associés avec des entités océanographiques ou géographiques (bancs simples) représentent en règle générale plus de 90 pour cent des calées effectuées en un trimestre. Seules les flottilles des Philippines et des Iles Salomon pêchent couramment sur DCP. La majorité des coups de filet sur animaux marins sont effectués par les flottilles japonaise et coréenne, mais représentent moins de 5 pour cent de l'ensemble des calées.

Les prises les plus abondantes de bonites par coup de senne proviennent généralement de calées effectuées sur des épaves et sur des bancs simples, alors que dans le cas des thons jaunes, elle proviennent de coups de filet effectués sur des DCP ancrés et des animaux. Les bancs simples et ceux qui sont associés à des animaux fournissent en général des prises homogènes de bonites ou de thons jaunes, alors que ceux qui sont associés à des épaves et des DCP produisent habituellement des captures mixtes. Les données d'échantillonnage indiquent que de 5 à 16 pour cent des "thons jaunes" (selon le poids) pris trimestriellement par les senneurs américains sur épave sont en fait des thons obèses. Par contre, ce pourcentage est inférieur à 2 pour cent dans les calées effectuées sur des bancs simples.

L'information sur les prises accessoires est maigre. Il est notoire que les prises accessoires sont plus importantes dans les coups de senne effectués sur épave et sur DCP que sur des bancs simples et des animaux. Les espèces qui se retrouvent le plus communément sont les coureurs arc-en-ciel, les mahi mahi, les balistes du large et les requins à peau soyeuse. Des marlins bleus sont souvent pris en petit nombre dans des calées sur épave.

Un échantillonnage des prises de senneurs américains indique que des thons jaunes de grande taille (>80 cm) sont pêchés régulièrement dans des calées sur banc simple, mais moins souvent dans des coups de senne sur épave. Les bonites de grande taille (>60 cm) sont également plus répandues dans les calées effectuées sur des bancs simples que sur des épaves. Les thons obèses de bonne taille (>80 cm) sont bien moins fréquents que les grands thons jaunes et sont pris plus souvent dans des coups de senne sur épave que dans des calées sur banc simple. Les données d'échantillonnage du projet régional de marquage des thonidés indiquent que des bonites, des thons jaunes et des thons obèses de très petite taille (>40 cm) se rassemblent souvent sous des épaves et des DCP. Ces petits poissons sont probablement pris également puis jetés par les senneurs et ne figurent donc pas dans les échantillons des prises commerciales.

Les coups de senne sur banc simple et sur épave semblent être concentrés sur deux bandes horizontales situées entre 2°N et 2°S et entre 3° et 6°N, ce qui correspond au courant équatorial (CE) dans le premier cas et au contre-courant équatorial Nord (CCEN) dans le second. La fréquence des calées sur épave semble augmenter au fur et à mesure que le CCEN portant à l'est se renforce. Les épaves et les thonidés associés sont également entraînés par les courants de mousson saisonniers au nord de la Papouasie-Nouvelle-Guinée et de l'Indonésie, qui portent à l'est pendant la première moitié de l'année et à l'ouest pendant la seconde.

La taille des concentrations de thonidés évoluant à proximité d'épaves s'accroît vers l'est; cela peut s'expliquer par l'âge des épaves et leur rareté relative dans cette région. Les coups de senne sur animaux marins (principalement sur des baleines vivantes) sont plus fréquents au nord de la Papouasie-Nouvelle-Guinée pendant les premier et quatrième trimestres de l'année. Cette association est peut-être provoquée par la présence d'une proie commune, l'anchois du large.

La majorité des calées sur épave et sur DCP sont effectuées juste avant l'aube, parfois au crépuscule. Les coups de senne sur banc simple et sur animaux marins se produisent en majorité en plein jour. Les calées sur banc simple et sur épave présentent peu de variations saisonnières dans l'ensemble; par contre, les coups de senne sur DCP sont plus communs lors des troisième et quatrième trimestres, alors que les calées sur animaux marins se produisent principalement pendant le premier trimestre. La tendance à long terme qui se dégage indique une augmentation des coups de senne sur bancs simples, observée plus particulièrement avec les flottilles américaines et coréennes. Les prises de bonites et de thons jaunes par coup de senne sur DCP et sur animaux marins présentent des variations dans le temps, mais les prises par coup de senne sur épave ont été plus stables, dans le cas du thon jaune en particulier. Les prises de bonites et de thons jaunes par calée sur banc simple présentent des caractéristiques cycliques opposées, qui sont peut-être reliées au phénomène El Niño dans le Pacifique occidental.

Les concentrations de thonidés évoluant à proximité d'épaves dépassent parfois 300 tonnes, mais sont souvent inférieures à 50 tonnes. On pêche souvent des mattes non associées de taille semblable. Les DCP exploités fréquemment présentent probablement des concentrations plus faibles, parce que le temps qui s'écoule entre les coups de senne successifs limite le recrutement. Les thons marqués peuvent se disperser rapidement ou continuer à évoluer autour des épaves plusieurs jours après leur marquage. Des déplacements importants peuvent se produire lorsque les thonidés évoluent avec des épaves qui dérivent avec le courant. La distorsion de la distribution spatiale des thonidés et les difficultés que comporte l'attribution d'une valeur quantitative à l'effort de pêche sur épave ou DCP sont deux problèmes qui se présentent lors de l'évaluation des méthodes de pêche qui exploitent l'association de thonidés à des objets flottants. Il convient d'élaborer des modèles mathématiques qui prennent en compte la dynamique de l'attraction exercée par les objets flottants sur les thonidés.

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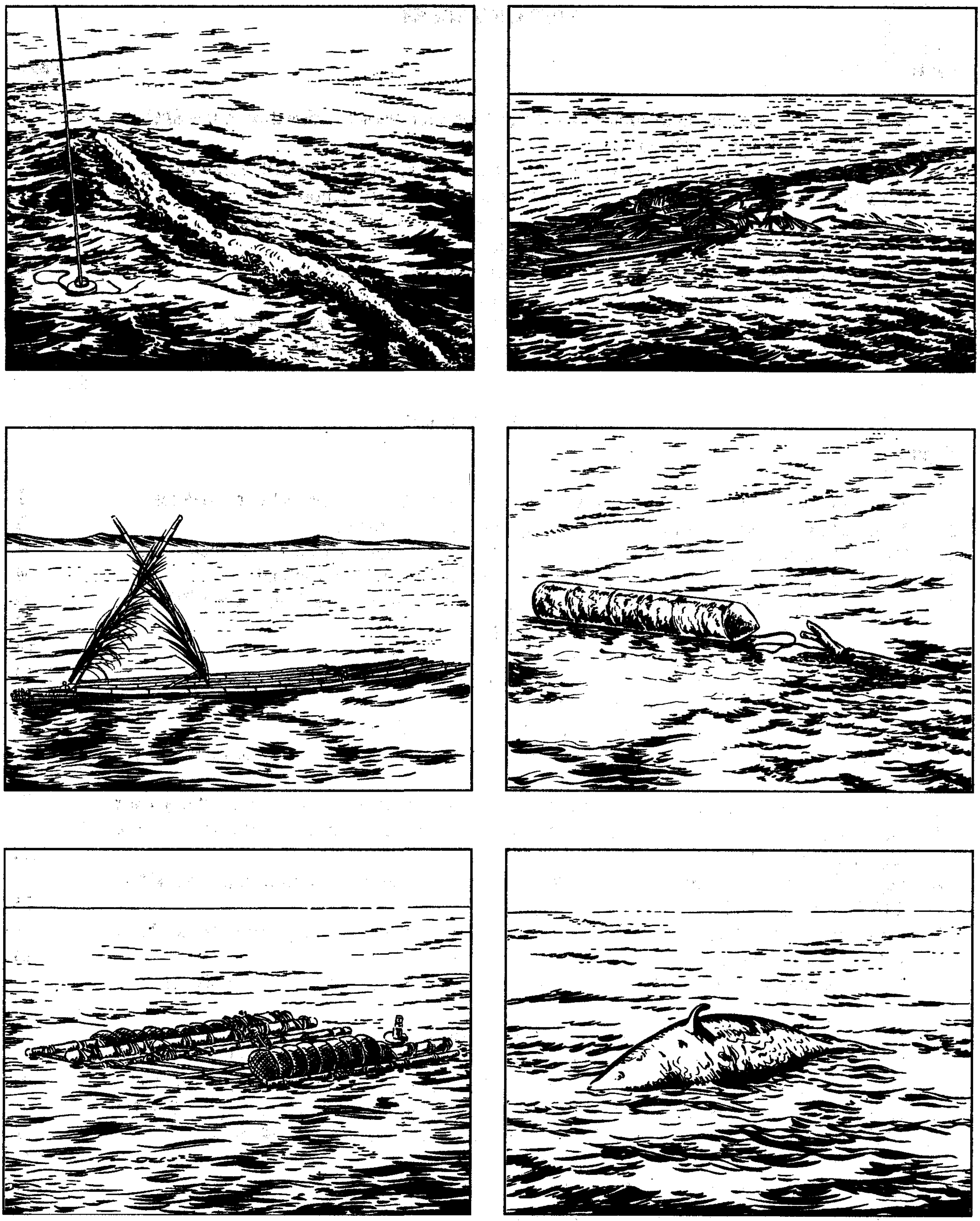


Floating objects in the western Pacific Ocean that attract and aggregate schools of tuna: 'log' with radio buoy for tracking (top left), current line of logs and debris (top right), anchored bamboo FAD (middle left), drifting Philippine drum FAD with log attached to enhance aggregation (middle right), Japanese drifting FAD of bamboo and plastic floats (bottom left), dead sperm whale (bottom right). (Illustrations by Jipé Le Bars)

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 South-east 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 purse 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 in logbook or cannery records. These fisheries are concentrated in tropical waters, although seasonal catches are made in waters adjacent to Japan, south-eastern 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. 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 1991, 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 1970s, 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 1990s with the further 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 on 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 shown in Figure 1.

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

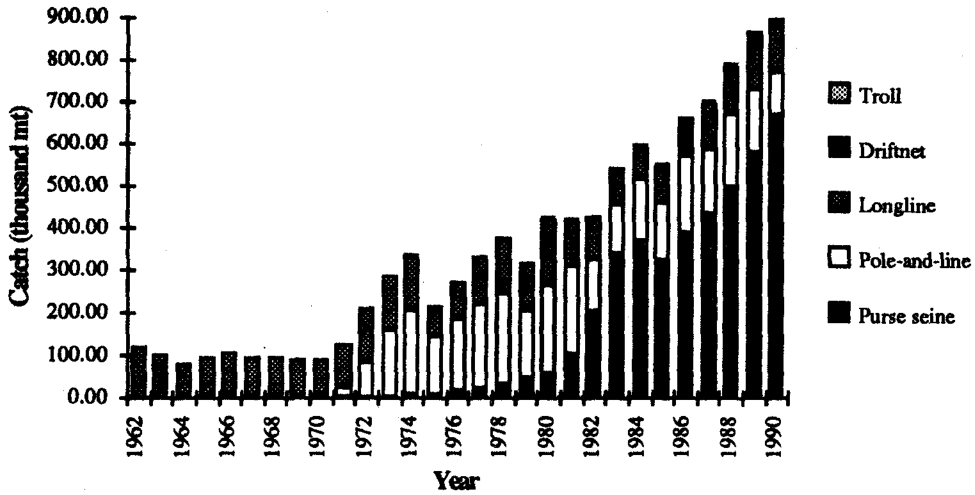
1.2 Scope and purpose of review

The purpose of this review paper is to provide information on tuna attraction to floating objects in the WPO and the influence of this behaviour on the fisheries in that region. The main fisheries influenced by tuna attraction to floating objects are the purse 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 Solomon Islands and Fiji, pole-and-line vessels fish regularly in the vicinity of FADs. The Japanese distant-water pole-and-line fleet also fishes tuna associated with floating objects. However, data available from these fleets are not sufficiently detailed for analysis. This review therefore concentrates on 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 fisheries scientists Bailey and 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 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.

(a) Total catch by gear



(b) Total catch by species

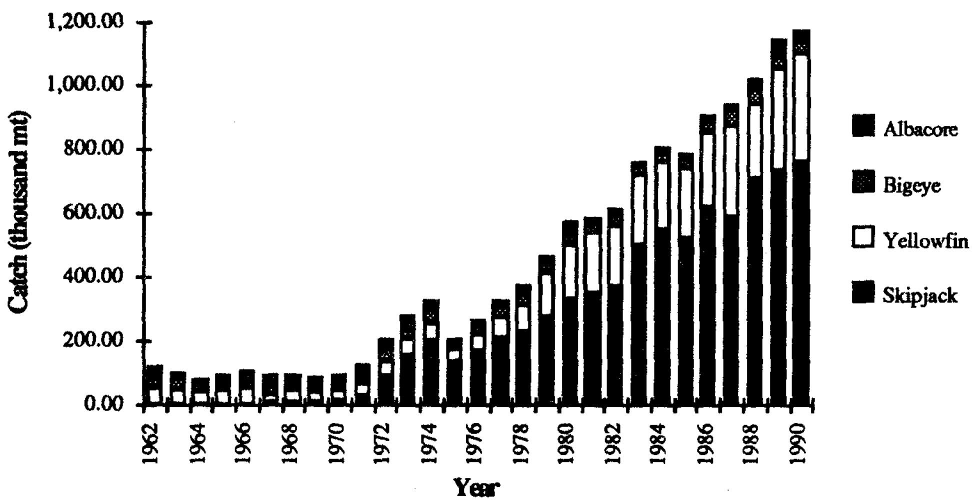


Figure 1. Tuna catch trends (a) in the Pacific Islands area (excluding the Philippines and Indonesia) by gear type and (b) in the WPO (including the Philippines and Indonesia) by species

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 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. 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 per cent of all sets, school sets about 15–45 per cent, and animal sets about 1–10 per cent per quarter. More details of set characteristics are given in Section 3.

By 1980, purse seine vessels from the United States, Korea and Taiwan had joined the WPO fishery. Korean and Taiwanese vessels were similar to Japanese single seiners and concentrated on log sets. US seiners were mostly in the super-seiner class, up to 2,000 GRT, and concentrated on log and free-swimming school fishing. 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 Russian, 32 Taiwanese and 43 Unites States (Lawson 1991). The trend in vessel numbers is shown in Figure 2 (a). The total purse seine catch shows a similar trend to vessel numbers (Figure 2(b)) and had reached nearly 700,000 mt by 1990. Indications are that vessel numbers and total catch will continue to increase in coming years.

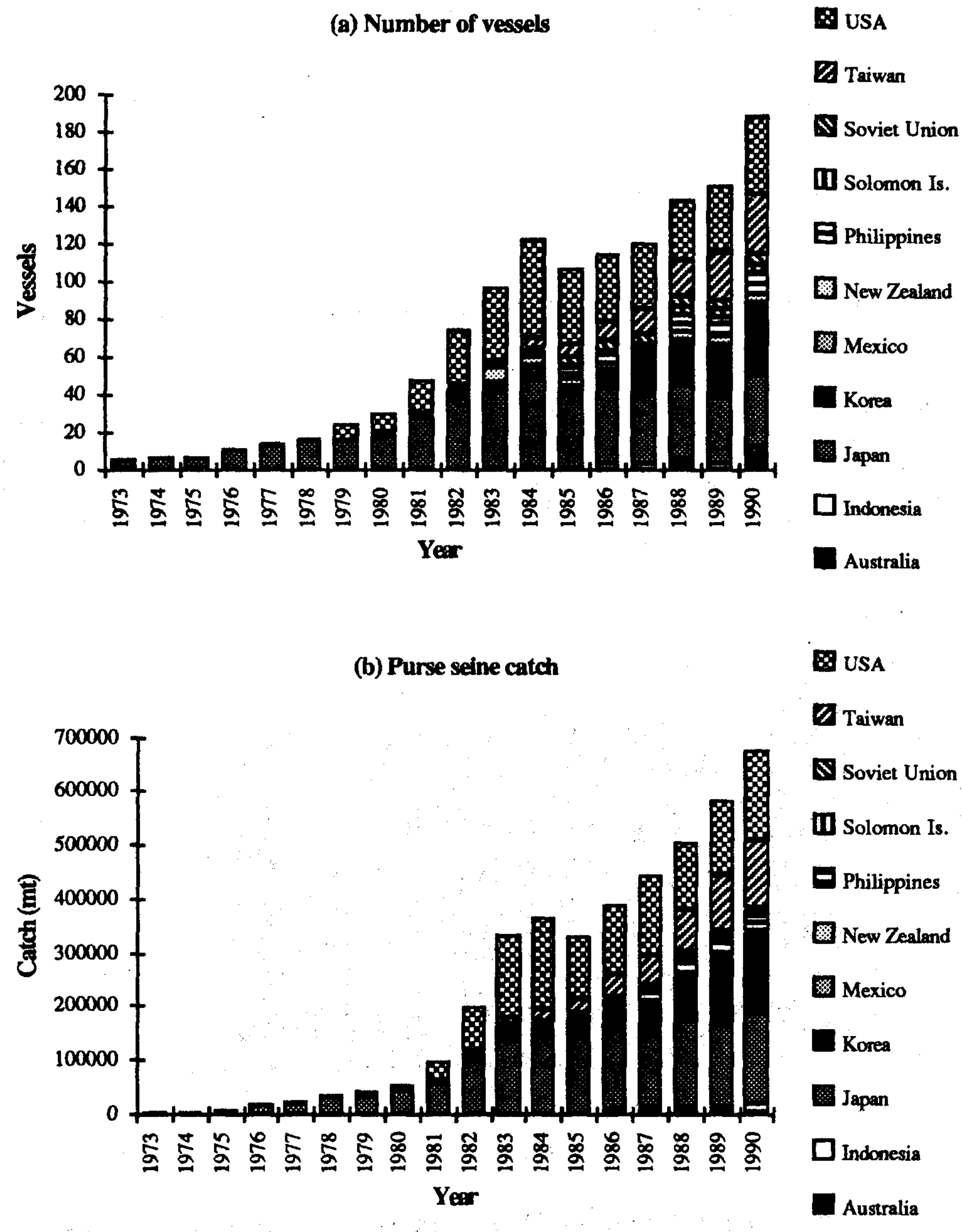


Figure 2. Time series of vessel numbers and total catch by vessel nationality

The fishery now extends approximately from 10°N to 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 SPC, is shown in Figure 3.

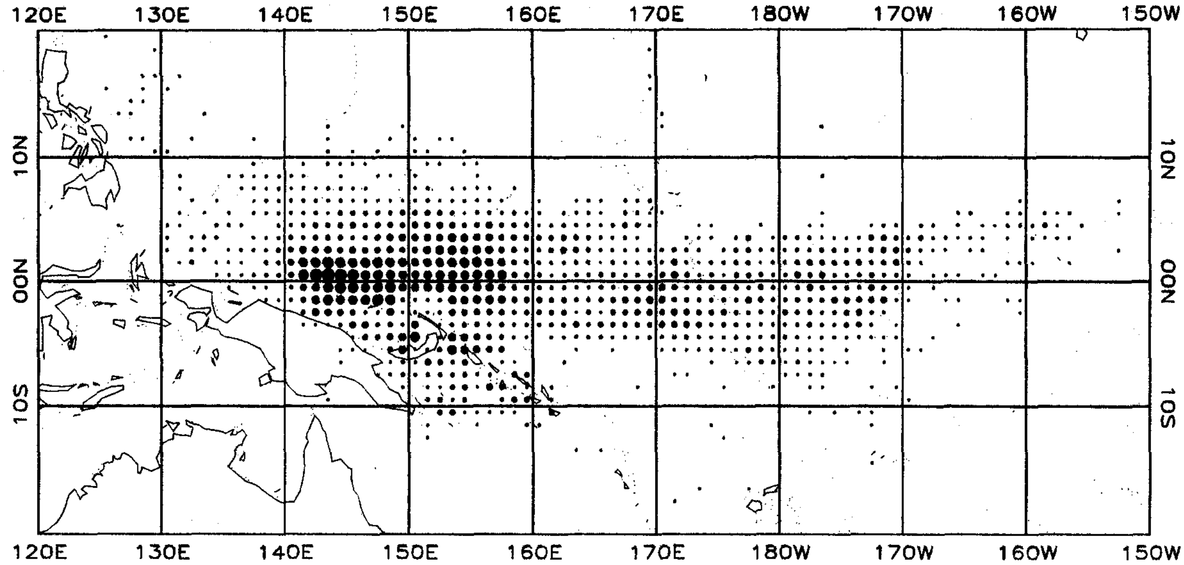


Figure 3. Distribution of purse seine effort in 1990, as indicated by logbook data submitted to SPC

The WPO purse seine fishery targets both skipjack and yellowfin tunas. The percentage of skipjack has varied annually between 60 and 85 per cent (Figure 4). Bigeye is usually recorded as yellowfin in purse seine logbooks, which means that there are no reliable separate catch statistics for these two species. References in this paper to yellowfin catches based on logbook records actually refer to the combined catch of yellowfin and bigeye, unless otherwise indicated.

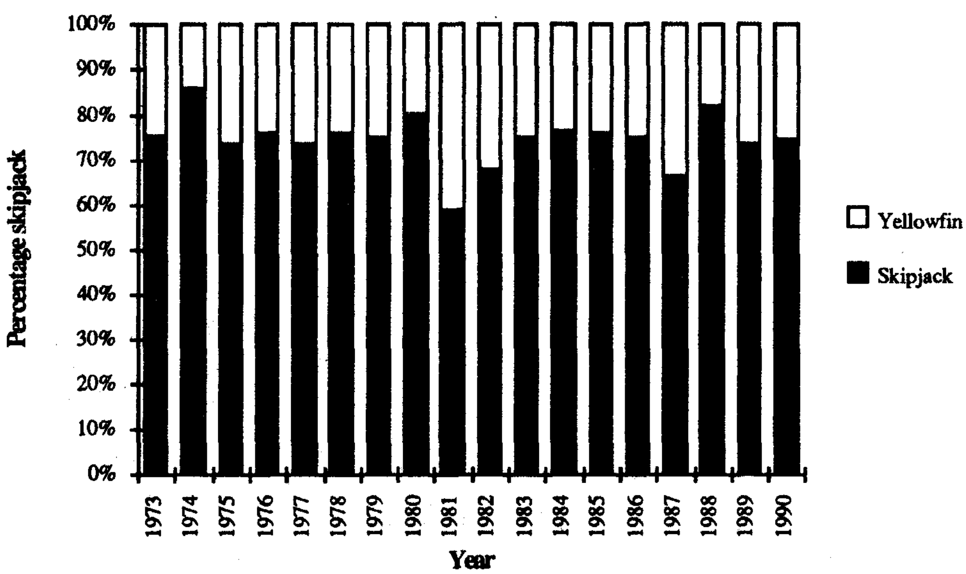


Figure 4. Species composition of the WPO purse seine catch as recorded in logbooks

The size of tuna caught varies in time and space, with some evidence that skipjack and yellowfin increase in 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

3.1 Types of association

Purse seiners in the WPO 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. Sets on schools of this type are collectively termed school sets, and are referred to in this paper as an association category, even though in many cases they are 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 (feeding, shelter, orientation) they contribute to 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 overboard from ships (drums, cable spools, canoes and boats, polystyrene floats, containers, and even funeral rafts). Logs, however, are the most common.

Although logs come in various shapes and sizes, a number of interrelated attributes make them effective for aggregating tuna and other fish. In the experience of Bailey (1985), these include minimum size, area under water, time at sea and 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 between logs. A small log will probably not hold a large volume of fish when other, larger logs are only a few kilometres away, but has been known to hold more than 100 mt of tuna if it is the only floating object within 50 nmi (about 90 km). Generally, 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 two-week period of consecutive-day seining in 1982 (K. Bailey pers. obs.).

Also related to size is the area under water, 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. 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; few fish are usually associated them. 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 enhances fish aggregation, but 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 among 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 central 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 deployed later 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 daylight hours, 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 they are within the fishing depth of the seine and are unaware of the activity going on around them because of the dark. After dawn, the school usually stays close to the log for two to three hours, possibly feeding, and is still 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 beacons and stand off until the following morning for what is considered a guaranteed catch, rather than attempting daylight sets that are often unsuccessful.

There is some evidence of vertical stratification of tuna under logs, with skipjack in the upper 10–20 m, yellowfin further below, and bigeye down to 100 m. Bigeye form the strongest association, as schools of them are apparent underneath logs throughout the day and night. Seiners 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 found in the middle. This has implications for the sampling of catches from the holds of seiners, particularly in the determination of species composition from log sets.

3.1.2 FAD associations

The effect of FADs in the WPO resembles that of logs in terms of fish aggregation, tuna behaviour in their vicinity (compared with tuna behaviour around FADs close to shore, e.g. Holland et al. 1990), and the general strategies used by seiners to set on them. Two basic types of FAD association are recognised: the first involving FADs that are anchored, usually within a network of similar units 5–10 nmi apart, and are disconnected from their mooring lines only during the set, and the second involving FADs that have broken loose from their mooring lines and drifted away or have been deliberately deployed without moorings. The Japanese include associations with logs and debris that have been roped together, as described in the preceding section, in the second category (Tanaka 1989). They are also known to anchor FADs near islands and release them to drift after a suitable 'ageing' period has resulted in the accumulation of encrusting life and a population of reef fish (D.G. Itano, pers. comm.).

FAD types 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 are deployed with underwater appendages such as coconut fronds, netting or plastic streamers, to enhance aggregation. Before the purse seine net is set, the raft and/or appendages are disconnected and towed away from the mooring line, with the tuna and bait following. At the end of the set, the raft and appendages are reconnected to the mooring.

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 to come together only 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.

Dead whale associations, which are rarely encountered, are similar to log associations, with attendant schools of bait fish that help to attract and concentrate tuna. Dead whales 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 whale and log associations in that the shark and tuna come together to feed on anchovy but stay together 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 them in the dark.

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, of which 61 were of the preferred three species, over a period of 772 searching/fishing days (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 1,794 tuna schools sighted and fished by the SPC tagging vessel in the WPO (excluding Indonesia and the Philippines) in 1990 and 1991 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 264 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 these associations involved either skipjack or mixed schools of skipjack and small yellowfin rather than the large yellowfin typical of the eastern Pacific association.

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 yellowfin–dolphin association (e.g. shallow thermocline, abundance of ommastrephid squid) are not usually present in the WPO.

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.

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 breeze blowing across the sea to stationary 'boilers' and 'foamers' that churn the surface into a white froth while feeding on ocean anchovy and other bait. The latter types 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 behaviour 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 the net can be pursed in less than 15 minutes.

Sub-surface 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 sub-surface schools visible at night as they pass through areas of phosphorising plankton. These schools appear to be extremely rare in the WPO; no records exist in the purse seine literature of their occurrence.

Geographic/oceanographic associations involve schools that aggregate near submerged reefs, banks and seamounts, emergent 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 association fished in the WPO vary 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 Figure 5) and log fish (65%), with much smaller numbers of sets on tuna associated with FADs (1%) and animals (3%). The US fleet, particularly in the last few years, has concentrated mostly on school fish (75%), with smaller numbers of log sets (24%). The Korean fleet fishes both school (39%) and log fish (55%), but the Taiwanese fleet targets almost exclusively on log fish (94%). The Philippine fleet fishes tuna associated with either drifting (49%) or anchored (26%) FADs, in addition to log fish (24%).

Table 1: Percentages by association of total sets recorded for each vessel nationality in the SPC Regional Tuna Fisheries Database

Vessel nationality	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	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	0	3.07
New Zealand	0	0	100.00	0	0
Philippines	0.71	24.25	49.20	25.80	0.04
Solomon Islands	0.84	2.32	0	96.83	0
Soviet Union	95.33	4.46	0	0	0.20
Taiwan	4.77	93.86	0.90	0.20	0.27
United States	75.32	24.39	0.17	0	0.12
All vessels	37.66	54.12	3.45	2.90	1.88

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 were on FADs that had 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 had been unhooked for setting (G. Preston pers. comm.)

The historical changes in set preference shown in Figure 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. This 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 made it possible to fish 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-1980s, 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 modernisation programme, with state-of-the-art US-built super seiners slowly replacing the 10- to 20-year-old ex-US seiners the fleet used first. 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; the vessels and gear are only suitable for fishing on floating objects. There is no indication that this fleet will, or needs to, modernise for school fishing.

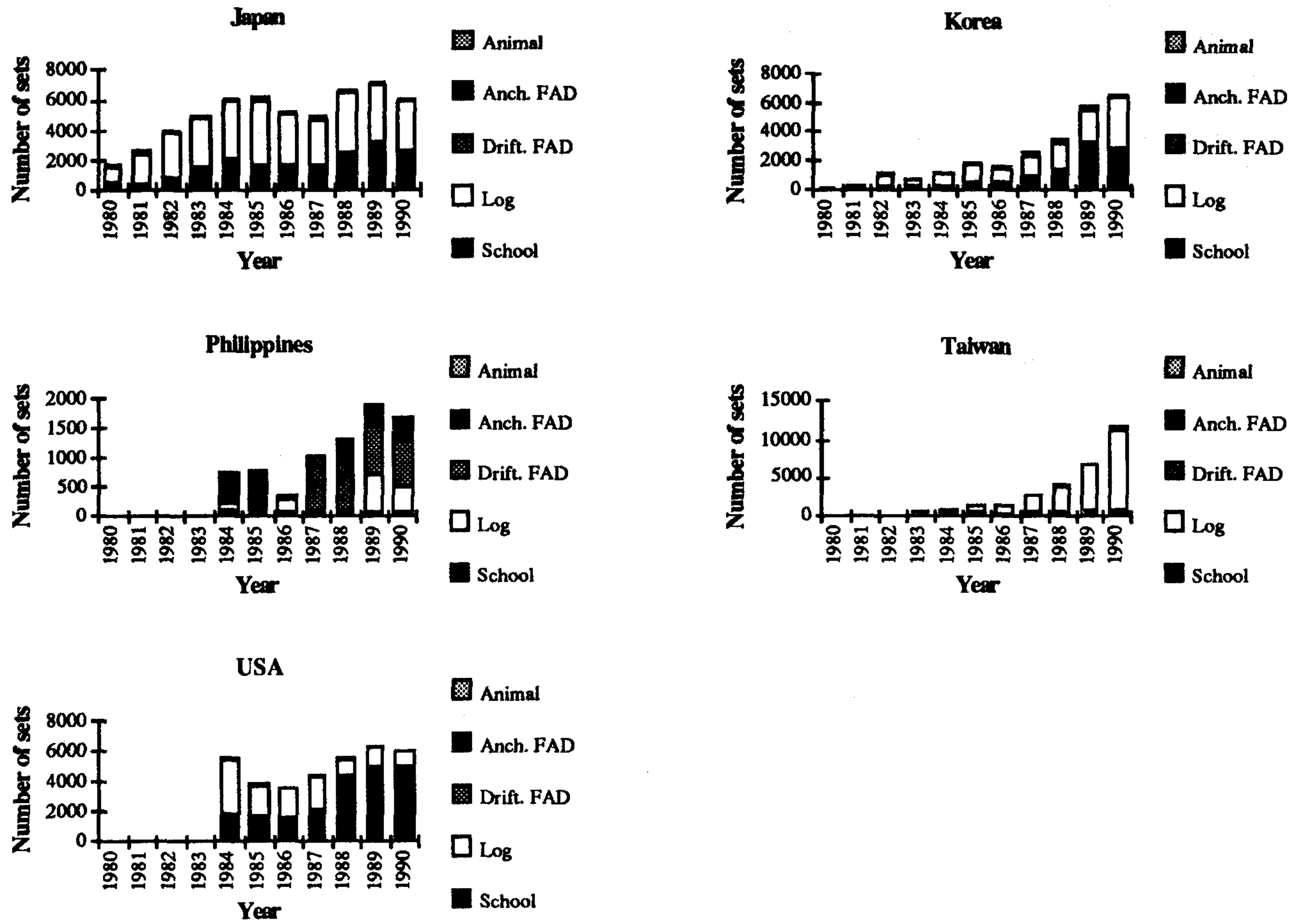


Figure 5. Total estimated sets, by school association, for selected purse seine fleets of the WPO

For the purse seine fleet as a whole, school fish (38% of all sets) and log fish (54%) are the most common associations fished (Table 1), generally comprising more than 90 per cent of all purse seine sets in any quarter-year (Figure 6). Sets on tuna associated with animals and FADs are significant in some quarters, but generally form only about two and six per cent respectively of the total.

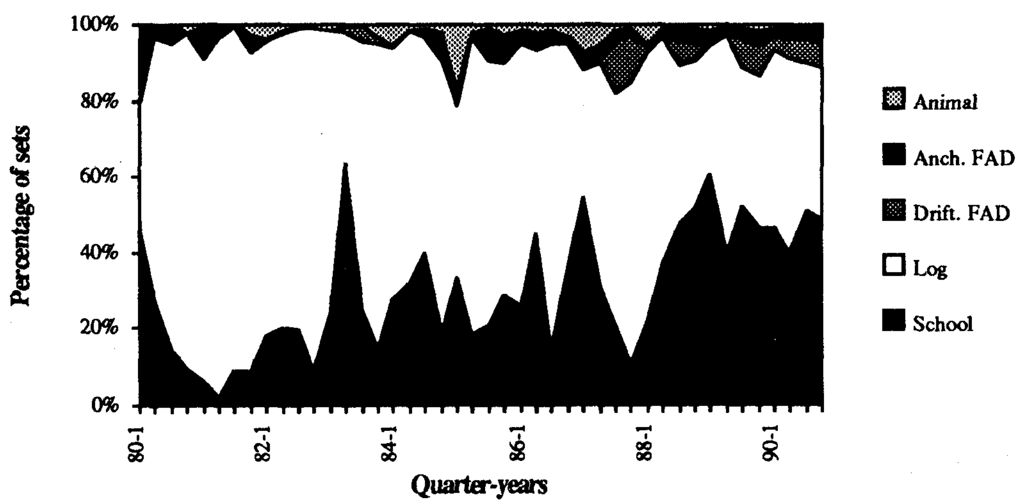


Figure 6. Relative number of sets, by association, on a quarterly basis

3.3 Total catch

The proportions of estimated total catches of skipjack and yellowfin attributable to sets on different tuna associations are shown in Figure 7. Most of the catches of both species are taken from sets on log fish and school fish. 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.

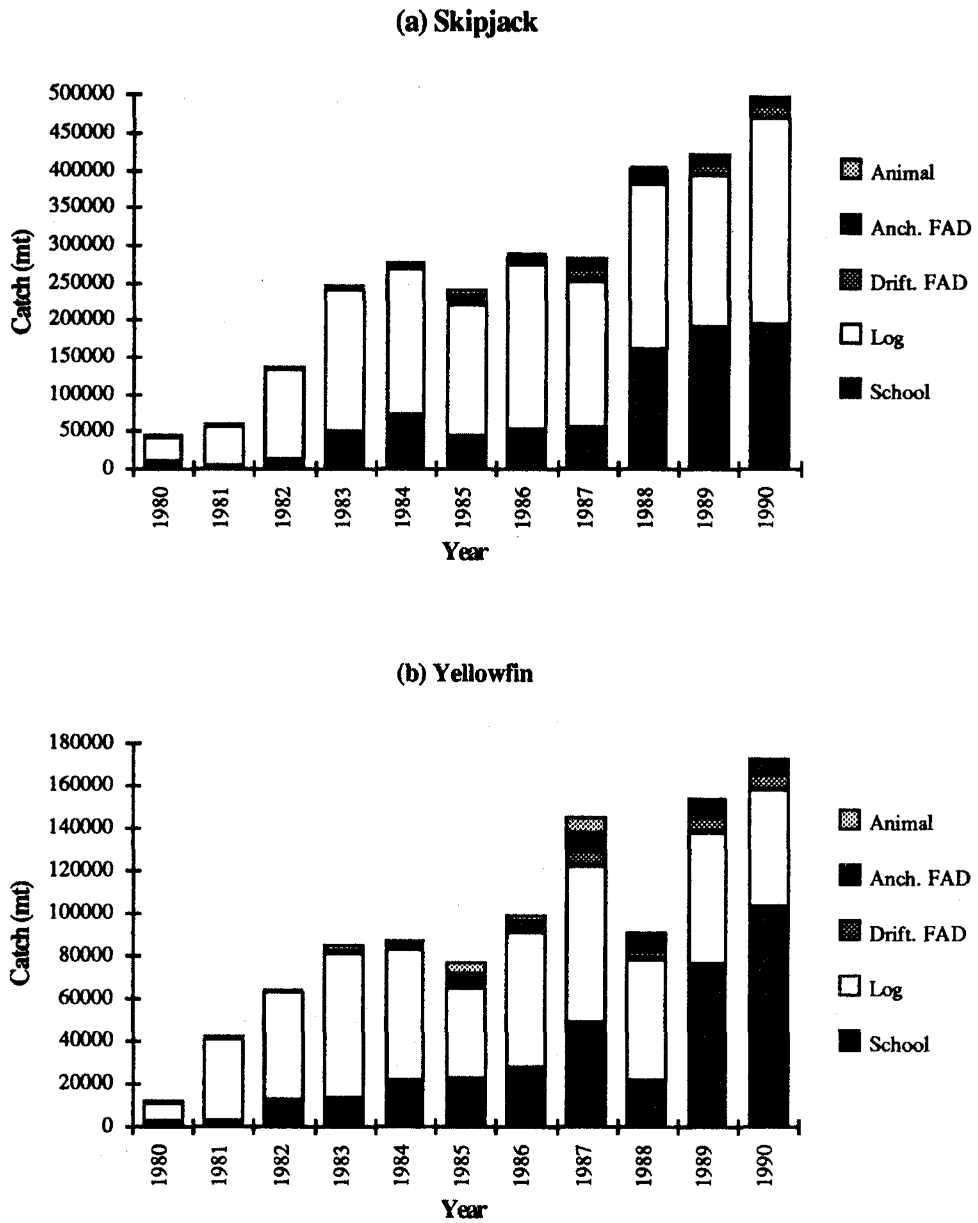


Figure 7. Estimated total skipjack and yellowfin catches by association

3.4 Catch per set

There is substantial variation in catch per set among school associations and vessel nationalities (Table 2). The highest total catches per set by Japan and Korea came from drifting FADs, although these are a very small percentage of their total sets (Table 1). The US fleets total catch per set from drifting FADs is high, but slightly lower than the rate for log sets. The highest total catch per set by the Taiwanese fleet is from animal sets, although these sets are very infrequent. It is interesting to note that, for the four main fleets

(Japan, Korea, Taiwan and US), sets on drifting FADs (which comprise less than one per cent of total sets in each case) perform better than log sets. However, the Philippine fleet, which sets mainly on logs and FADs, obtains a higher total catch rate from logs than from drifting FADs.

Table 2: Skipjack, yellowfin and total catch per set (mt) for all sets recorded in the SPC Regional Tuna Fisheries Database, by vessel nationality and school 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	0	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	-	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	8.28
	Total	21.39	20.16	38.00	3.67	17.92
Mexico	Skipjack	17.09	11.04	-	-	0
	Yellowfin	0.44	10.17	-	-	0
	Total	17.53	21.21	-	-	0
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
	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
All vessels	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

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; K. Bailey pers. obs.).

Histograms of set success for all vessel nationalities combined (Figure 8) provide additional information on the nature of the various tuna associations. In terms of total catch, 50 per cent of all sets on school fish are unsuccessful, i.e. they result in catches of less than 1 mt. In contrast, less than 10 per cent 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 per cent of sets being unsuccessful. This suggests that most animal sets involve live whales.

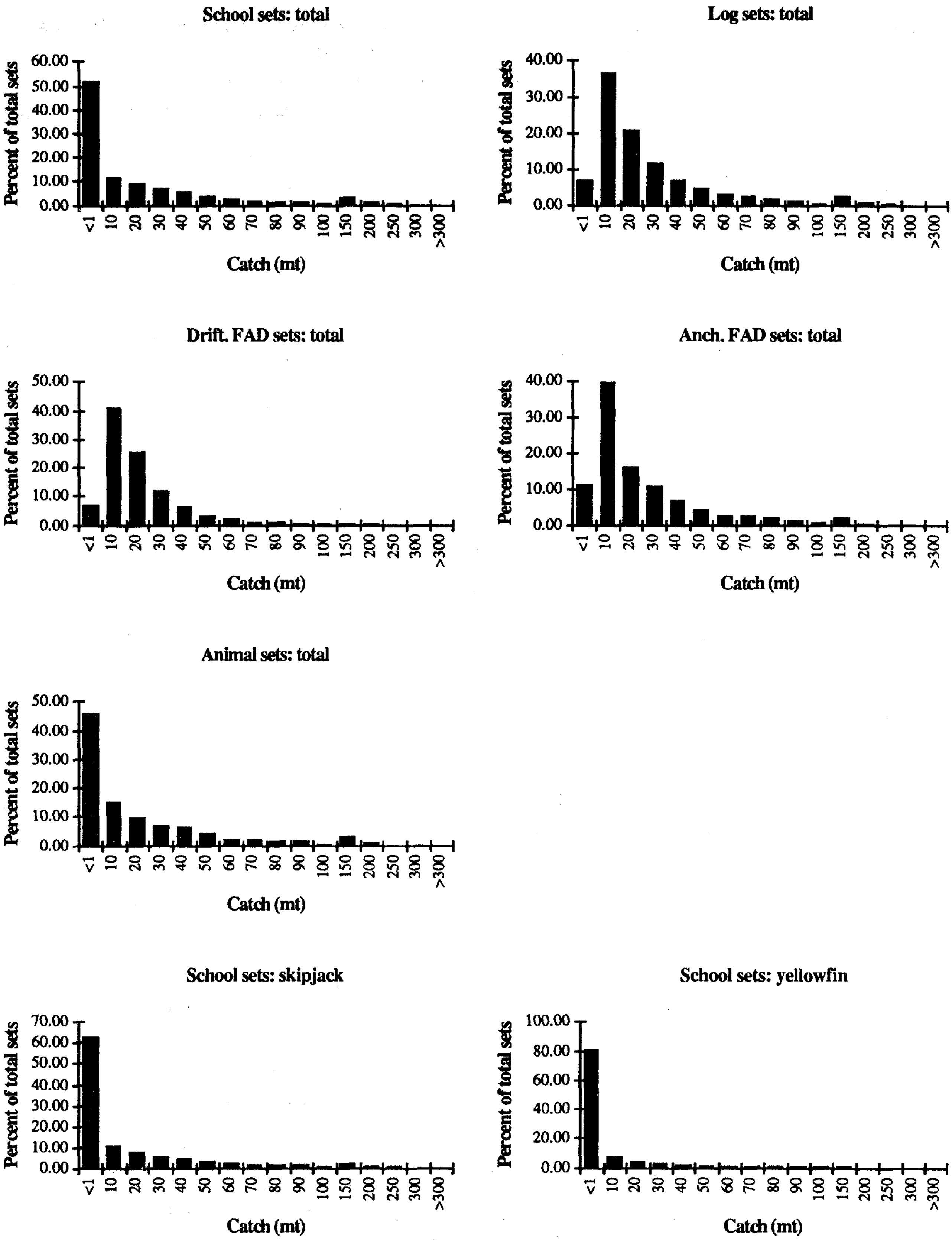


Figure 8. Set success histograms for the WPO purse seine fishery

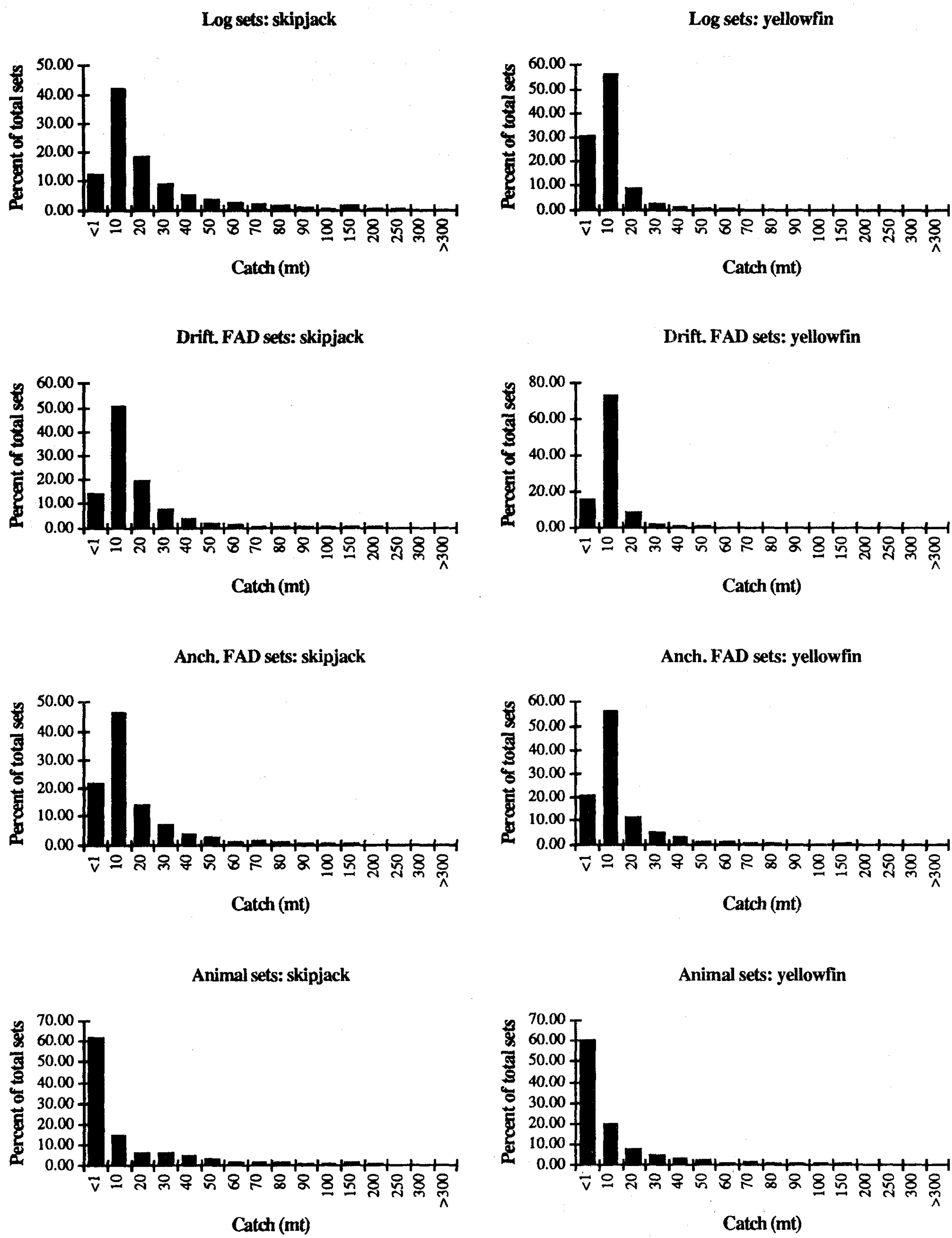


Figure 8. Set success histograms for the WPO purse seine fishery (continued)

Some differences between the success rates for skipjack and yellowfin are apparent in Figure 8. The percentage of school sets that result in catches of less than 1 mt is greater for yellowfin (80%) than for skipjack (60%), suggesting that either pure skipjack schools are fished more often than pure yellowfin schools or pure yellowfin schools are less vulnerable to purse seine gear. Similarly, 30 per cent of log sets result in less than 1 mt of yellowfin, whereas only 12 per cent 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 have similar patterns of set success for skipjack and yellowfin. However, in all associations (apart from school) the percentages of sets yielding 1–10 mt are higher for yellowfin than for skipjack.

Time series of skipjack and yellowfin catch per set for all vessel nationalities combined are shown in Figure 9. No distinct trends are evident in any of the time series.

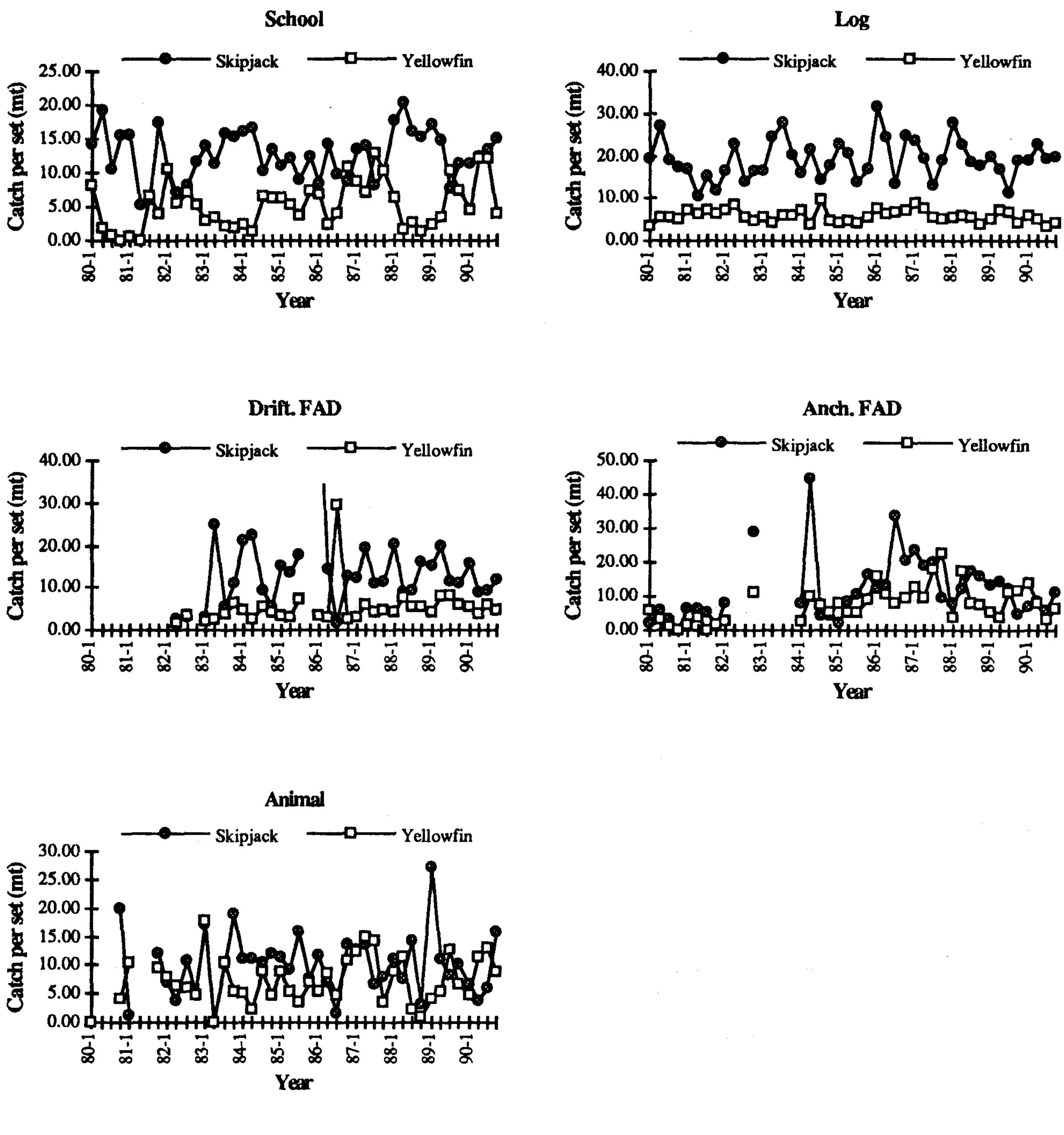


Figure 9. Average catch per set, by association and year

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 (Figure 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.

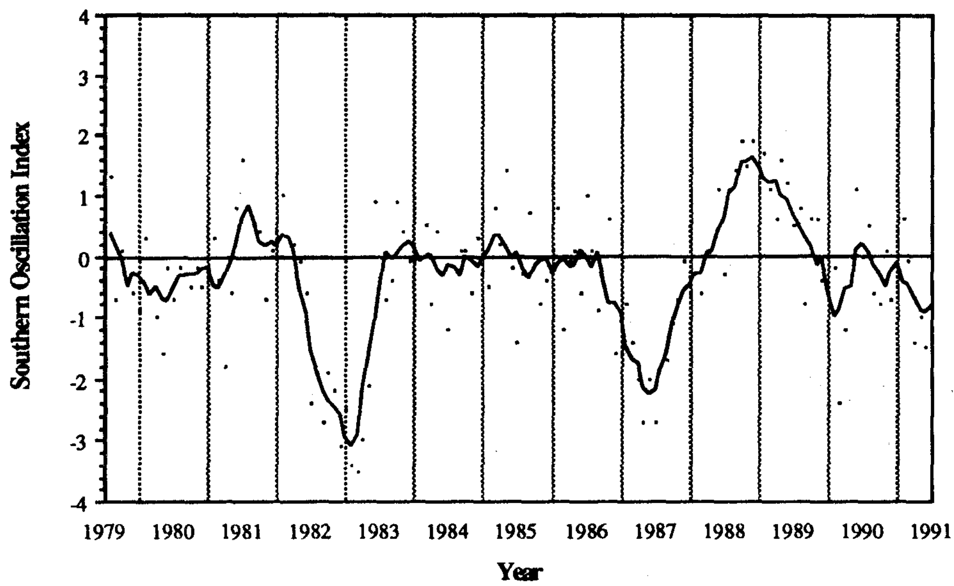


Figure 10. Southern Oscillation Index in the tropical WPO, 1980–1990. Dot points are actual index values and the line indicates the indices smoothed by a 5-month running average. Periods of positive indices represent La Niña events, and periods of negative indices represent El Niño events.

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 occurrence of skipjack in purse seine sets (based on weight) show very different patterns for the different school associations (Figure 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 per cent of log sets yield pure skipjack, but only 6 per cent yield pure yellowfin (bigeye). Skipjack is generally the dominant species in log sets, with 84 per cent of sets containing more than 50 per cent skipjack. Both categories of FAD set show higher frequencies of mixed schools.

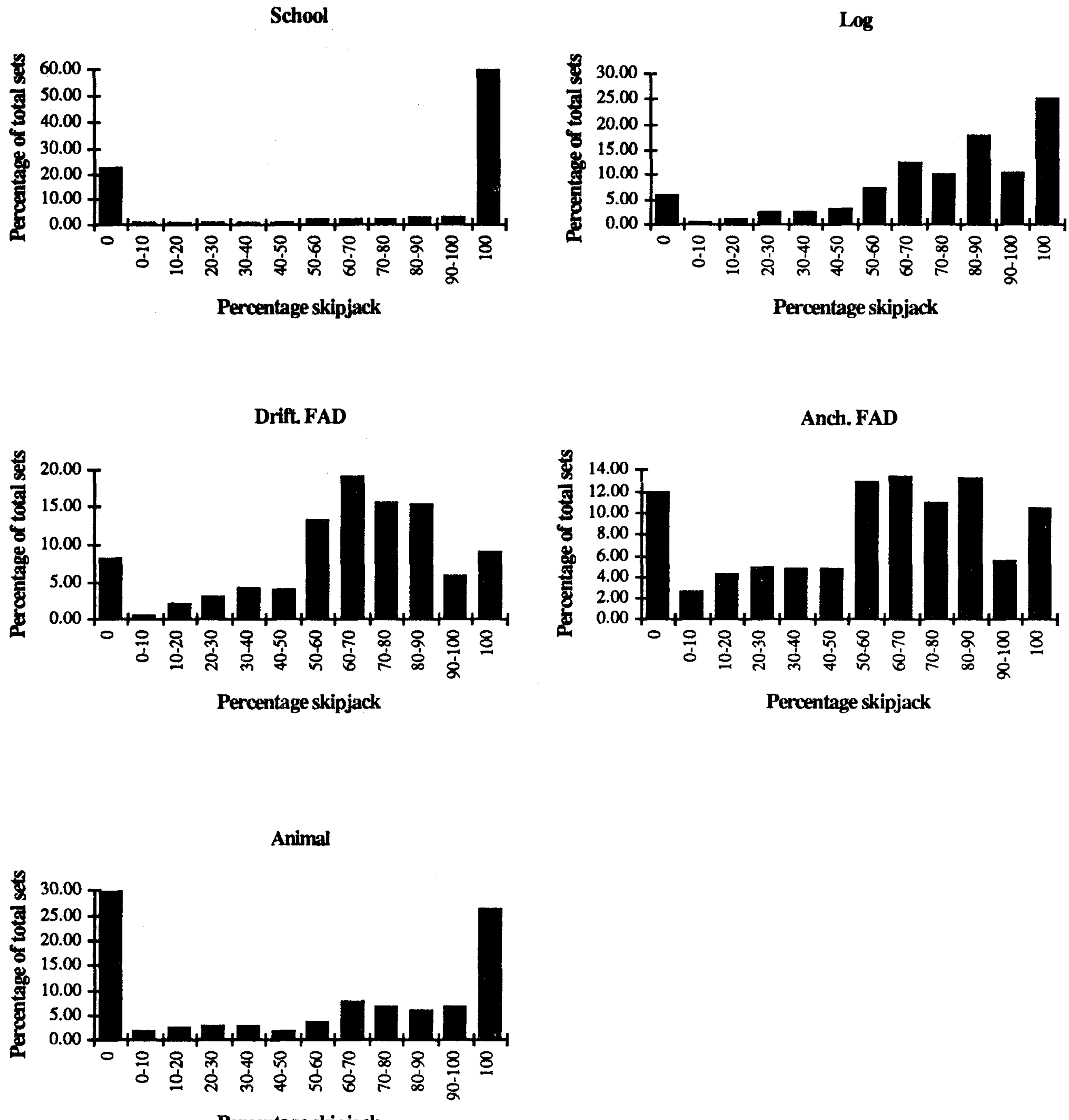


Figure 11. Frequency distributions of the percentage occurrence of skipjack in purse seine sets, by association. Occurrence is based on the percentage weight of skipjack caught in each set.

Time series plots of the percentage occurrence of skipjack in purse seine sets show no overall trends but substantial temporal variability (Figure 12). The exception to this is log sets, which have shown a remarkably constant species composition over time. The variation in percentage of skipjack in school sets reflects the catch-per-set time series in Figure 9.

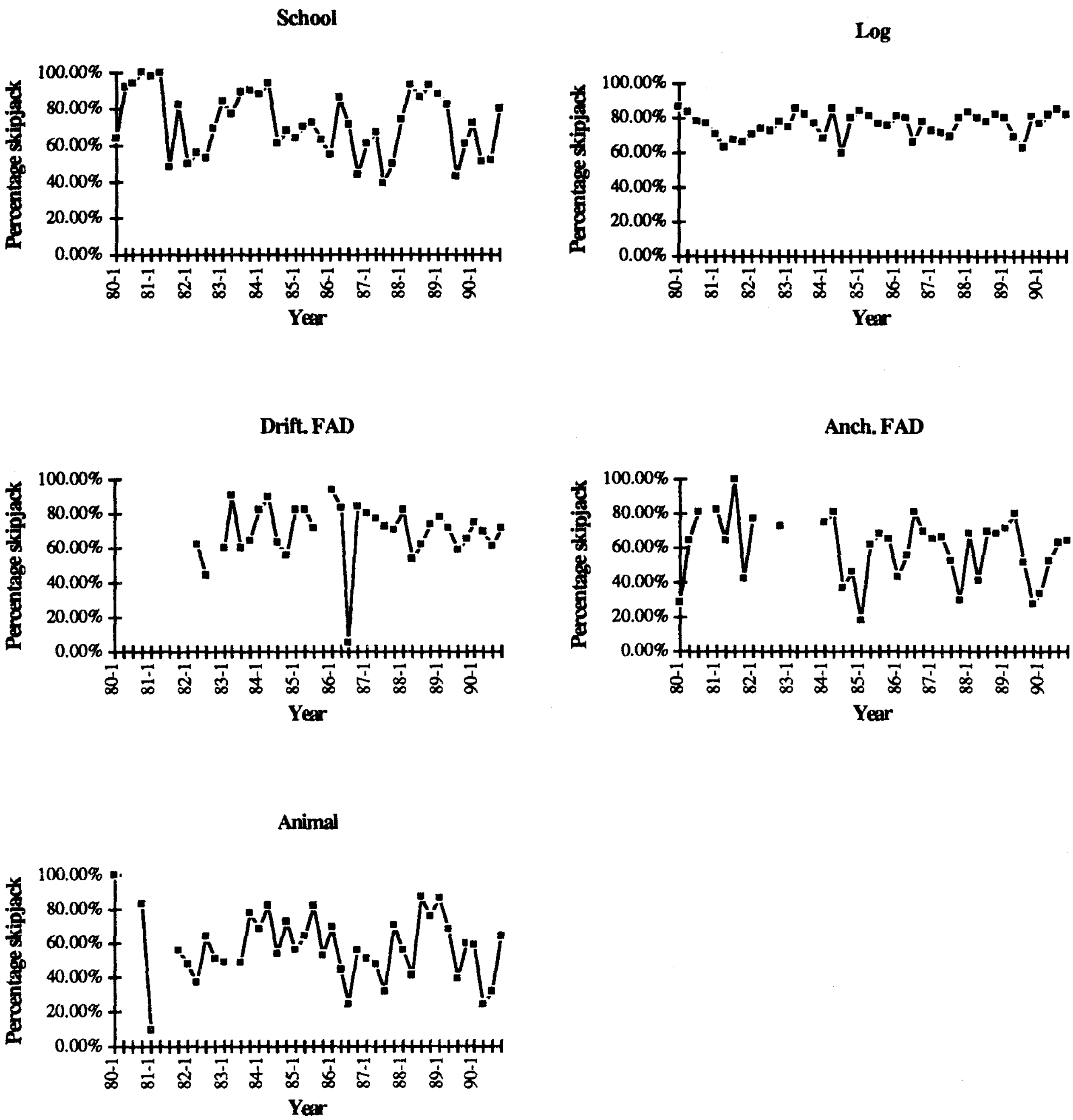


Figure 12. Percentage occurrence of skipjack in purse seine sets, by association, on a quarterly basis

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 programmes. Tanaka (1989) presents statistics indicating that bigeye comprised 1–4 per cent (by weight) of the total Japanese purse seine catch between 1976 and 1985. These data suggest that 3–15 per cent 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 1–28 per cent of the quarterly yellowfin catch from log sets in terms of weight, but are usually within the 5–16 per cent range. In comparison, the bigeye percentage from school sets is much less, ranging between 0.1 per cent and 1.3 per cent of the yellowfin catch.

Table 3: Species composition of US purse seine catches sampled in American Samoa. The last two columns show the bigeye composition as a percentage of the yellowfin and bigeye catch (+ = < 0.1)

Year	Quarter	School type	Skipjack %No.	Skipjack %Wt	Yellowfin %No.	Yellowfin %Wt	Bigeye %No.	Bigeye %Wt	Bigeye/Big. + Yfn %No.	Bigeye/Big. + Yfn %Wt
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

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 in the literature. By-catch data held in the Regional Tuna Fisheries Database are summarised in Table 4 by fleet and school association, while Table 5 attempts to synthesise the literature and the experience of various SPC staff into a list of by-catch species and their relative abundance in the different associations.

The information in Table 4 only covers the amount of by-catch taken in 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 therefore presumably noticeable. This is apparent for school sets declaring by-catch, where four of the six fleets all have catches of over 5 mt per set from a total of 12 sets. In comparison, observer reports show that school sets quite often have by-catch, but it is usually limited to a small quantity of apex predators such as blue marlin and silky and oceanic whitetip sharks that may approach 1 mt per set (e.g. various PTDF reports; Gillett 1986a, b; Itano 1991). 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.

Table 4: Mean by-catch per set (mt) for each association type. Figures are mt per set for sets in 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	5.8	1.7	-	-	1.0
	No. by-catch sets	6	37	-	-	2
	% by-catch sets	0.2	1.1	-	-	0.6
New Zealand	By-catch/set	-	-	2.3	-	-
	No. by-catch sets	-	-	17	-	-
	% by-catch sets	-	-	13.9	-	-
Philippines	By-catch/set	0.2	4.5	1.6	1.5	-
	No. by-catch sets	2	236	13	177	-
	% by-catch sets	6.3	21.6	0.7	15.2	-
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	3.3	-	-	-
	No. by-catch sets	33	215	-	-	-
	% by-catch sets	0.2	5.0	-	-	-
Total	By-catch/set	3.2	3.5	1.9	2.8	1.0
	No. by-catch sets	47	585	32	340	2
	% by-catch sets	0.2	1.4	1.5	15.2	0.1

Log schools produce the highest overall by-catch, 3.5 mt per set from 585 sets in which a by-catch has been declared, with a range of 1.0 –4.5 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 (up to 44 species, as listed in Table 5), dominated by rainbow runners, mahimahi, ocean triggerfish, mackerel scad and silky sharks, but also the purse seine operation does not allow for 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 sac begins to deteriorate in the high temperatures. In addition, logs become less productive if the bait population that attracts the tuna is diminished or removed. 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 be successful, most sets usually end with the species listed above, which 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 (4.5 mt per set, 21.6% of log sets) may relate in part to the fact that many of these vessels retain by-catch for sale in the Philippines.

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	Animal associations: Dead whales	Animal associations: Whale sharks
Sharks and rays							
Blue shark (*Prionace glauca*)	-	R	-	-	-	-	-
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 (*M. mazara*)	S	S	S	S	-	-	-
Broadbill swordfish (*Xiphias gladius*)	-	R	-	-	-	-	-
Sailfish (*Istiophorus platypterus*)	R	R	-	-	-	-	-
Shortbill spearfish (*Tetrapturus angustirostris*)	-	-	-	R	-	-	-
Striped marlin (*T. audax*)	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 (*A. 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; K. Bailey, pers. obs.

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 1986a, b). 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 (32 sets with declared by-catch) to 2.8 mt for anchored FADs (340 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.

Two 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 to school sets, particularly the oceanic whitetip and silky sharks. Dead whale sets have the same predominant species as log and FAD sets. Information on the species taken in dead whale sets is limited, with only nine species recorded (Table 5). 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.

In both live whale and whale shark sets, the animal is usually unharmed and escapes once the net is pursed by punching a hole through the webbing or by swimming over the corkline. Small whale sharks are released from the purse seine sack immediately prior to brailing.

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 Figure 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 to 70 cm and a minor peak from 80 to 110 cm (mean = 65.8 cm). Yellowfin over 120 cm in length 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 SPC Regional Tuna Tagging Project (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 Figures 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 lanternfish feeding association that occurs seasonally in the Coral Sea. Thus, the distributions for yellowfin and bigeye are comparable with the US purse seine data for the smaller 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.

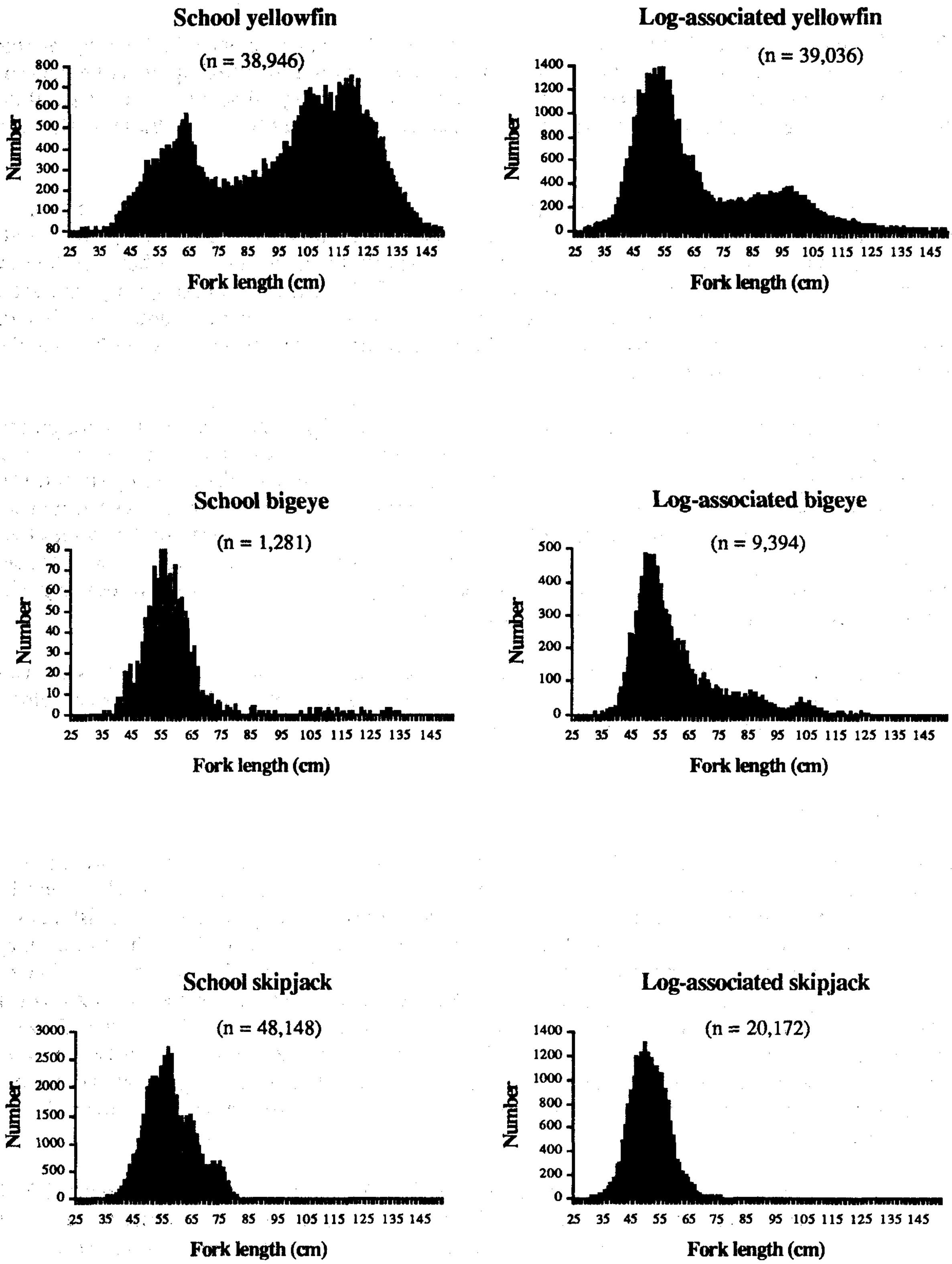


Figure 13. Size composition of yellowfin, bigeye and skipjack from school and log sets by US purse seiners, 1988–1991

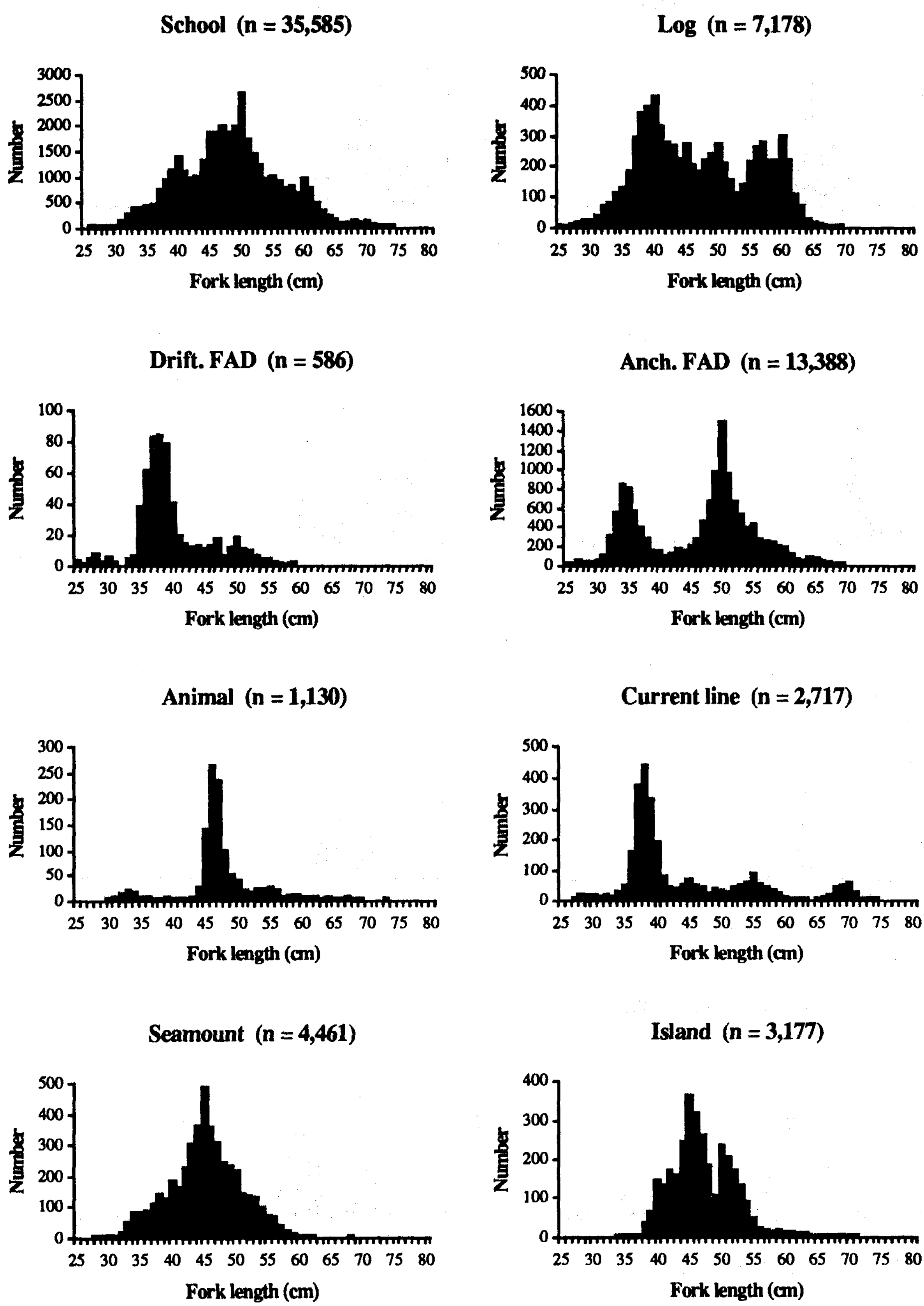


Figure 14. Size composition of skipjack from different school associations encountered by the SPC RTTP tagging vessel

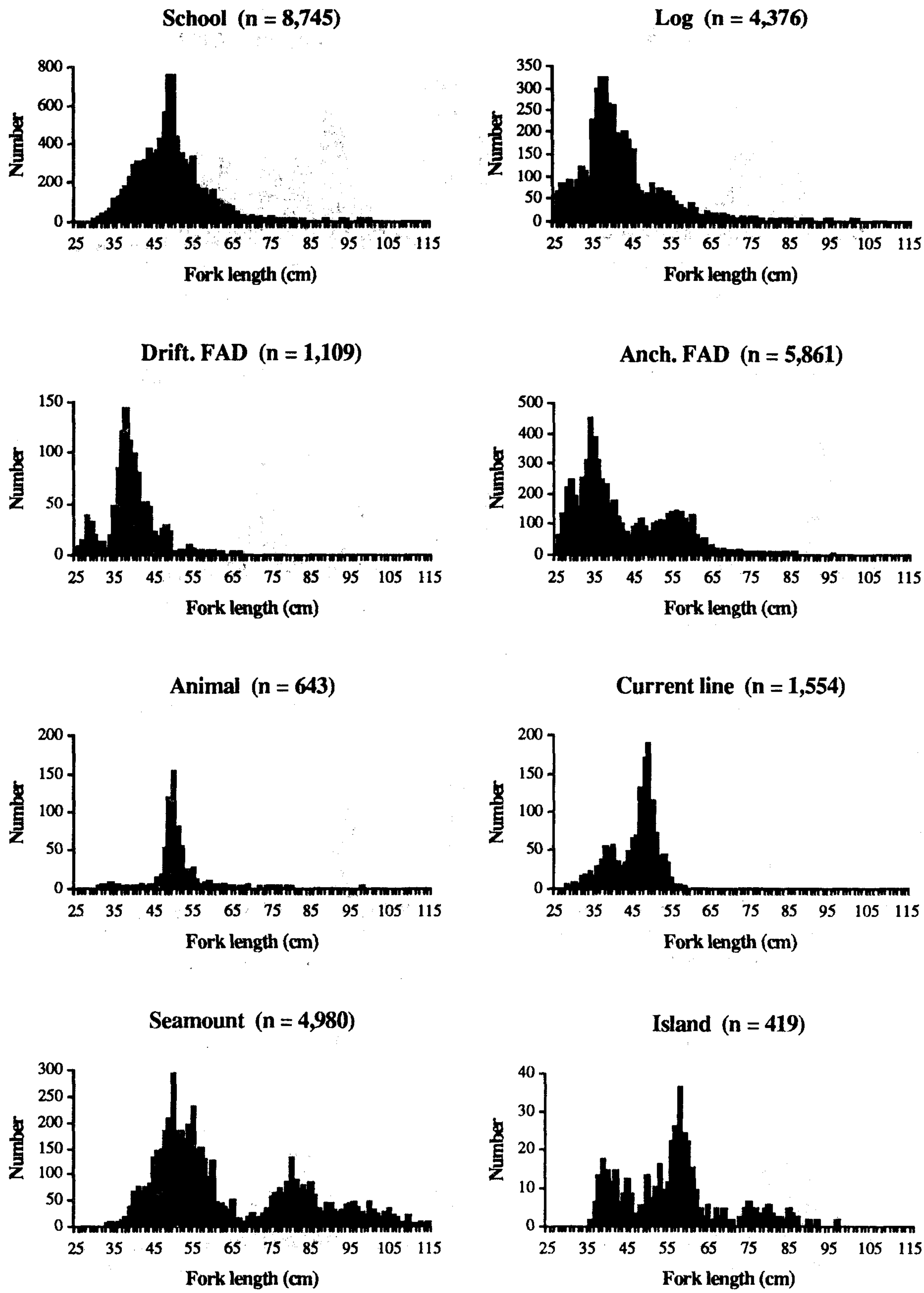


Figure 15. Size composition of yellowfin from different school associations encountered by the SPC RTTP tagging vessel

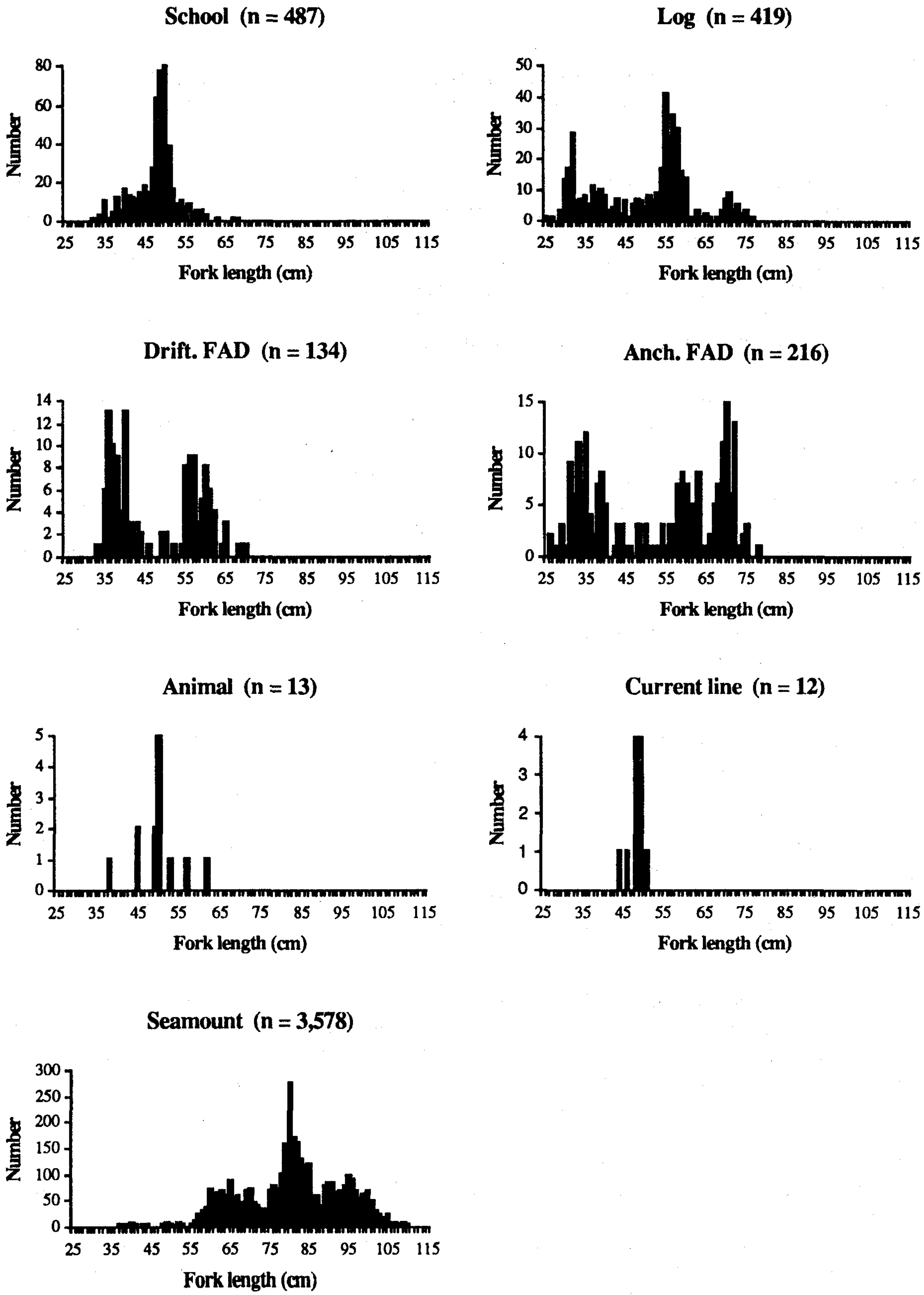


Figure 16. Size composition of bigeye from different school associations encountered by the SPC RTTP tagging vessel

3.7 Spatial patterns

The spatial patterns of purse seine sets are shown in Figures 17–21 by association and quarter, while Figure 22 shows effort and Figure 23 catch per set 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.

Within these longitudinal boundaries, school and log sets appear to be concentrated in two main areas, from 2°N to 2°S, particularly south of the Equator, and from 3° to 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 (PNG). Tanaka (1989) notes that Japanese seiners fishing 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 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 North-west and South-east 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 terms 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 Solomon Islands and been carried west by the EC.

The area of convergence between the NECC and EC results in the formation of current eddies and 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 North-west Monsoon Current that runs parallel to the Irian Jaya/PNG coastline. Most of these logs probably originated in Irian Jaya, PNG and the Indonesian archipelago. The Sepik, Ramu and Markham Rivers of northern PNG and the Sungai Mamberano River in north-west Irian Jaya are probably the major contributors of logs in this area throughout the year, but particularly during the Northwest Monsoon season when rainfall is at its highest. The North-west Monsoon Current weakens in the second quarter and is replaced in the remaining two quarters with the westward-flowing South-east Monsoon Current. This current coupled with an intensified EC results in a westward drift of logs that originated in PNG and Solomon Islands, and logs that first came from the east in the North-west Monsoon Current. There may also be logs that first travelled in the NECC.

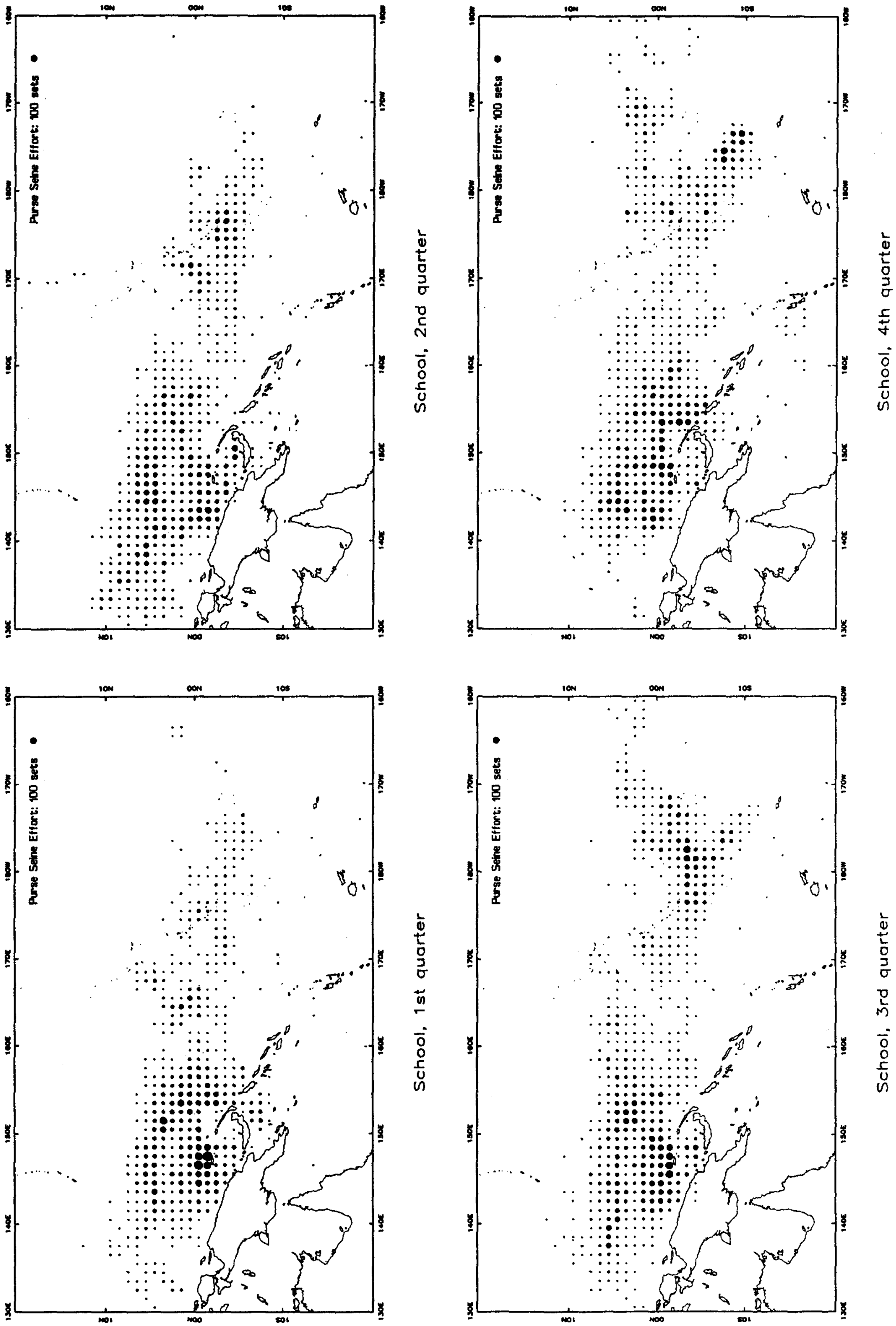


Figure 17. Geographical distribution of school sets by purse seiners, by quarter, 1979–1991

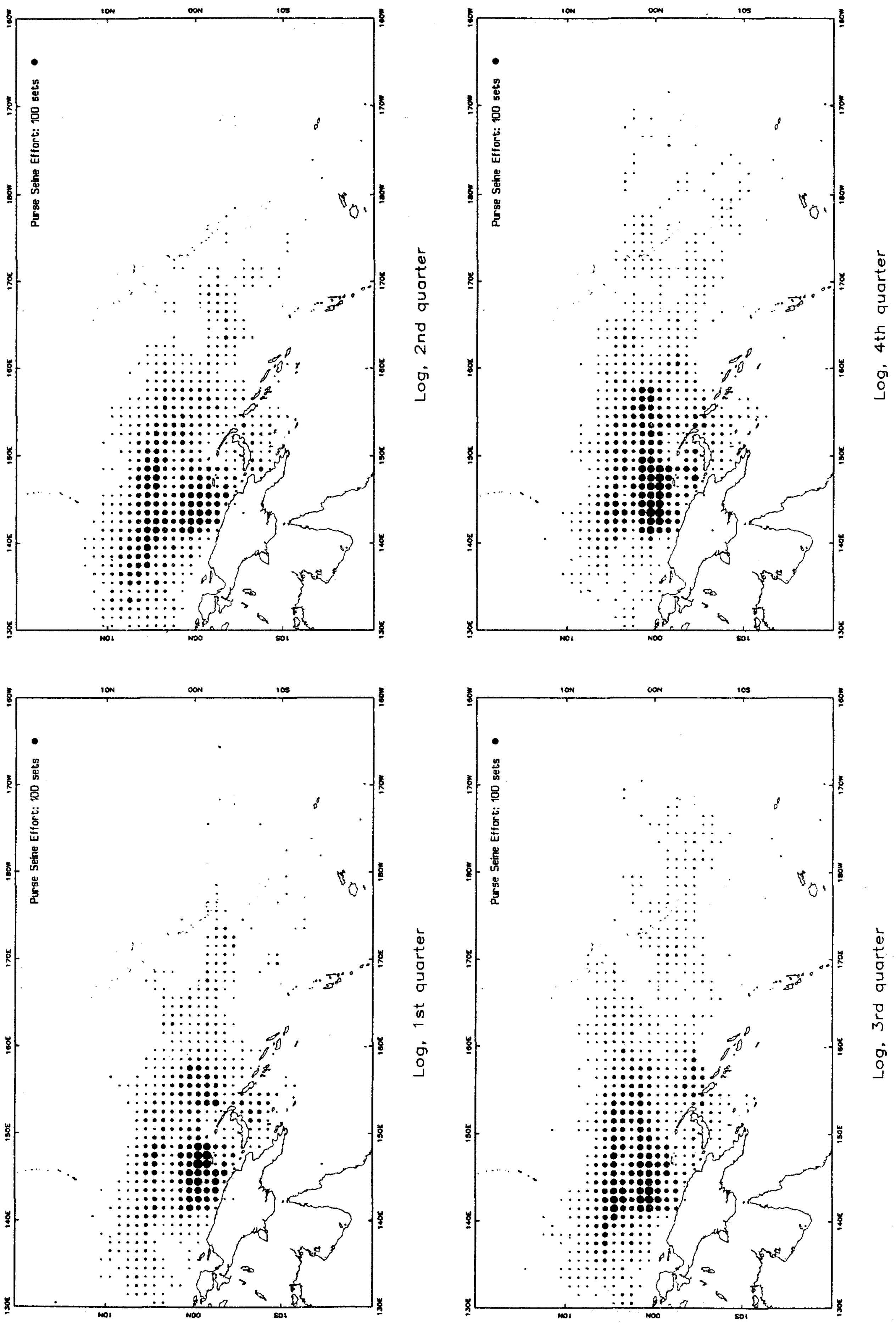


Figure 18. Geographical distribution of log sets by purse seiners, by quarter, 1979–1991

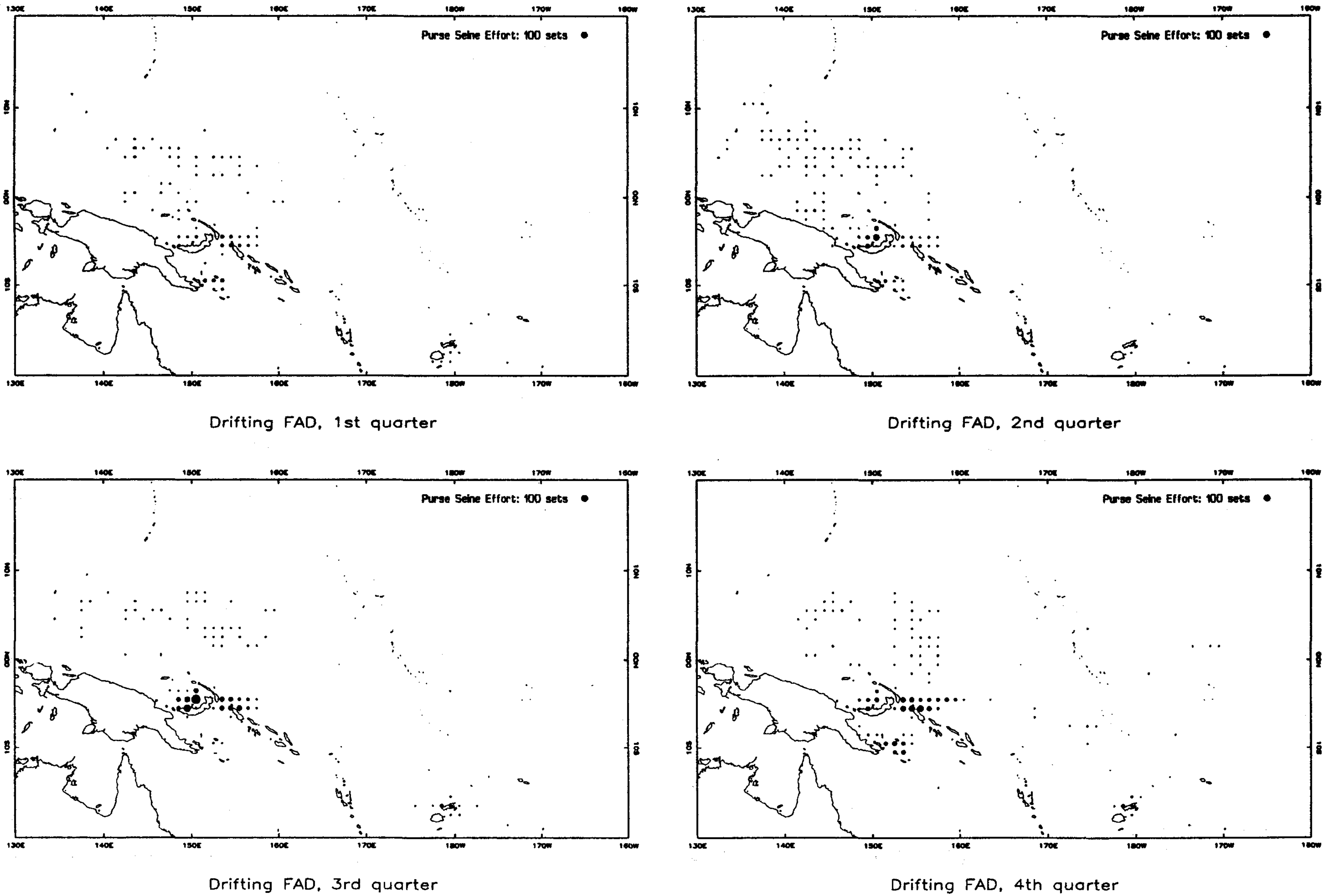


Figure 19. Geographical distribution of drifting FAD sets by purse seiners, by quarter, 1979–1991

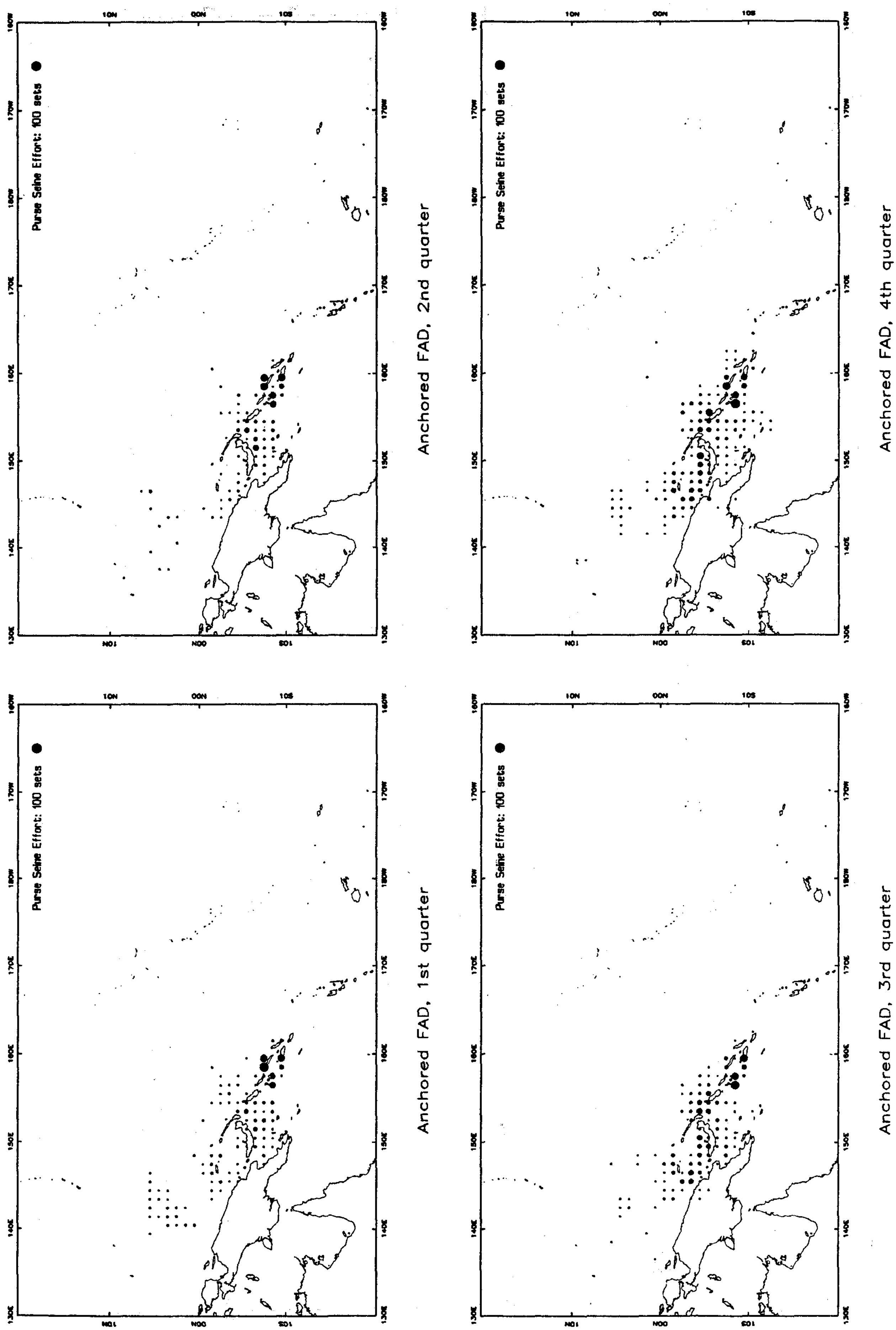


Figure 20. Geographical distribution of anchored FAD sets by purse seiners, by quarter, 1979–1991

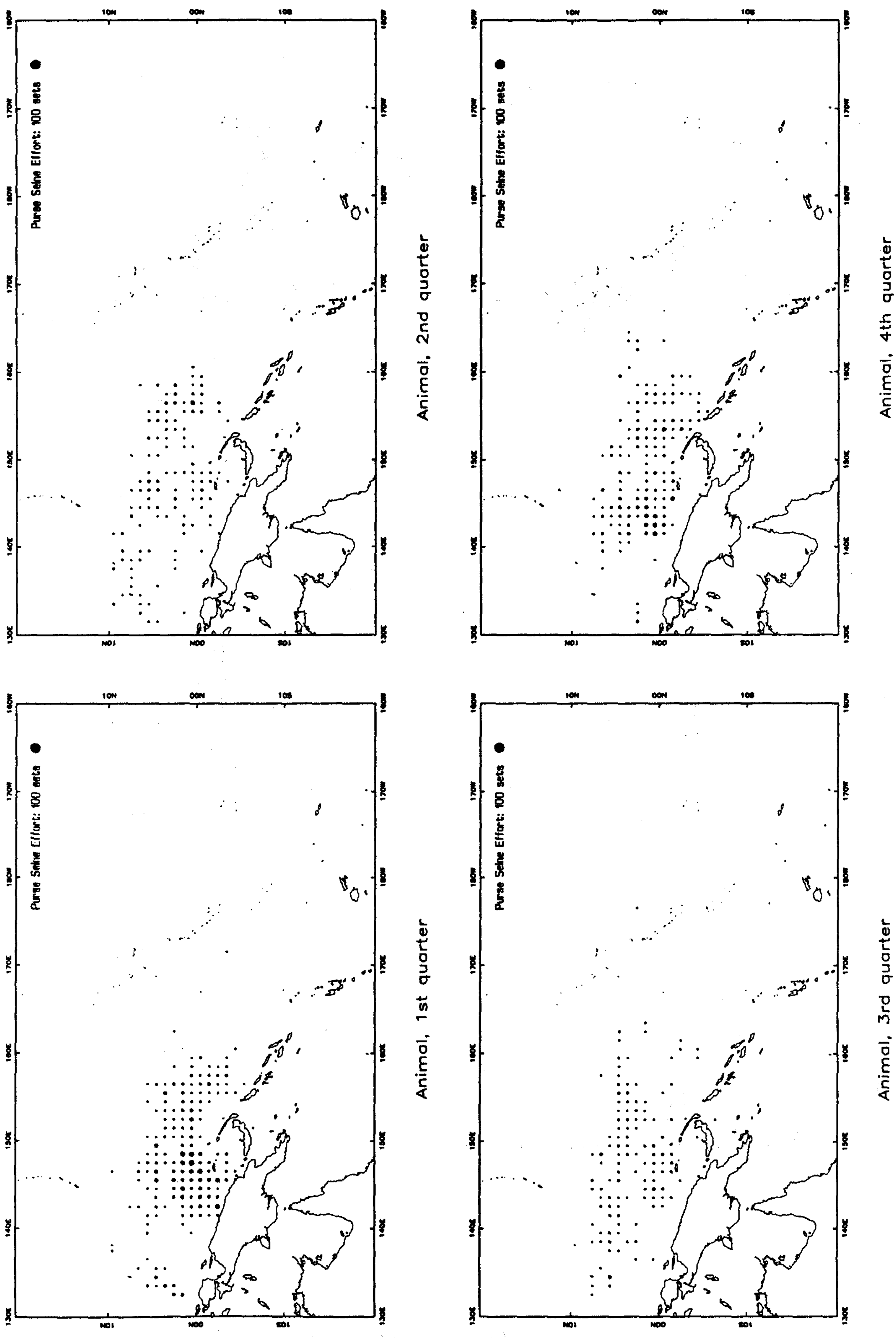


Figure 21. Geographical distribution of animal sets by purse seiners, by quarter, 1979–1991

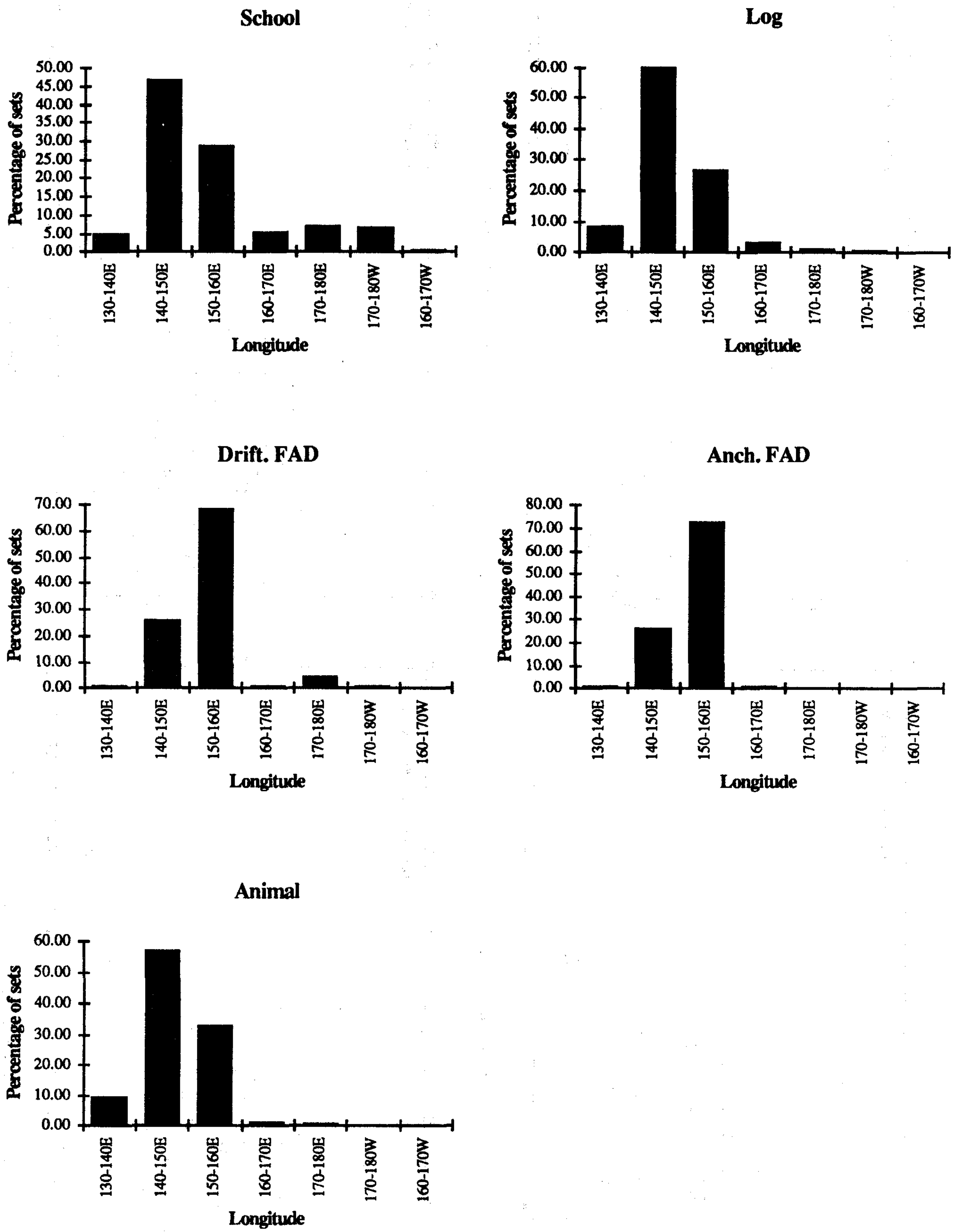


Figure 22. Distribution of purse seine sets, by longitudinal bands

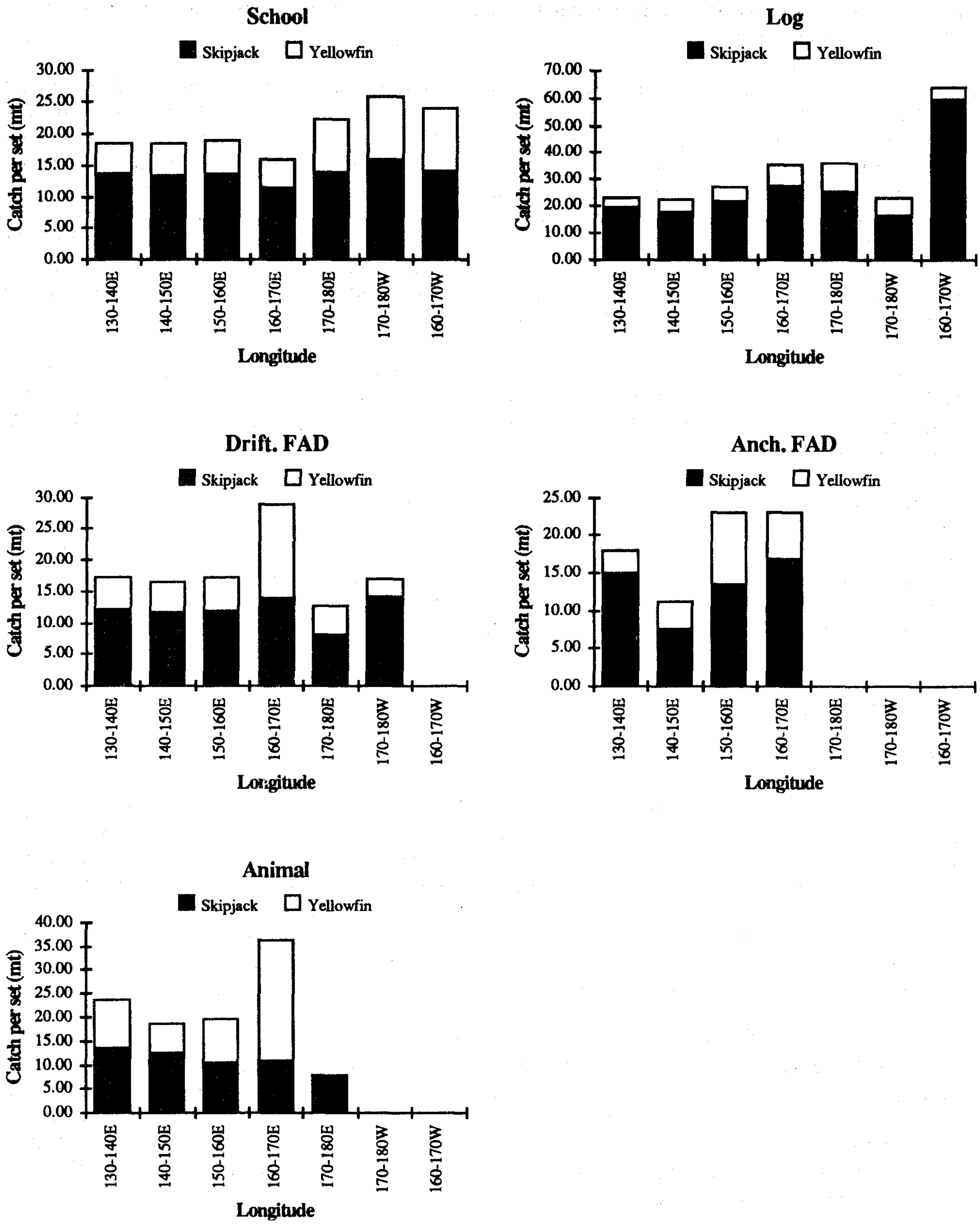


Figure 23. Distribution of purse seine catch per set, by longitudinal bands

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° (Figure 23). This suggests that log schools are larger in the east, which is also seen with the catch rates of unassociated schools (Figure 23). An alternative explanation is that logs found in the east have been at sea for a considerable time, having drifted from the west (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 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 east of 160°E but still in the Solomons produce a similar catch rate. Anchored FADs deployed north of Irian Jaya and east Papua New Guinea between 130° and 140°E yield an average of 18 mt per set, while the lowest catch rate, 12 mt per set, occurs in the western Bismarck 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 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 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 Figure 24 as percentage of sets (by all fleets) against time of day and in Figure 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 favourable 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 is made during the night, probably on sonar-located spots of tuna and/or baitfish. 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 catch of over 150 mt made in the early morning may have been a sonar-assisted set.

Over 90 per cent of all log sets are made in the early morning between 0300 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 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 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 from drifting FADs are due to single sets that yielded large catches and are therefore not representative of the association.

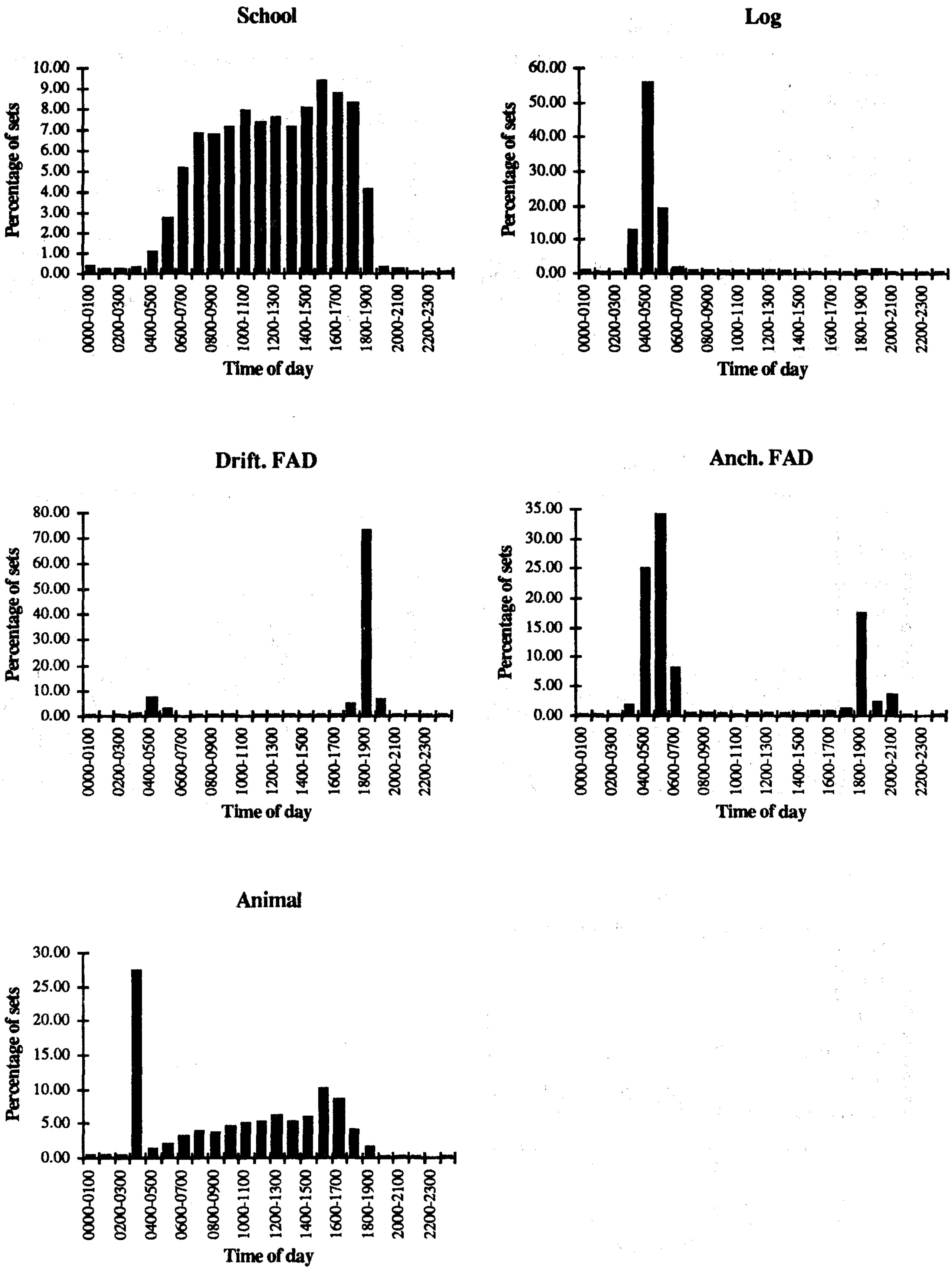


Figure 24. Distribution of purse seine sets, by time of day

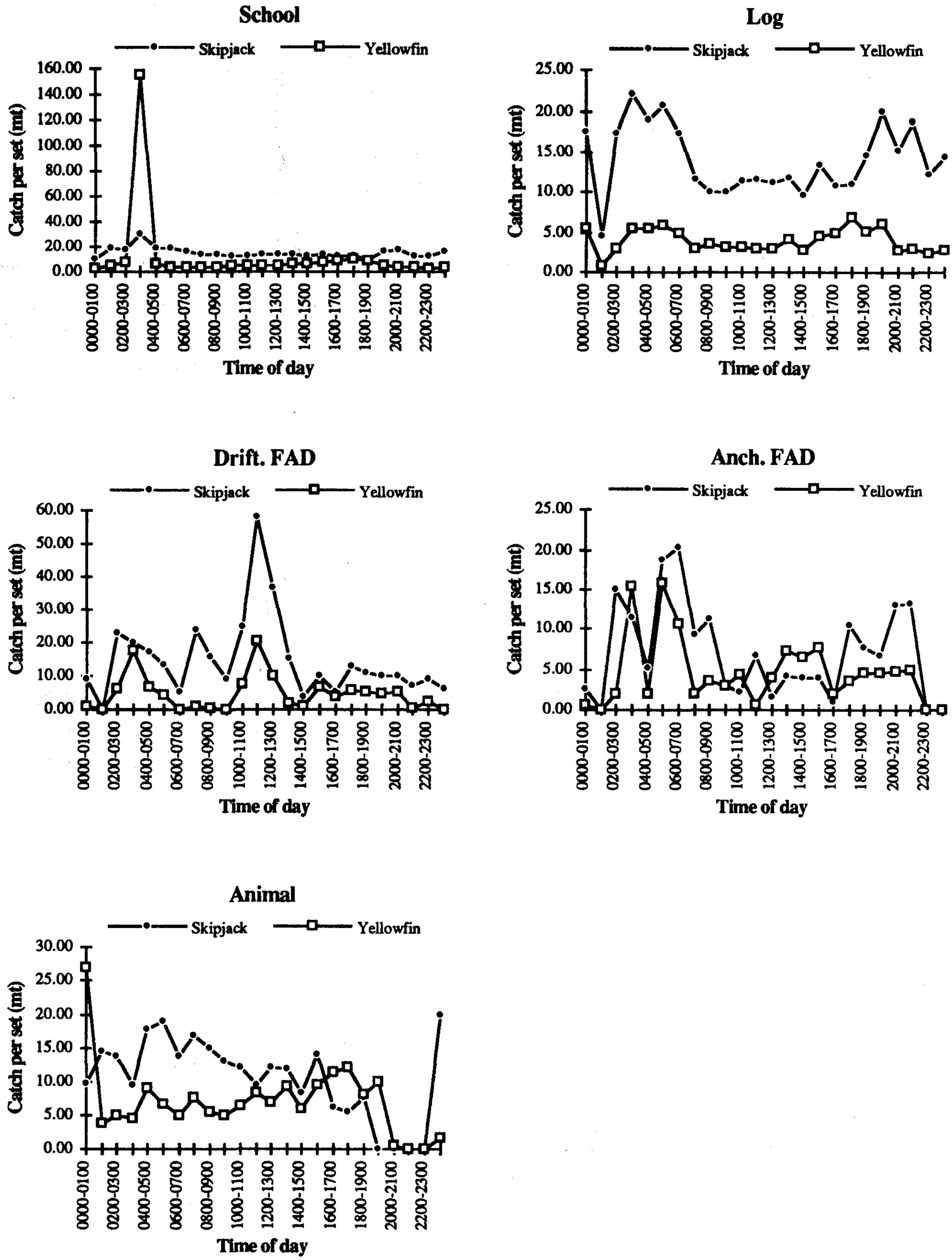


Figure 25. Distribution of purse seine catch per set, by time of day

Over 70 per cent 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 schools, 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. The percentage of sets made from 0300 to 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), as such associations will usually be treated in a similar way 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 for early morning and late afternoon when the tuna schools are close to them.

3.8.2 Seasonal patterns

There appears to be little seasonal variation in the numbers of school and log sets (Figure 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.

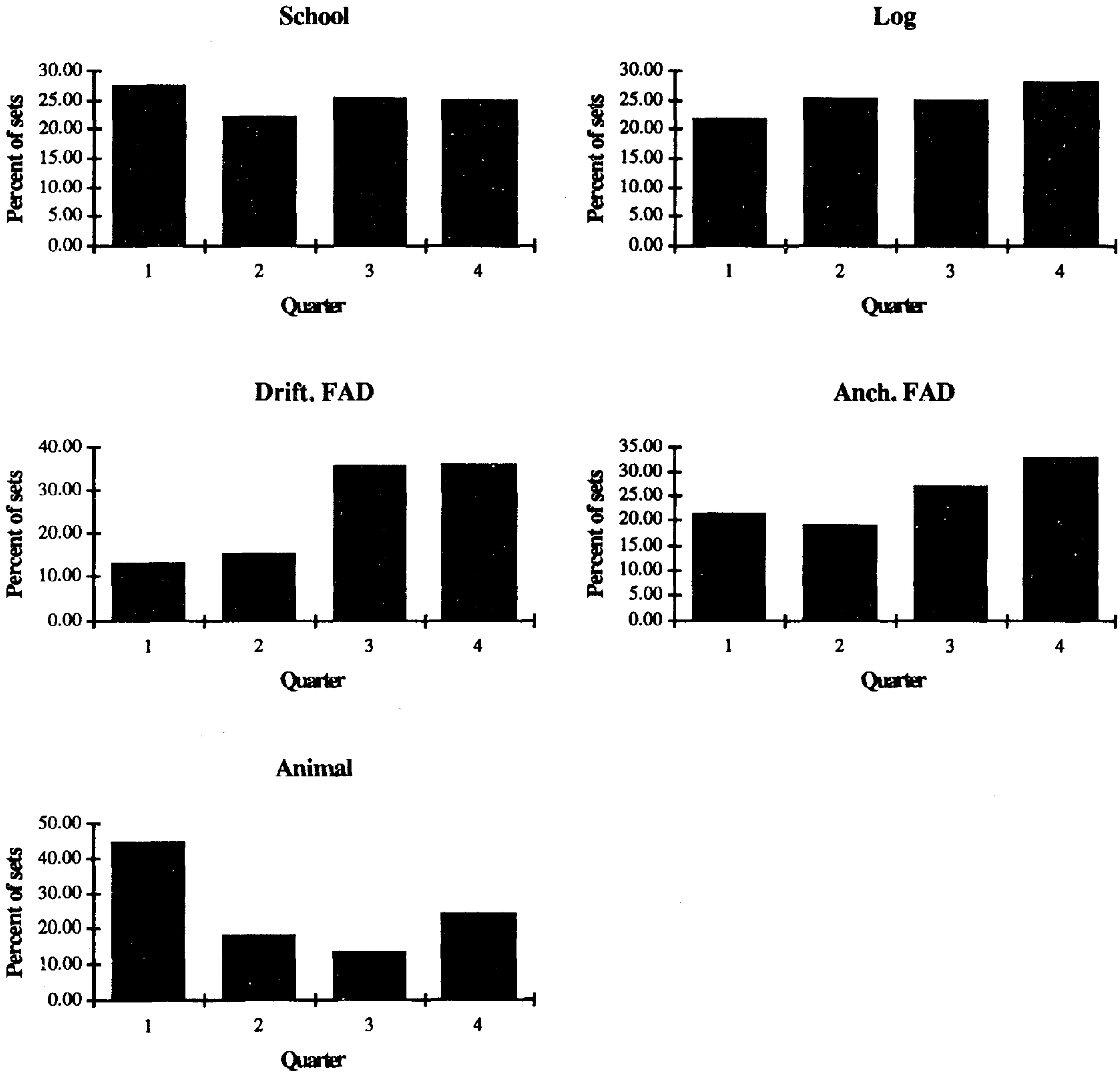


Figure 26. Distribution of purse seine sets, by quarter

The distributions of catch per set by quarter for the different associations are unremarkable (Figure 27).

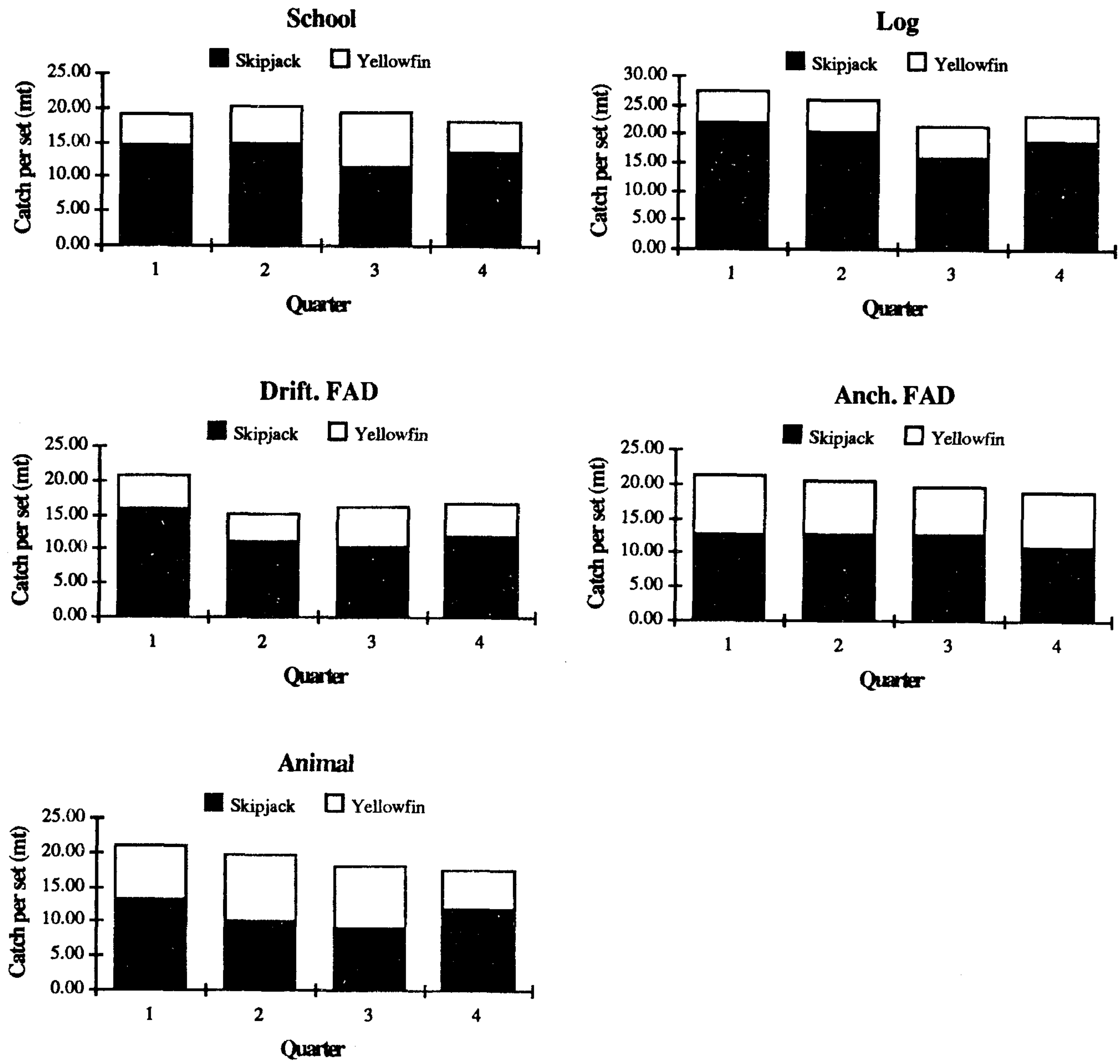


Figure 27. Distribution of purse seine catch per set, by quarter

A description of the seasonal influences on the spatial distribution of set types and catches is provided in Section 3.7.

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 (Figure 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 Figure 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 in 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.

Table 6: Maximum set sizes (mt) recorded in the SPC Regional Tuna Fisheries Database

Association	Skipjack school	Yellowfin school	Mixed school
School	300	308	318
Log	327	272	354
Drifting FAD	235	294	300
Anchored FAD	138	123	165
Animal	280	220	280

Some estimates of aggregation sizes are available from tag recapture data for several cases where fish were tagged from an association that 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 more than 50 mt.

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 binomial 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	3	3,614	1,613
		Yellowfin	51	500	7	3,194	1,056
		Bigeye	19	167	1	1,596	916

The samples caught in the FSM example are derived from logbook catch weight estimates and average weight estimates.

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 dispersed 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; they would 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 logbook forms does not normally allow the identification of repeated sets on the same log, FAD or other floating object, and therefore data of this type are relatively rare. Available data for the WPO are given in Appendix I. They have not yet been analysed and are listed here for researchers interested in this topic.

The dynamics of aggregation size, recruitment to the aggregation and movement away are likely to be affected by a variety of factors. Some of these were noted in Section 3.1 for the various associations. For log and FAD associations, the characteristics of the floating objects are important, along with their density in the fishing area and the local biomass of fish not associated with such objects. Modelling 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 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 tagged from different types of association give some insight into their movement dynamics (Figures 28–30). Most fish tagged from unassociated schools of skipjack 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 displacement rates greater than 15 nmi/day. This may result from some tagged skipjack remaining associated with logs or FADs that have drifted substantial distances with the current. The small numbers of large displacement rates for fish tagged from stationary associations and from unassociated schools lend 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 8).

Table 8: 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
Drifting FAD	17.2	25	16.0	42	22.5	25
Anchored 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	-	-

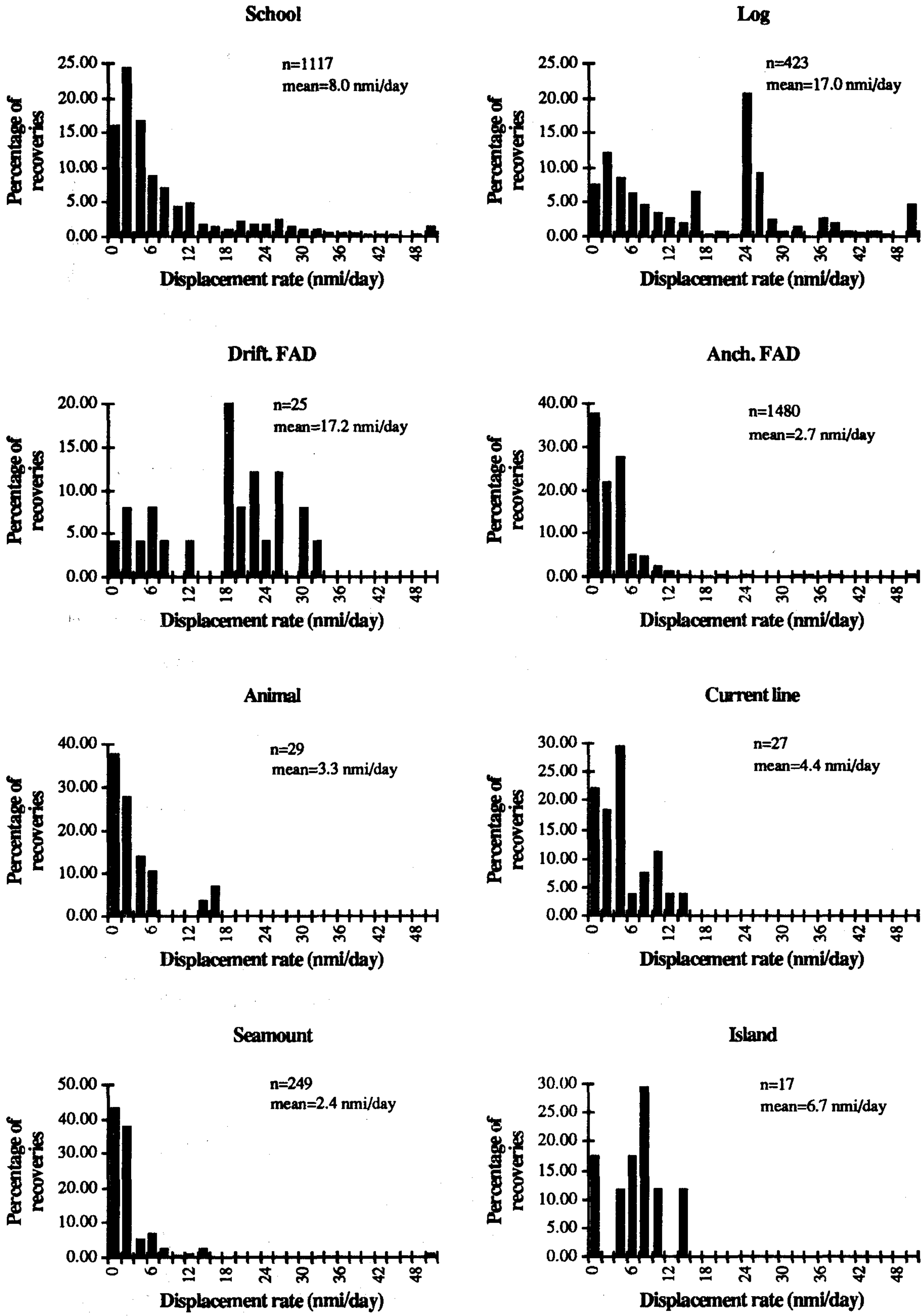


Figure 28. Displacement rate histograms for skipjack tagged from different associations

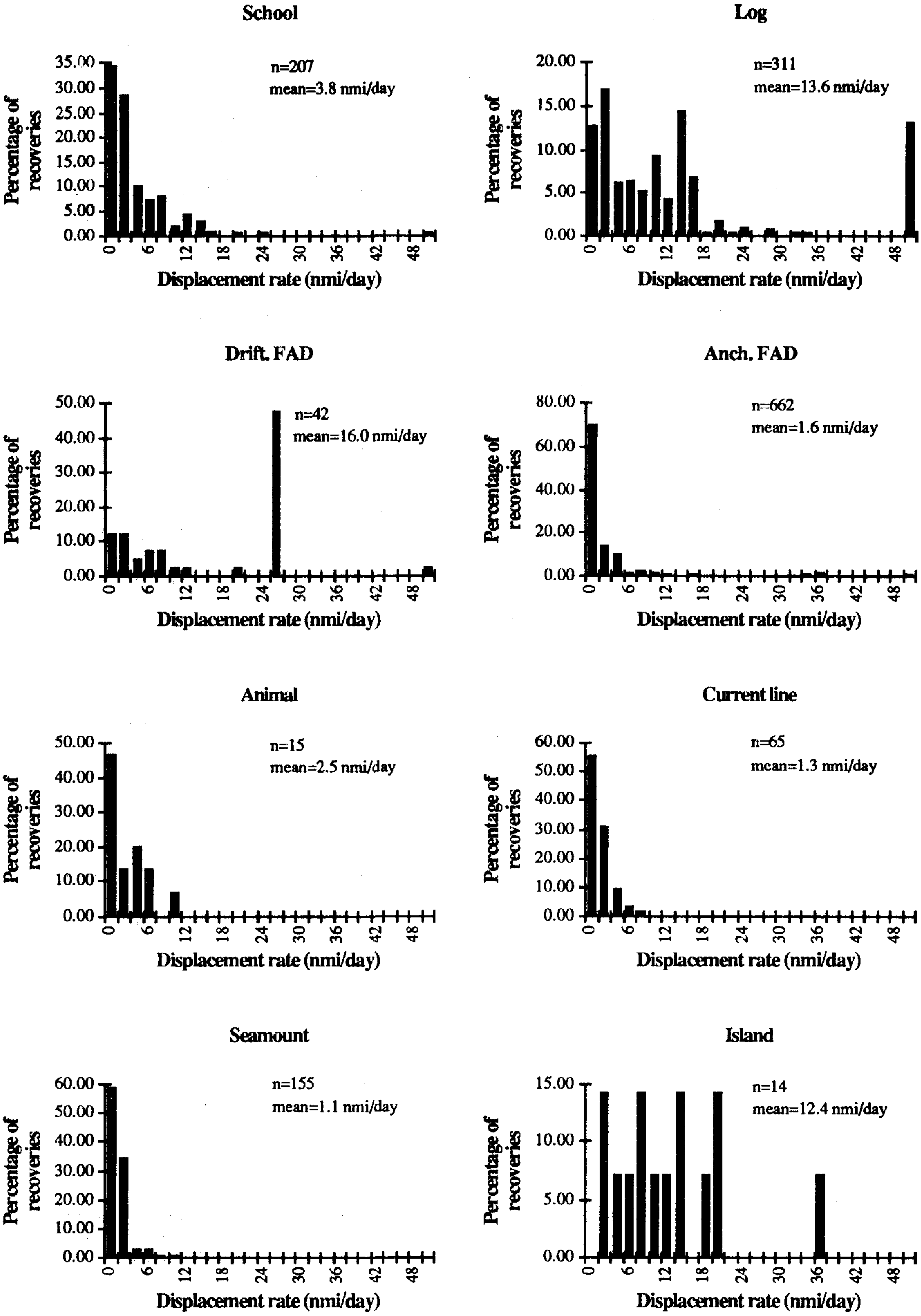


Figure 29. Displacement rate histograms for yellowfin tagged from different associations

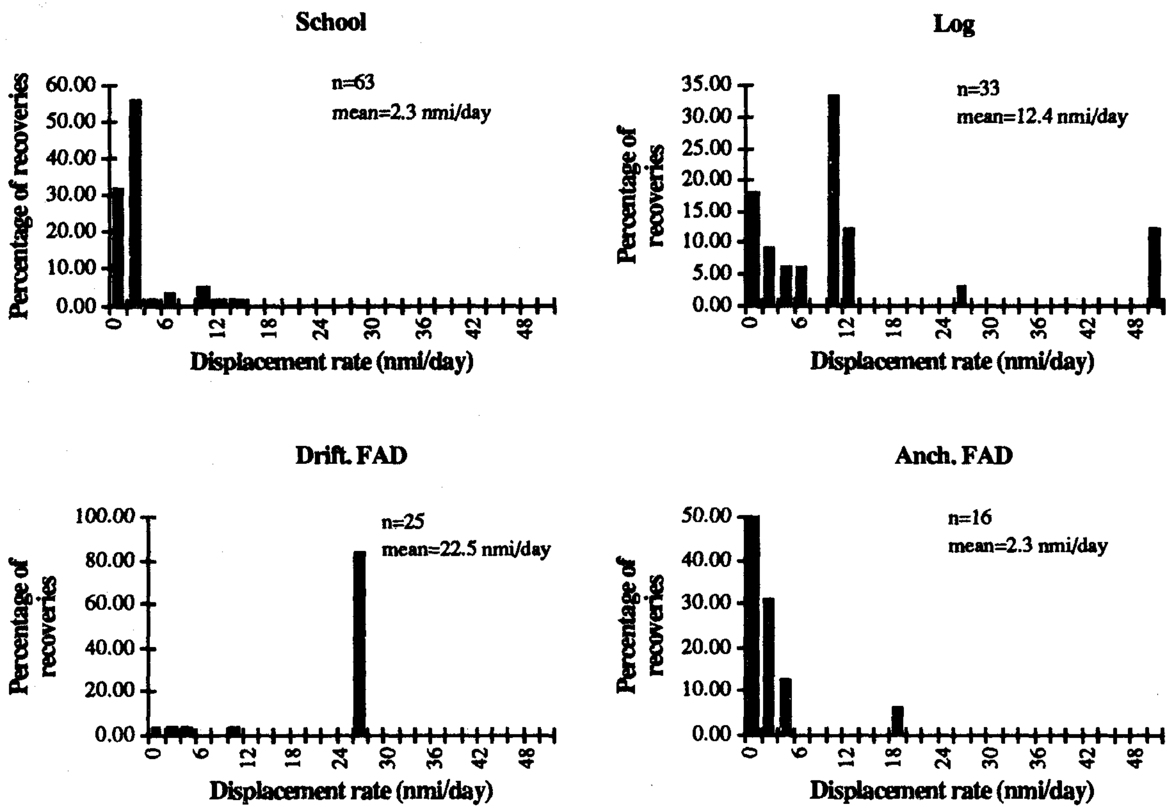


Figure 30. Displacement rate histograms for bigeye tagged from different associations

The interpretation of Figures 28–30 and Table 8 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 made later.

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°39'N, 153°20'E and 1,862 skipjack, 194 yellowfin and one 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. They included three skipjack caught in a set 212 nmi south of the release point on Day 4 and 25 skipjack and 9 yellowfin recaptured in one set on Day 5. Given the large distances involved and the fact 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. This probably also applies to 3 skipjack recaptured in two sets about 300 nmi south-east of the release point on Days 7 and 8.

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 one 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, eight skipjack were recaptured from a set further to the east (>600 nmi from the release point), another in a separate set to the north and one skipjack was recovered from a set >700 nmi to the west.

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 their effect 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 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 logbook forms only give information relating to individual log sets, usually with no indication of sets on logs that were discovered some time before the set and were marked with radio beacons. Therefore, the usual searching-time measure of purse seine fishing effort cannot be derived, as searching will have occurred before logs are set on for the first time, but not for repeat sets on marked logs. Similarly the usual notions of searching-time do not apply to sets on anchored FADs and other stationary, charted attractors.

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 other population-dynamic parameters of interest. The analysis of a skipjack tagging experiment carried out recently in 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 and 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 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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APPENDIX

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	

Vessel	Day	Yellowfin	Skipjack	Bigeye	Total	Source
Western Pacific	1	-	-	-	104.4	D.G. Itano (pers. obs.)
	2	-	-	-	34.5	
	1	-	-	-	227.0	"
	2	-	-	-	7.3	
	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	