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A SUMMARY OF OPERATIONAL, TECHNICAL AND FISHERY INFORMATION ON WCPO PURSE SEINE FISHERIES ON FLOATING OBJECTS

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A SUMMARY OF OPERATIONAL, TECHNICAL AND FISHERY INFORMATION ON WCPO PURSE SEINE FISHERIES ON FLOATING OBJECTS[1]

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[1] The majority of this paper is excerpted from a document prepared by the author under contract to the Forum Fisheries Agency who requested and facilitated the original document and agreed to release of technical and published information contained here.

A SUMMARY OF OPERATIONAL, TECHNICAL AND FISHERY INFORMATION ON WCPO PURSE SEINE FISHERIES ON FLOATING OBJECTS[2]

David G Itano

1 Abstract

The rapid expansion and adoption of FAD use by purse seine fleets has significantly shifted harvesting characteristics of the overall fishery toward small yellowfin and increased total fishing mortality on juvenile bigeye tuna. The combined surface fisheries of Indonesia and the Philippines, most of which are FAD-based, also contribute heavily to fishing morality on small and juvenile tuna of both species. FAD directed management has been proposed as one avenue to reduce effort on small-sized tuna that has resulted in several meetings and workshops to examine FAD issues. Management discussions would benefit from a better understanding of the technical and operational aspects of FAD and floating object directed fishing effort. This paper provides a review of yellowfin and bigeye biology and aggregative dynamics to floating objects, and proposes specific terminology for different types of floating object directed effort. The technical details of FAD design, FAD fishing strategies and the spatio-temporal patterns of FAD use by different purse seine fleets are described.

2 Introduction

The WCPO equatorial purse seine fishery developed following Japanese and US fishery surveys that demonstrated that tropical tunas could be reliably harvested from natural floating objects throughout the year (Watanabe 1983; Doulman 1987). The floating object fishery that developed is well described by Hampton and Bailey (1999); a fishery that takes advantage of the natural tendency of tropical tuna to aggregate beneath and around flotsam. Over time, purse seine fishermen have increased their catch rates and overall efficiency by enhancing natural drift objects with netting and other materials or by deploying purpose built drifting FADs (DFADs). A detailed and illustrated description of the development and use of anchored and drifting FADs by WCPO fisheries is provided in Itano et al. (2004).

3 Problem statement

Anchored FADs have been used to successfully develop artisanal fisheries at relatively low FAD densities. However, the deployment of hundreds or even thousands of anchored and drifting FADs to support industrial fisheries or large numbers of small scale gear types in concentrated areas have raised concern as to their impact on pelagic resources. The problem arises from the characteristics of floating object aggregations that tend to increase vulnerability of:

- juvenile market species of tuna before they have had an opportunity to reproduce;
- undersize tuna that have low or no commercial value that are often discarded producing wastage;
- pelagic bycatch species (dolphinfish, wahoo, rainbow runner, pelagic triggerfish, etc.);
- commercially important, non-target finfish (i.e. billfish species);
- bycatch species of special concern (i.e. sea turtles, marine mammals, oceanic sharks; and,
- mixed aggregations of tropical tuna species that are difficult to separate during the purse seine process (e.g. maintain skipjack catch while attempting to exclude small-sized yellowfin and bigeye).

The unwanted take of small tuna and bycatch contributes to wastage in the form of smashed or discarded catch that is often unreported or under-reported, representing a significant source of undocumented fishing mortality. Entanglement of sea turtles and non-target finfish in drifting FADs

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has been noted as an area of special concern by scientists and the purse seine industry (Delgdo de Molina 2005) and remains an issue that could expand with negative repercussions to surface fisheries.

Large scale purse seining on anchored and drifting FADs represents a relatively recent and dramatic increase in fishing mortality for juvenile tuna, and has reduced the yield per recruit of the stocks of both species. FADs have been specifically identified as a significant factor toward increased exploitation on both stocks and reduced stock condition. The large, but inadequately documented landings of small tuna from the Philippines and Indonesia have also been named as a significant factor toward overfishing and a significant source of model uncertainty related to WCPO bigeye and yellowfin stock assessment. It should be noted that the tuna fisheries of both countries rely heavily on tuna schools found in association with anchored FADs, thus both issues are closely related.

4 WCPFC and FFA directives on FADs

The Second Regular Session of the WCPFC (Pohnpei, FSM 12-16 December 2005) agreed that:

- *CCMs shall develop management plans for the use of FADs (anchored and drifting) within waters under national jurisdiction which shall be submitted to the Commission.*

- *The Commission will work with CCMs to develop methods to reduce catches of juvenile bigeye and yellowfin tuna caught in association with FADs.*

- *Beginning in 2006, the Scientific Committee and the Technical and Compliance Committee shall undertake to explore and evaluate mitigation measures for juvenile bigeye and yellowfin taken around FADs, in cooperation with other RFMOs, and present the results annually to the Commission. This work shall continue on an annual basis*

At the Third Regular Session of the WCPFC (Apia, Samoa 11-15 December 2006), the FFA Member countries proposed that:[3]

- *CCMs whose vessels fish in areas beyond national jurisdiction shall develop management plans for the use of FADs (anchored and drifting) in areas beyond national jurisdiction which shall be submitted to the Commission.*

- *Recognising the urgent need to reduce fishing mortality of juvenile bigeye and yellowfin from fishing on FADs, the Commission will adopt a measure at its next session to limit fishing effort on FADs. The Commission directs the Scientific Committee and the Technical and Compliance Committee to provide advice to the Commission on a measure to reduce fishing mortality of juvenile bigeye and yellowfin from fishing on FADs for consideration at the next session of the Commission. The advice from the Technical and Compliance Committee shall include advice on requirements for implementation and compliance with the measure. The Executive Director shall ensure that the Scientific Committee and the Technical and Compliance Committee are provided with the information necessary to provide advice on a measure to limit fishing on FADs.*

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[3] WCPFC3-2006-DP01

5 Summary of paper contents

Effective FAD management and mitigation of the take of small or juvenile tuna on floating objects will require a basic understanding of the technical aspects of FADs and the operational considerations of their use by different fleets. Technical terms should be clearly defined and illustrated allowing all parties to discuss the issues on the same level. The purpose of this paper is to:

- provide a brief review the biological characteristics of bigeye and yellowfin tuna in the WCPO and of their aggregative behaviour on floating objects;
- propose terminology to clearly differentiate the different types of floating objects and floating object associations that are exploited by WCPO surface fisheries;
- describe the technical design of FADs and associated fishing methods used on anchored and drifting FADs in the WCPO;
- describe the associated gear and other enhancements that assist FAD-dependent fisheries (i.e. buoy electronics, FAD tender vessels, light boats, etc.);
- describe the historical development and recent status of FAD use by WCPO surface fisheries; and
- summarize spatial and temporal patterns of FAD use by purse seine fleets that operate on floating object associations.

The technical data contained here is intended to provide basic information useful for any discussion on FAD management, the collection of technical data and the development of FAD management plans by CCMs.

6 The tuna species and aggregative dynamics

6.1 Literature review

Basic information on WCPO yellowfin and bigeye tuna has been compiled by Wild (1994) and Miyabe (1994). Focused reviews of information on Pacific bigeye biology and fisheries have been compiled by others, including Whitelaw and Unnithan (1997) and Hampton, et al. (1998). Information on the physiology and ecology of both yellowfin and bigeye useful for examining fisheries impacts have been compiled by Block and Stevens [eds] (2001). Detailed information on the biology and stock assessment of WCPO yellowfin and bigeye can be found in the proceedings of the Standing Committee on Tuna and Billfish and the Scientific Committee of the WCPFC. Much of this information has been reviewed and compiled by the WPRFMC (2006).

6.2 Basic biology

Both yellowfin and bigeye tuna share many characteristics of the tropical tunas, i.e. broad tropical and sub-tropical distribution, opportunistic feeding, rapid initial growth and high fecundity. Sex ratios at 1:1 up to around 120 cm in fork length after which males gradually predominate. Size or age at maturity estimates vary considerably depending on area and study methods, but yellowfin are thought to mature rapidly at around 2 years of age. Length at 50% maturity (L_{50})[4] has been estimated at 104.6 cm for yellowfin sampled from the equatorial WCPO surface and sub-surface fisheries (Itano 2000) and 107.8 cm for longline caught fish taken north of the Philippines (Sun et al. 2005). The estimated L_{50} of yellowfin from the Eastern Pacific Ocean is significantly lower at 92.1 cm (Schaefer 1998), possibly due to higher regional productivity in the EPO resulting in accelerated growth and maturity.

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[4] Fork length at which 50% of a population is estimated to be sexually mature

Bigeye age, growth and maturity have not been thoroughly studied in the WCPO, but age at first maturity occurs around 100 cm in length and bigeye maturity schedules are recognized to be slower than for yellowfin. Schaefer et al. (2005) estimated a L_{50} of Eastern and Central Pacific bigeye at 135 cm and confirmed serial spawning within 15° of the equator during most months of the year at high rates. However, caution should be applied when comparing L_{50} estimates from the EPO to the WCPO due to the likelihood of regional differences in reproductive parameters. Limited mixing of bigeye between the eastern and western Pacific has been suggested from tagging studies supporting the importance and need for regional studies to define spatial heterogeneity in reproductive parameters (Hampton and Williams 2005; Schaefer and Fuller 2005).

Bigeye and yellowfin growth rates have been validated and are similarly rapid during the first two years of life. However, bigeye growth appears to slow down significantly after that with maturity occurring at 3 to 4 years of age. Maximum age for both species is not fully understood but empirical evidence from large-scale tagging studies suggest that yellowfin live to around 6-7 years while bigeye can live to 13-15+ years.

6.3 Spawning and reproduction

Both species are serial spawners, releasing millions of eggs per spawning event at near-daily intervals over protracted periods of time in surface waters (Nikaido et al. 1991; Schaefer 1998; Schaefer et al. 2005). Reproduction of WCPO yellowfin takes place throughout the year in equatorial waters and seasonally in sub-tropical areas when SST rise above around 24°C (McPherson 1991; Itano 2000; Sun et al. 2005). The reproductive parameters of WCPO bigeye have not been adequately documented by WCPO regional studies. However, existing information suggest that WCPO bigeye spawning is more restricted than for yellowfin, occurring throughout the year within 10° of the equator and seasonally at slightly higher latitudes (to around 15°), at SSTs above approximately 24°C but ideally above 26°C. There is some evidence for year around equatorial spawning of WCPO bigeye that peaks between the February – September period (Kikawa 1966, Sun and Yeh 2006), but these studies are considered restricted in geographic and temporal scales and need to be expanded.

Both yellowfin and bigeye spawn in warm waters but can range widely to feed at higher latitudes or at depth. Yellowfin primarily inhabit the upper mixed layer, moving deeper with greater body size to inhabit areas at or near the thermocline (Holland et al. 1990; Block et al. 1997; Brill et al. 1999) but have been reported to descend to much greater depths by archival tagging data (Dagorn et al. 2006). Bigeye have adapted to cooler, deeper water to feed at or below the thermocline on organisms of the deep scattering layer with larger fish frequenting deeper strata (Holland and Sibert 1994; Dagorn et al. 2000).

The main conclusion is that both yellowfin and bigeye are capable of spawning throughout the entire region of the WCPO tropical purse seine fishery and water temperatures will support spawning and recruitment throughout the year.

6.4 FAD related aggregation and vulnerability

Juvenile tropical tuna and bigeye and yellowfin in particular aggregate to free-drifting objects, moored buoys and slow moving large marine organisms such as manta rays and whale sharks; all of which increase their vulnerability to commercial fisheries (Calkins 1980, Hampton and Bailey 1993, Itano and Holland 2000). As for many other pelagic species, yellowfin and bigeye typically exhibit a deep day vs shallow night behaviour that has been well documented through the use of sonic and electronic tags. However, this classic vertical behaviour breaks down when the tuna are found in association with floating objects (i.e. FADs and logs) or seamounts.

Schaefer and Fuller (2002) characterized four vertical behaviour modes for EPO bigeye: open water, floating object associated, intermediate, and deep diving. Juvenile bigeye in particular exhibited the characteristic shallow night behaviour with abnormally shallow behaviour during the day when in association with FADs. Bigeye were acoustically tracked and seen to exhibit more diffuse, deeper behaviour at night than day, assumed to be related to night foraging behaviour within the mesopelagic deep scattering layer. On anchored FADs, larger bigeye remained deeper on average than small bigeye but this pattern reversed at night. Both sizes of bigeye remained deeper on average than tagged skipjack throughout the day/night cycle compared to skipjack but were observed to be shallower than skipjack when associated with the free drifting vessel (Schaefer and Fuller 2005).

The bigeye were observed acoustically to form tightly aggregated, mono-specific schools during the day that were located upcurrent of the anchored FAD but downcurrent from the free-drifting vessel. These findings are generally in agreement with anecdotal information from the fishing industry. Bigeye schools became more diffuse and individuals were tracked deeper, presumably linked to foraging behaviour. The schools returned to the FAD or vessel before dawn. Night time vertical behaviour has also been seen to vary in relation to moon phase, with full moon inducing a deeper average depth distribution (Schaefer and Fuller 2005, Musyl et al. 2003).

Sonic tracking of juvenile yellowfin tuna confirm their preferred habitat in the upper mixed layer above the thermocline (Block et al. 1997; Brill et al. 1999; Cayré 1991; Holland et al. 1990; Marsac and Cayré 1998). Juvenile yellowfin in Hawaii were observed to remain in the mixed layer or just above the thermocline (Holland et al. 1990) while large, adult size yellowfin in the same region were observed by sonic tracking to spend about 60% to 80% of their time in or immediately below the mixed layer but above 100 m (Brill et al. 1999). Sonic tracked juvenile yellowfin were recorded to move away from anchored FADs in Hawaii at night, sometimes orienting along a shallow shelf contour and returning in a direct line to an anchored FAD more than ten km away by dawn (Holland et al. 1990). Rapid, apparently directed between-FAD movements of sonic tagged juvenile yellowfin have been recorded in French Polynesia and Hawaii that suggest the animals can orient towards a FAD at distances of up to tens of km, although the mechanism of orientation is not yet understood (Girard et al. 2004, Dagorn et al. 2006).

7 FAD technical information

7.1 FAD terminology

The term Fish Aggregation Device (FAD) has been defined in a number of ways by different management bodies and for various purposes. The FAO Fisheries Glossary[5] defines a FAD as:

> *"Fish aggregating device: Artificial or natural floating objects placed on the ocean surface, often anchored to the bottom, to attract several schooling fish species underneath, thus increasing their catchability."*

This is equivalent to the definition used in management related literature utilized by the FFA, PrepCon and WCPFC where FADs are defined as:

> *"any man-made device, or natural floating object, whether moored or not, that is capable of aggregating fish"*

These definitions group all types of man-made FADs (anchored and drifting) with naturally occurring flotsam such as logs, branches, seaweed, etc. This is equivalent to the term "floating object" which is used to describe catch and effort on tuna schools found in association with man-made or natural anchored or drifting objects, i.e. "floating object sets" or "caught in association with floating objects".

However, more specific terms with unambiguous meaning are required for technical discussions on FAD-related issues. For the purposes of this paper, the following terms and acronyms will apply in reference to floating objects that aggregate tuna that can be exploited by fishermen.

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[5] http://www.fao.org/fi/glossary/

- **Anchored FAD (AFAD)**: Any floating object moored directly to the bottom of the ocean purposely set for the purpose of aggregating fish to enhance fishing operations.

- **Drifting FAD (DFAD**): Any freely drifting object used for the purpose of aggregating fish to enhance fishing operations. This can include purpose-built DFADs (i.e. rafts, netting, plastic floats) and also natural drift objects that have been altered to enhance the aggregation of pelagic species (i.e. netting, bamboo or floats attached, natural drifting objects tied together, etc.)

- **Natural drifting FAD (LOG)**: Any drifting object encountered by fishermen on the high seas capable of fish aggregation, either of natural origin or man-made flotsam or jetsam (e.g. drift logs, lumber, rubbish, discarded rope, cable spools, dead whales, etc.)

- **Floating Object (FO)**: Any floating object, either anchored or free drifting composed of any combination of natural or man-made materials that is capable of aggregating fish. Therefore, floating objects can be AFADs, DFADs or LOGs.

- **Live FADs (LFAD):** Any living animal capable of aggregating fish that is targeted or encircled during fishing operations. Note, dead drifting whale carcasses would be considered LOGs in this paper.

7.2 FAD descriptions

7.2.1 Anchored FADs

7.2.1.1 AFAD development

Anchored FADs (AFADs), or payao have been used in the Philippines since before WWII to concentrate large tuna for handline fisheries (de Jesus 1982). Early Philippine AFADs consisted of simple bundles of bamboo or rafts anchored in coastal waters (**Figure 1**). More elaborate and robust bamboo rafts held together with material from automobile tires have used and many are still encountered in the south and central Philippines (**Figure 2**). Almost every country and territory in the WCPO and several in the Indian Ocean have developed domestic AFAD programs to enhance artisanal troll and handline pelagic fisheries ((Preston 1990; Itano 1995). This paper will not consider these artisanal/subsistence/recreational programs but will concentrate on FADs as they have been used to enhance medium and large-scale commercial fisheries. FAD based or FAD dependent purse seine fisheries are currently the main concern of the Commission due to the efficiency of this gear type to exploit small and juvenile tuna. However, industrial scale pole and line fisheries and concentrated handline fisheries for large tuna that rely on FADs will also be discussed. Thousands of AFADs are spread throughout the central and southern Philippines and northern Indonesia in the region of the Sulu Sea, Moro Gulf and Celebes Sea that support all gear types. In the Philippines, AFADs support small purse seine and ringnet fisheries for small-sized tropical tuna and handline fisheries for large yellowfin, bigeye and other pelagics.

7.2.1.2 AFAD Fisheries – Handline and Pole and line

The municipal handline fishery for large tunas and billfish comprises a significant fishery in the Philippines. However, it is estimated that more than half of the domestic catch is taken outside Philippine waters, primarily in Indonesia (Barut and Garvilles 2006). The main vessel type are diesel powered double outrigger *bancas* similar to the one pictured in (**Figure 3)**. The vessels are approximately 3 – 5 gross ton with an average crew size of six men and make 6 to 10 day trips (Itano 2000). These vessels target large FAD associated yellowfin but also take large bigeye tuna and billfish (**Figure 3**). Babaran (2006) reported the mean lengths of Philippine landings of handline caught yellowfin, bigeye and albacore tuna at 116.2 cm, 126.3 cm and 105.2 cm respectively.

Large tunas are graded on landing with the highest quality fish sent to sashimi markets while lower grades are used for fresh markets, are treated with carbon monoxide for export or are used by canneries. The fishery is based on large pelagics found in association with anchored FADs. This style of handline fishing also exists in Indonesia and has been exported to areas of Papua New Guinea where Philippine-style purse seine operations have become active in recent years.

The Fiji domestic pole and line fishery began in 1976 averaging around 4,000 t/year supplying product to the Pacific Fishing Company (PAFCO). The vessels operated on AFAD associated and unassociated schools but is now essentially defunct. The same can be said of the pole and line fisheries of Papua New Guinea, Palau, Kiribati and Tuvalu. Small or remnant pole and line fisheries that operate seasonally on AFADs still exist in Hawaii and French Polynesia.

The Solomon Islands has had a domestic or joint venture pole and line fishery within its EEZ since the early 1970s with more reported landings close to or above 20,000 t per year throughout the 1980s and to 1999 (WCPFC 2005). The fishery has relied heavily on a large network of AFADs anchored by the fishing companies and mainly in archipelagic waters. Only five pole and line vessels were active in 2005 but two new modern vessels were added to the fleet to supply the domestic cannery.

Large numbers of AFADs have supported Indonesian domestic pole and line and handline operations (**Figure 4**, Merta and Gafa 1992). The main target species is skipjack that supplies local canneries and raw material for *arabushi* production for use in the production of Japanese *katsuobushi*. In recent years, the pole and line fishery has declined with the increase in activity by Philippine based or affiliated purse seine operations.

7.2.1.3 AFAD Fisheries – Purse seine and ringnet

Small scale purse seine ventures based on anchored FADs have been attempted in several WCPO, Pacific Island countries and territories as reviewed in Itano (1995) and Itano et al. (2004). FAD-based purse seine operations taking place during the 1980s, often involving only one or two vessels were described or noted in the Marshall Islands, Samoa, Wallis and Futuna, Fiji, Tonga, French Polynesia, Federated States of Micronesia and the Solomon Islands. Commercial purse seine ventures based on anchored FADs in Fiji (Pacific Fishing Company, Mar Fishing Company), FSM (Caroline Fishing Company, Mar Fishing Company) and the Solomon Islands (Solomon Taiyo, Ltd) are described in greater detail in these documents.

The experiences of the New Zealand flag purse seiners F*V Western Pacific* and *Western Ranger* and the Philippine flagged *FV Heron* in Fiji are described and alanysed in detail by Itano (1989). With the exception of the Solomon Islands experience, these early attempts at anchored FAD based purse seining outside the Philippines did not persist for long or enjoy significant financial success. Reasons for termination of these projects included inadequate mooring designs for open ocean environments, FAD vandalism and setting by other vessels, small vessel size, short/shallow net and strong currents. In the higher latitude areas away from the equatorial purse seine grounds, profitability was hindered by strong seasonal Trade winds, currents and strong fluctuations in seasonal availability of tuna (Itano 1989).

The Solomon Islands operated successful single and group purse seine operations since 1984 on a large anchored FAD array surrounding the Solomon Island archipelago, initially through the Japanese backed Solomon Taiyo, Ltd. In 1988, two medium-sized 499 GRT single purse seiners began operations primarily on the same anchored FADs for the National Fisheries Development, Ltd. (NFD) (Lawson 1992). After overcoming many operational difficulties, the single seiners operated with considerable success on anchored FADs prior to disruption of operations brought about by domestic instability and economic uncertainty within the Solomon Islands. During 2005, NFD operated three purse seiners in the Solomon Islands EEZ and four small seiners (<100 GRT) were operated by Global Fishing Company (Diake 2006). When fully operational, the Solomon Taiyo group purse seiner was very productive, landing over 5000 t per year at CPUE greater than 30 t per fishing/searching days (WCPFC 2005). Domestic fishing activity has improved significantly with greater domestic stability.

A number of factors appear to benefit the Solomon Islands in relation to FAD based purse seine and pole-and-line operations that include: relatively calm and protected waters, year around tuna and baitfish resource, archipelagic attraction and retention of tuna, reduced likelihood of vandalism by foreign fleets, local transshipment, with close proximity to offloading and processing facilities.

Barut and Garvilles (2006) note 200 small/medium purse seine and ringnet vessels (<250 GT) operate within the Philippine EEZ similar to those pictured in **Figure 5**. The small purse seine and ringnet vessels target small pelagics and juvenile yellowfin and skipjack tuna generally less than 30 cm in fork length (Babaran 2006). A large number of support vessels operate with each catcher vessel that include light boats, sonar boats, tankers, refrigerated carriers or brine boats. Fishing effort by these vessels is based almost exclusively on anchored FADs in the southern Philippines..

The greatest success in development of anchored FAD associated purse seining in the WCPO region has been achieved through the export of Philippine technology and effort to Indonesia and PNG. Barut and Garvilles (2006) recorded 70 Philippine purse seiners (>250 t) and 350 support vessels that operate outside the Philippine EEZ that supply Philippine and Indonesian-based canneries. These vessels are larger than the domestic ringnet and purse seine vessels that operate in the Moro Gulf but are generally less than 800 t. Many of these vessels operate on anchored FADs in Papua New Guinea or Indonesia with a small number operating under access agreements with FSM, Kiribati and other PINs. Forty two purse seiners were licensed to fish in PNG waters in 2005 with 22 of these regarded as domestic vessels. Fourteen of these are Philippine flag vessels associated with a PNG based cannery where catches are landed and processed (Kumoru and Koren 2006). These and other vessels operated by Philippine origin companies operate under domestic access arrangements and fish almost exclusively on several hundred purpose set anchored FADs within archipelagic waters of the Bismarck Sea and adjacent areas to the north **(Figure 6**). FAD-based purse seine fishing in PNG is monitored under conditions of the National Fish Aggregating Device Management Policy administered by the National Fisheries Authority that mandates a maximum of 1000 anchored FADs for commercial surface fisheries in the PNG EEZ.

7.2.1.4 AFAD design

Bamboo rafts are still used to support purse seine and ringnet operations in some locations where it is locally available (**Figure 7**). However, most of the AFADs now in use for large-scale purse seine operations controlled by Philippine interests conform to the types depicted in **Figure 8** to **Figure 10**. These consist of either a flat rectangular steel raft or a cylindrical steel float. Often, some form of vegetation is positioned vertically on the float to increase visibility by the fishing or support vessels. These AFADs are seldom if ever lit or marked with radar reflectors or other navigational aids. The most common type used in PNG are foam filled steel cylinders with a rounded nose cone measuring approximately 3.5 m long x 0.8 m in diameter. The buoys are moored with sheathed steel cable and polypropylene line attached to clusters of concrete filled steel petroleum drums. Portions of automobile tires are used to attach anchors and floats to the mooring system (**Figure 11 to Figure 13**).

Coconut fronds, unlayed polypropylene rope, plastic strapping and other materials are usually suspended beneath the anchored FAD float. These are believed to help attract baitfish and tuna (**Figure 14**). These materials are referred to as “FAD appendages”. The efficacy of these materials has not been scientifically proven but they are commonly deployed, especially with the Philippine purse seine fleets. **Figure 15** provides an underwater view of an anchored FAD set in support of purse seine operations. The mooring line is attached to a steel swivel with automobile tire shock absorber. Additional automobile tire rings are suspended from the stern of the float which are used to attach appendages. On this particular FAD, a separate rope held bunches of coconut fronds that were weighted down to position them at approximately 25 meters or more below the float.

7.2.2 Drifting FADs

7.2.2.1 DFAD development

The use of drifting FADs to aggregate tuna has developed in all ocean basins as a way to take advantage of the behavioral tendency of tuna to associate with natural drifting objects. **Figure 16** shows a typical natural drift log marked with a radio buoy by a WCPO purse seine vessel.

Natural drift objects can be enhanced by tying several logs together or adding floats and surplus netting to add buoyancy and mass (**Figure 17**). A LOG so enhanced would be considered a DFAD by regional observers onboard purse seiners (P. Sharples pers. comm.) and for the purposes of this paper. The development and use of drifting FADs was initially promoted by the U.S. National Marine Fisheries Service in the Eastern Tropical Pacific as an alternative fishing method to setting on tuna associated with dolphins. Several different drifting FAD designs were tested in the ETP from 1990 – 1994 and proved highly successful in aggregating juvenile tuna (**Figure 17** from Armstrong and Oliver 1995). However, the objective of developing an alternate method of capturing large yellowfin as are taken in dolphin-associated schools was not achieved. Over time, all the major WCPO purse seine fleets and purse seine fleets worldwide have incorporated drifting FADs into their fishing strategies.

7.2.2.2 DFAD Design

The drifting FADs tested and described by Armstrong and Oliver (1995) consisted mainly of simple rafts or bundles of purse seine corks wrapped with purse seine webbing with a weighted vertical panel of netting suspended beneath the floatation similar to **Figure 18**. The netting was hung below the FAD 11 – 18 meters. Some drifting FADs were enhanced a drum of fish oil that was thought to attract baitfish. The **Figure** also shows a Japanese DFAD constructed of bamboo with additional floats.

Different styles of drifting FADs for purse seine operations are described in detail by Itano et al. (2004) as used by purse seine fleets from USA, Japan, Korea and Chinese Taipei. Most DFADs consist of a FAD float constructed of purse seine corks or a bamboo raft with additional corks added for flotation as shown in **Figure 18 - Figure 19**.

US purse seine captains interviewed by Armstrong and Oliver (1995) felt that the deployment location of a drifting FAD, ease of storage, deployment and recovery was more important than expending a great deal of effort on designing special features into the FAD float structure. In this regard, the DFADs constructed of a row of purse seine floats are superior as the sub-surface netting can be rolled around the float for storage. Although surface float types vary, all WCPO purse seine fleets appear to construct their DFADs with a considerable amount of sub-surface netting or other materials that are weighted to hand vertically in the water column. Itano (1998) discussed the importance and possible significance of the hanging panel of netting on DFADs:

> *"This generalized <DFAD> design varies from vessel to vessel, but there is a consensus among fishermen that a significant amount of subsurface area is important to a successful FAD.* It is common knowledge in the fleet that the most successful natural drifting object besides a dead whale is a large log that has become waterlogged and floats vertically with only a small portion above the surface (Hampton and Bailey, 1993). Several theories have been put forth to explain the importance of sub-surface structure to drifting and anchored FADs, including:

- vertical logs are vertical because they have become waterlogged with time and have been in the water longer and have had more time to aggregate tuna;
- sub-surface mass holds or tracks better in the water column, positioning the FAD in productive current gyres or current boundaries, rather than drifting with surface winds;
- sub-surface structure offers greater surface area for shelter and habitat for baitfish and

associated drift communities, including juvenile tuna;

- tuna <may> discern, locate and aggregate to logs or FADs with large a sub-surface area at greater distances either through auditory, visual or other means.

> *The reason for the apparent success of FADs with large sub-surface structure is not clear but the fishermen believe this to be true and fashion their drifting FADs accordingly. The predictable drift of FADs that hold well in the prevailing current is an additional benefit as one vessel may be tracking and monitoring more than 10 FADs at the same time.*"

The European Union purse seine fleets of the Atlantic and Indian Oceans rapidly adopted DFAD technology into their fishing strategies. Initially, EU seiners in the Indian Ocean fished on unassociated schools but the use of free drifting bamboo rafts became more common in the 1990s as described by Morón, et al. (2001). Purse seining on floating objects and DFADs in particular has become the dominant fishing mode in the Indian Ocean, particularly in the Somalia gyre and around the Seychelles plateau. **Figure 20** shows the older style bamboo raft DFADs used by EU purse seiners in the Indian Ocean stacked on the deck of a large purse seine vessel.

As noted earlier, the configuration of DFADs below the surface is particularly interesting and appears to play an important role in the aggregative dynamics of DFADs. **Figure 21 and Figure 22** show sub-surface views of drifting FADs supported by bamboo rafts similar to those pictured in **Figure 20**. The **Figure**s show rafts with one to three lengths of nylon purse seine webbing suspended from the rafts. The webbing is weighted down with sections of chain, steel purse cable or steel pipe to a depth of 15 – 25 m (Itano, Taquet pers. obs.).

The importance of the subsurface netting to fishermen and their DFAD construction is clear. To emphasize this point, it has been observed that newer style drifting FADs used in the Indian Ocean do not have any surface raft or floatation at all aside from some purse seine corks and the radio/GPS buoy. **Figure 23** shows two styles of sub-surface DFADs currently being used in the Indian Ocean to support purse seine operations. Carefully ballasted plastic oil drums suspend the nylon netting appendage. This style of DFAD is becoming increasingly popular as it reduces the visibility of the FAD which reduces poaching of associated tuna schools by other vessels. It is not known to what degree this style of DFAD is in use in the WCPO.

7.2.2.3 DFAD enhancements

Advancements in marine electronics and radio buoys have made DFADs extremely efficient and significantly increase the effective fishing effort of purse seine vessels. DFADs can be equipped with autonomous sonar buoys that can report GPS position, current speed, SST, battery condition and sonar images of the associated tuna schools to the catcher vessel located thousands of miles away. The use of marine electronics to enhance FAD operations can be common to AFADs and DFADs and will be discussed in a separate section below.

Improvements to the ability of DFADs to aggregate tuna is another subject and little information is readily available to the research and management community. The use of chum barrels filled with fish oil was noted in the EPO by Armstrong and Oliver (1995) but its use in the WCPO has not been noted. Kumoru (2002) reported on experimental FADs equipped with an underwater light for bait attraction but the status of similar developments has not been updated (**Figure 24**). Lennert-Cody et al. (2007) examined gear influence on bigeye catch by EPO purse seine vessels. Greater depth of the FAD aggregator and deeper nets were positively correlated with bigeye catch, but geographic location within the EPO had the highest influence on bigeye catch. It was noted that a relatively small number of vessels caught a disproportionately high percentage of the EPO surface bigeye catch suggesting that other gear or operational factors may influence higher bigeye catch rates (Harley et al. 2007).

8 FAD fishing methods

8.1 AFAD – Handline and pole and line fishing methods

Fishing on AFADs with handline and pole and line gear simply implies fishing in proximity to the AFAD to target the tuna and pelagic species found associated to the buoy. The Philippine and Indonesian handline fishery is interesting as it appears to be based entirely or almost entirely on fishing on anchored FAD associated tuna; both for bait and for the larger target tuna species and billfish. Yamanaka (1990) and Itano (2000) reported that single handlines are baited with scads and small tunas jigged at anchored FADs and deployed at depths of 100 – 200 meters using large circle hooks and lead weight.

Pole and line fishing in the Solomon Islands is carried out in a similar manner to that described for Japanese style vessels by Ben-Yami (1980). The vessel types and fishing methods used by Indonesian pole and line boats when fishing on anchored FADs is described by Itano (1993) and Subani and Barus (1988/89).

8.2 DFAD – purse seine fishing methods

Purse seine operations on drifting FADs are essentially identical to setting procedures as described for fishing on natural floating objects (LOGs), usually referred to as “log fishing”. Detailed technical descriptions of purse seine setting on LOGs are provided in given in Gillett (1986a; 1986b), Farman (1987), Itano (1990, 1991). The WCPO Pacific seine fishery of PNG and the FSM was originally based on purse seining on logs and natural floating objects that originate in the western area of the fishery and collect along the Equator on east/west current boundaries that form between the North Equatorial Current and the Equatorial Countercurrent. The critical difference with DFADs is that they can be purposely set in locations devoid of LOGs but thought to be favorable to tuna aggregation or set upcurrent and allowed to drift through areas while they aggregate tuna schools. This practice is well known among industry and has been conducted since the beginning of DFAD use in the region.

DFADs and promising LOGs are deployed with some type of radio buoy to facilitate relocation and monitoring. More advanced types can transmit an estimate of school biomass density and depth. Promising DFADs are evaluated using scanning sonar by the catcher vessel or sonar-equipped support vessel before a decision to set is made. Sets on floating objects in the WCPO are almost always made in the few hours before dawn. This has to do with the extreme clarity of water and great depth of the thermocline in the WCPO that greatly reduces the success rate of daytime sets. This is in contrast to purse seine operations in other oceans where water clarity is greatly reduced or where shallow thermocline depths make purse seining relatively easy throughout the day such as in the Eastern Tropical Pacific and western Indian Ocean.

Vessels either tie up to the DFAD or drift at some distance from the DFAD at night depending on fleet practices and personal preference of the captain. Artificial light may be deployed near the DFAD to enhance aggregation but this is not always practiced. The aggregation can be assessed by the catcher vessel using sonar or by support vessels using echo sounder and radio communication or by tele-sounder devices on support vessels that transmit echo sounder images to the catcher vessel as described by Itano (1991). .

WCPO sets on floating objects begin approximately two hours before first light. A small auxiliary craft ties up to the DFAD to slowly maneuver the object during the set, assess school density/depth and to deploy underwater bait attraction lights (if used). The catcher vessel slowly circles the object to assess school size, relative location to the floating object and school depth prior to the set. Information from sonar, Doppler current meter and sea state is evaluated to position the vessel in the optimal orientation to the floating object to begin the set.

The actual fishing operation commences approximately one hour before first light and is timed to take full advantage of the tendency of tuna (including bigeye) to be relatively shallow during the early morning hours (especially on floating objects) before descending at dawn. The main determinant of setting time is based on the length of time a particular vessel requires to complete the set and purse the net. Pursing should be well advanced by the time of dawn. The success rate on floating object sets is very high as the schools are stabilized under the log but still unable to see and avoid (dive below) the net in pre-dawn darkness.

The mechanics of the set proceed as for any tuna purse seine operation except the DFAD may be maneuvered within the net circle to position the school and pursing may be intentionally slowed to allow the net to descend to its maximum operational depth. As for log fishing, the DFAD may be towed directly over the corkline or slowly towed out between the vessel and the stern end of the seine to encourage associated bycatch species to leave the net, i.e. rainbow runner, oceanic triggerfish, mackerel scad. Normally the tuna will remain deep in the seine during this process while the smaller FAD-associated species will remain close to the floating object. Unfortunately, sharks often remain inside the net.

After pursing is complete, the DFAD is normally tied to the catcher vessel opposite the net to allow a check of the radio buoy device and to allow scattered bycatch species to re-associate with the DFAD. The presence of the associated bycatch species is believed by some fleets to enhance the ability of a floating object to attract tuna schools. Also, avoidance of bycatch reduces the time required to remove gilled fish from the net and sort catch during the fish loading process (Hampton and Bailey 1993).

8.3 AFAD purse seine fishing methods

Purse seine fishing on anchored FADs is more complicated as the FAD mooring line must be excluded from the set to avoid tangling the net and purse cable. Setting occurs before dawn in the WCPO fishery allowing the use of powerful underwater lights to draw the school away from the FAD mooring line. A small generator equipped light vessel attempt to drift the school down current from the mooring line. FAD appendages may be transferred to the light vessel to encourage the school to move away from the FAD while another small tow boat pulls the FAD float and mooring line upcurrent. A detailed description of this process is given in Bailey et al. (1994). A variety of vessel types that use artificial light to enhance AFAD fishing operations are described in a later section that describe auxiliary vessels to purse seine operations.

8.4 purse seine fishing methods

Live FADs refer to large marine animals that either aggregate tuna or somehow increase catch rates of tuna due to their presence. Tuna are known to form slowly moving associations with whale sharks and manta rays. However, during purse seine operations it is believed that the whale shark is often not detected until after completion of the set which is conducted like a free school operation. Large schools of non-tuna species are also common on whale shark associations, i.e. rainbow runners and mackerel scads. Whale sharks associated schools were regularly fished when the domestic PNG pole and line fishery was active and Indonesian pole and line boats also target whale shark associated schools (Itano pers. obs).

In the eastern Pacific Ocean, yellowfin tuna of larger sizes associate with dolphins (e.g. *Stenella attenuata, S. longirostris, Delphinus delphis*) and are targeted by purse seine and pole and line vessels. For whatever reason, tuna/dolphin associations are extremely rare in the WCPO and are not exploited by purse seine.

9 Auxiliary equipment

9.1 Electronics

The efficiency of purse seining on floating objects has increased in a step-wise fashion in time with technological developments in sonar and radio transmitting buoys. However, improvements in communications, increased use of satellite imagery and radar (for detection of DFADs) have also increased DFAD efficiency over time. These advancements allow purse seiner vessels to minimize search time, assist in the detection of DFADs set by other vessels and help direct vessels to the most productive fishing grounds and DFADs available. Advances in marine electronics that improve DFAD efficiency are described in detail by Morón et al. (2001) and Itano (2002; 2003).

GPS receivers were incorporated into transmitting radio or satellite transmitting buoy design in the 1990s which revolutionized tuna purse seine fisheries. These devices are attached to DFADs and can transmit the position, SST, course, speed, current data, and battery state to the catcher vessel at distances of 1000 nm or more. **Figure 25** shows the Serpe style GPS radio buoy that is commonly used by EU purse seine fleets. Radio buoy antennae can be detected by high definition radar which has promoted the development of low profile GPS radio buoys that reduce poaching of DFADs by other vessels. Limitations on power limited by battery lifespan have been overcome by the incorporation of onboard solar panels to maintain battery power. **Figure 26** shows newer style low profile GPS radio buoys with no visible antennae, an integrated buoy tracking system and a solar powered GPS radio buoy.

More advanced GPS satellite linked buoys act as remote sonar units capable of transmitting an image of biomass density and depth to the catcher vessel (**Figure 27)**. A variety of low-profile GPS radio buoys are shown in **Figure 28**, including sonar transmitting and solar powered units. Recently developed echo sounding radio buoys can reportedly transmit a much improved image of fish beneath an AFAD useful for more accurate biomass and even species recognition.

In general, marine electronics to assist DFAD purse seining serves three main purposes:

- to remotely provide fishing captains with real time information on position and aggregation levels;
- to help conceal their DFADs from other vessels; and
- to assist in the detection of other operators' DFADs.

9.2 Auxiliary vessels

In addition to light boats, a variety of auxiliary craft assist AFAD and DFAD purse seine operations. Small towboats are used to maneuver LOGs and DFADs during the set and to tow them out of the seine after the net has been pursed (**Figure 29**). Specially fitted search boats such as the one pictured in **Figure 30** are a key component of Japanese group seine operations, significantly expanding the effective searching range of the catcher vessel. This particular vessel measured 35 m and used sonar and bird detecting radar to assess tuna schools associated with drifting objects and to search for surface schools. The vessel was also used as a large light boat on floating object sets and was equipped with a tele-sounder that sent echo sounder readings to the catcher vessel. A saltwater spray system was also installed on the vessel similar to those used by pole and line vessels and used n attempts to stabilize unassociated tuna schools prior to setting operations (Itano, 1991).

A small auxiliary light boat to assist a single purse seine vessel for AFAD operations is shown in **Figure 31**. Larger light vessels of approximately 15 meters are used in large-scale AFAD seining operations such as those existing in Papua New Guinea which are actually based on Philippine style AFAD purse seine groups. Larger vessels of approximately 30 – 40 m are called "Ranger boats" are an integral component of Philippine style AFAD operations. Ranger boats maintain and deploy anchored FADs, reprovision catcher vessels, transfer crew and observers at sea, assess tuna abundance on FADs, and protect company FADs from being set on by other vessels. A Ranger boat loaded with mooring line, appendages and a FAD float ready for deployment is shown in **Figure 32**. Some of these functions will be shared with the smaller light boats.

The Spanish purse seine fleet operating in the western Indian Ocean are assisted by two types of supply vessels: mobile and anchored. Arrizabalaga et al. (2001) conducted observer trips on these vessels and describes their activities in detail. Mobile supply vessels assist the operations of a single seiner or a group of vessels in relation to DFAD fishing in a similar way that ranger boats assist

AFAD operations. The primary duty of a supply vessel is to search for DFADs and LOGs and to build, deploy and repair their own DFADs while assessing tuna abundance on any floating object encountered. If a productive DFAD belonging to another vessel is located, the supply vessel will generally exchange radio buoys and claim it as their own. If other vessels are nearby, the supply vessel will protect a productive DFAD by remaining in close proximity to it until its catcher vessel arrives. These vessels are also used to exchange crew with the catcher vessel, evacuate injured crewmen, deliver provisions and assist with at sea repairs.

Anchored supply vessels are a special category currently referring to two large vessels that are permanently anchored on the Coco de Mer Seamount north of the Seychelles, Indian Ocean. The seamount itself aggregates tuna schools while the large anchored vessels act as huge AFADS. Their primary purpose is to reserve the seamount summit for the sole benefit of catcher vessels from their respective companies. These vessels also operate a large array of surface lights every night to further enhance the aggregation effect (Itano 2002). **Figure 33** shows a mobile FAD supply vessel and anchored supply vessels operating in the Indian Ocean. Note the large array of quartz lights on ringing the bridge of the anchored supply boat.

10 Spatial and temporal patterns of FAD use in the WCPO

10.1 Overview of purse seine catch by set type

This section will describe the general pattern of AFAD, DFAD and LOG use in the WCPO as it applies to the major purse seine grounds roughly bounded by 130°E - 142°W longitude and 10°N - 10°S latitude in relation to bigeye and yellowfin catch and effort.

Combined purse seine effort and effort by set type for 1999-2005 is shown in **Figure 34** from Williams and Reid (2006). WCPO purse seine effort generally extends eastward of 160°W during El Niño conditions and contracts westward during La Niña periods to the historical purse seine grounds of PNG and FSM. Purse seine effort by set type is shown in the right portion of **Figure 34**. The importance of unassociated and DFAD sets to the eastern area (1999-2002) is evident including a significant eastward shift of unassociated sets during the 2002 El Niño event. Reduction in DFAD use from 2003-2005 may be related to an unusually high availability of natural logs east of 160°W in 2002 followed by a contraction of the fishery westward where unassociated and log associated schools were located. Purse seine effort on anchored FADs is only significant in PNG and to a lesser extent in the Solomon Islands.

Figure 35 indicates the spatial distribution of purse seine tuna catch by species for years 1999-2005 (left panel), reinforcing the multi-species nature of the fishery which makes bigeye-specific management extremely difficult. ENSO state is noted for each year. Reported bigeye catch are directly proportional to the incidence of yellowfin taken in floating object sets which are shown in the previous **Figure 34.** The purse seine catch by set type for skipjack, yellowfin and bigeye are shown in **Figure 36 and Figure 37**. Unassociated and DFAD yellowfin catch was important east of 160°W in 1999-2002 contracting westward as noted earlier. The influence of DFAD, LOG and AFAD effort on bigeye catch is very clear in **Figure 37.** Bigeye catches increase for all floating object categories since 2003. However, high skipjack catches are closely linked to both yellowfin and bigeye catch, particularly for DFAD, AFAD and LOG associated effort.

Figure 38 to **Figure 40** indicate quarterly purse seine catch for yellowfin LOG sets (**Figure 38**), DRIFTING FAD sets (**Figure 39**) and ANCHORED FAD sets (**Figure 40**) for the period 2001 – 2006. The same data is represented for bigeye tuna in **Figure 41**, **Figure 42** and **Figure 43**. Note that these **Figure**s are extended westward to include the Philippines and eastern Indonesia. The dichotomy between catches by (1) log sets in the west, (2) drifting FAD sets in the east, and (3) anchored FAD sets in PNG, Solomon Islands, Indonesia and the Philippines is clear for both yellowfin and bigeye. ANCHORED FAD sets are basically restricted to the waters of the Philippines, Indonesia, PNG and the Solomon Islands. LOG sets predominate in the western area of the fishery while DRIFTING FADs are more often used in the eastern area where natural LOGs are less abundant.

10.2 Spatial and temporal patterns of FAD use by fleet

Annual trends in purse seine effort (top) in days fished or searched and catch (t) for the five major purse seine fleets for the period 1996 – 2005 are shown in **Figure 44**. Catch and effort by the Korean and Japanese fleets has remained relatively stable over the period. Trends in US participation and catch have declined since 1999 but may increase with two vessels returning to the region from the EPO and possible expansion of fleet numbers in coming years. Trade offs in catch and effort may be linked to inter-annual shifts in the ratio of associated vs unassociated fishing effort. Chinese-Taipei fleet has been the lead producer until being surpassed by combined Pacific Island fleets operating under the FSM Arrangement. This tradeoff in catch and effort is correlated to the re-flagging of Chinese Taipei vessels to operate within the FSM Arrangement.

Similar information for total percentage of catch from the fishery by fleet (1988 – 2006) is shown in **Figure 45**. The dominance of Japan and the US during the earlier years of the time series has been diluted by a rapid development of Korean and Chinese Taipei fleets during the early 1990s followed by more recent development of Pacific Island participation. During this period, catch by Japanese vessels has remained relatively constant compared the gradual decline of catch by the US due primarily to reductions in fleet size.

In terms of total catch, **Figure 46** provides the same time series of catch from the major DWFN fleets in comparison to smaller fleets that rely heavily on floating object sets. Note that the scope of catch and vertical scales differ with Chinese Taipei, Japan, Korea, USA and FSM Arrangement fleets set to 275,000 t while plots for the Solomon Islands, PNG Domestic fleet and Philippines distant water set to 80,000 t.

In general, the proportion of unassociated sets increased slightly for the major fleets in 2005 but the Korean fleet continued to be concentrates on unassociated schools (80% of all sets). In relation to floating object sets, the Asian purse seine fleets have had a higher proportion of LOG sets vs DFAD sets compared to US and FSM Arrangement vessels that rely more heavily on DFADs. These differences are simply a reflection of the more eastern area of operation of the US and many of the FSM Arrangement vessels where LOGs are less common. The heavy reliance on AFADs is apparent for the Solomon Islands and PNG Domestic purse seine vessels. Philippine DWFN vessels are Philippine flag purse seiners operating outside their EEZ, primarily in the EEZs of Indonesia, PNG and bordering high seas zones operating mainly on LOG schools and AFADs in the outer PNG EEZ.

Figure 47 shows the same data scaled to percentages of set types by fleet. DFAD use by Japan and the US peaked in 1999 after which Japan returned to LOGs while the US has seen a gradual increase in DFAD use since 2003. It is difficult to generalize on the FSM Arrangement vessels as they are made up of a mix of types, but consist of vessels managed by the Pacific Island “Home Parties” of PNG (17 vessels), the Solomon Islands (3), the Marshall Islands (6), FSM (6) and Kiribati (1). Many of these are former Chinese Taipei flagged vessels and still operate in a similar mode, hence the similarity between the set type **Figure**s for Chinese Taipei and FSM Arrangement fleets.

10.3 Catch, effort and FAD use by fleet

This section will provide historical catches and recent spatial distributio of effort for major WCPO purse seine fleets in general order of participation in the fishery. Temporal patterns in FAD use by fleet will be discussed where known.

Williams (2004) examined average vessel catch for WCPO purse seine fleets for the period 1980 – 2003. He noted two distinct periods of entry into the fishery, the first being a period of establishment where vessel numbers and average catch increased gradually and stabilized, followed by a period of consolidation and increasing efficiency. Poor performers dropped out while remaining vessels gradually increased efficiency resulting in gradual increases in annual production.

The Japanese fleet had established by 1983 and been nearly stable since. The US fleet has fluctuated a great deal, establishing by the mid 1980s with rising catch rates followed by declining vessel numbers and production since 1999. The Korean fleet went through a gradual increase in vessel numbers from 1980 – 1990 and shows high variability in production between vessels. The Chinese Taipei fleet increased steadily from 1983 to stabilize after 1992 followed by increasing efficiency.

10.3.1 *Japanese purse seine*

The Japan Marine Fishery Resource Research Center (JAMARC) was charged with the development of distant water purse seine fisheries and helped to perfect techniques to seine on floating objects and improve success rates on unassociated schools (Doulman 1987). Catches rose gradually through the 1970s and have been relatively stable since at close to 200,000 t/yr. Effort for the past two decades has concentrated in FSM, Nauru, the Solomon Islands and neighboring high seas zones (**Figure 48**). Significantly, Japan negotiated bilateral access to PNG in 2006 after being absent from the zone for 19 years. **Figure 49** shows the historical pattern of purse seine catch by set type since 1988. Japan has traditionally relied on floating object sets, having lower apparent interest or success at fishing unassociated schools. Aside from a departure into heavy DFAD use from 1999 – 2001, the fleet relies on locating and fishing LOGs and free schools. However, DFADs have been used by the Japanese since the beginning of the fishery and Gillett (1986b) noted that one observed Japanese purse seine vessel:

> “made extensive use of free-drifting bamboo rafts. These rafts were constructed aboard the vessel, and were set adrift on the fishing ground after being marked with a radio beacon and flashing light. The fishing techniques used in association with these “artificial” logs were identical to those used with those logs encountered by searching”.

JAMARC also experimented with the design and development of DFADs during development cruises of their research purse seine vessel RV *Nippon Maru*. However, DFADs appear to be secondary to LOGs with the Japanese fleet.

Historically, Japanese purse seiners have not pursued unassociated school fish to the extent of some other fleets. One significant difference between Japanese purse seine vessels is the relatively light construction of the seine using knotless webbing. This net style is generally not suitable for maximum pursing speeds or fishing in areas of strong current. On the other hand, the webbing is very efficient for pre-dawn floating object sets where pursing speed is not required. A major advantage of knotless webbing is that it requires very little storage space compared to a comparable knotted seine which allows the relatively small Japanese vessels to carry a large (long and deep) purse seines (Itano 1998).

Another aspect of setting strategy may be linked to marketing preferences and domestic markets. A segment of the Japanese purse seine fleet specializes in catching higher grade skipjack and skipjack is considered a high grade fish in Japanese culture. The skipjack taken on LOGs and floating objects is considered of higher quality and condition in comparison to the large spawning fish taken on unassociated schools (Miyabe pers. comm.).

10.3.2 *USA purse seine*

Expansion of the US purse seine fishery into the western Pacific has been well documented and the fleet became well established by the early 1980s (Doulman 1987, Gillett et al. 2002). **Figure 50** documents historical catches by the fleet since 1976 and the spatial area of operation during 2005. Larger bigeye catches are evident in the data since 1996. This is likely due to a shift toward greater effort on floating object sets in combination with good reporting rates from the US fleet. The vessels worked east of the PNG and FSM EEZs during 2005, concentrating effort in Kiribati (primarily Gilbert and Phoenix Islands), Tuvalu and Tokelau.

There are several issues that relate to FAD use and fishing strategy with the US fleet, but economics, proximity to unloading ports and marketing appear to be important factors. The US fleet entered the western Pacific fishery via the New Zealand skipjack fishery that takes place during the austral summer (Gillett et al. 2002). Oceanographic conditions in New Zealand are similar to the EPO with a shallow thermocline and plankton rich water allowing the vessels to use relatively shallow, short nets to harvest large unassociated schools. However, the season only lasts 3-4 months and conditions on the equator required significant modifications to the purse seine and hauling machinery to accommodate the larger, deeper nets. Successful entry into the WCPO equatorial fishery depended on a significant reliance on LOG fishing and early experimentation with DFADs.

Seasonal abundance of large yellowfin and skipjack on baitfish schools prompted vessels to make further modifications for successful school fish operations in the warm, clear water, i.e. deeper nets, heavier chainline, larger mesh, thinner twine, more powerful purse winch, larger purse block and faster brailing systems (Itano 1998, 2002). Despite the lighter net construction necessary to facilitate a faster sinking and pursing seine, the nets remained heavily built compared to Japanese seines in order to withstand the fast pursing speeds and strong currents necessary to catch unassociated schools. Aside from the challenge and esteem of catching school fish, the main attraction of unassociated schools is related to the larger size and possibility of catching pure schools of large yellowfin with a higher market value. The US fleet was traditionally unique in the region being composed of owner/operators who could benefit directly from a higher value catch making unassociated school fishing more attractive. It is believed that pay bonus incentives are also available to fishing captains and officers in the US and possibly other fleets, but renumeration schemes for all fleets are poorly documented.

Figure 51 indicates US purse seine catch since 1988 by set type. Initially, catch was split between unassociated and floating object associated effort. Success rates on unassociated schools improved with experience and gear modifications throughout the 1980s as the majority of the catch and effort shifted to unassociated sets into the mid-1990s. An unusually high recruitment of skipjack in the early 1990s provided raw material for the US preference for school fish setting, peaking in 1991 when 90% of sets were on unassociated schools and the fleet achieved its peak catch of 216,000 t. Catches were spread throughout the area of the fishery with major unloading and home port facilities established in American Samoa (east) and Guam (west). Negotiation of the US Tuna Treaty in 1988 provided the US fleet almost complete access to the WCPO which proved a great advantage over other DWFNs restricted by annually negotiated bi-lateral agreements. The US vessels could move east and west depending on ENSO conditions and availability of unassociated schools in the eastern region of the fishery.

By 1996 the strategy of the US purse seine fleet began to change with 56% of sets made on DFADs and LOGs in the Kiribati and Tuvalu zones. Floating object sets peaked in 1999 when a remarkable 90% of sets were made on DFADs and 6% on LOGs. Catch rates were very high and made possible in part by the adoption of a faster fish brailing system (Spanish style brailing) and enhanced refrigeration systems to load and preserve large sets.

Coan and Itano (2001) examined factors influencing catch rates of the US purse seine fleet operating in the WCPO and updated the analyses yearly for the Standing Committee on Tuna and Billfish (Coan and Itano 2002, 2003). Two time periods after the fleet had become well established were examined

(2001) characterized as: 1989-1995 period of low DFAD use; and 1996-1999 period of high DFAD use.

The authors noted that changes in overall production between the time periods is likely due to a combination of the shift to DFAD-based seining and a mix of factors related to advancements in fishing gear, technology and experience. The individual impact of all these factors on effective fishing effort are extremely difficult to quantify which prompted the authors to examine general performance factors such as catch per set, catch per year, trip length, etc. The original study was updated in 2002, examining a subset of 15 vessels that were in full operation during the full time period. The study showed on average:

- 18% increase in the number of trips per year;
- 11% decrease in trip length;
- 12% decrease in number of days fished per trip;
- 28% decrease in number of sets per day;
- 6% increase in days with successful sets during the period of high FAD use.

In other words, working with FADs resulted in what FADs are supposed to do, i.e. improve efficiency and reduce search time. Vessels were able to increase the number of full deliveries (trips) made per year and enjoyed fast trips with high catch rates. The shorter times required to fill their holds were accomplished through a combination of a reduction in the number of “zero catch” days during the trip, an increase in catch per set and an increase in catch per day during the period of high FAD use (1996-1999). For example, catch per set increased dramatically by 84% from 25 t/set in 1989-1995 to 46 t/set in 1996-1999, with a peak of 55 t per set in 1999.

The paper notes however that the shift to a fishing strategy based on drifting FADs has resulted in significant increases in the take of small tropical tunas and juvenile bigeye tuna. The reported percentages of bigeye tuna in the catch increased 500% from 1.25% in 1989-1995 to 6.25% during the period of high FAD use (1996-1999). The increased catch of bigeye tunas was also accompanied by a 33% increase in the numbers of small tropical tunas (<7.5 pounds) caught, Although the study did not specifically examine bycatch issues, the authors suggest that levels of FAD associated bycatch had likely increased in a similar manner.

The area of the US DFAD fishery is of great interest in relation to efficiency and changes in fleet dynamics. Fishing operations on DFADs remained in the Gilbert Island, Phoenix Island and Tuvalu zones despite the fact that 1999 was classified as a La Niña year. Under these conditions, the fleet might be expected to operate west of 160°W on LOGs and free schools in PNG and FSM. Also, transshipment at sea was banned in 1993 and the Guam/Tinian purse seine support facilities became insolvent in 1995 forcing the US fleet to rely heavily on Pago Pago for unloading and supplies. Rising oil prices are another likely factor in their preference to remain in the eastern region closer to American Samoa. DFADs offered an opportunity to exploit tuna that were formerly unavailable or difficult to catch when unassociated, and relatively close to home.

DFAD use by the US fleet dropped significantly after 2000 but floating object sets have slowly increased in recent years, accounting for more than half the catch in 2005. The decline in DFAD use was precipitated by extremely low cannery prices and a more discerning US cannery market unwilling to process very small fish or offering very low prices for tuna <40 cm. Self-enforced tie ups resulted in 2001 until prices recovered. One mechanism to overcome low prices was a shift away from DFADs and juvenile tuna in pursuit of larger, higher value yellowfin from unassociated schools. In recent years it appears that the US fleet prefers to operate as far to the east as possible, setting on LOGs and DFADs but exploiting large school fish when available.

10.3.3 *Korean purse seine*

The Korean distant water purse seine fleet began operations in the region in the early 1980s and became fully established by 1990. Fishing practices of the fleet are unique in the region, maintaining a preference for targeting larger, higher-value tuna on unassociated, or free schools. As a consequence, incidental catch of bigeye and bycatch of undersize tuna and other finfish is believed to be low. The spatial distribution of the Korean fleet in 2005 covered a broad expanse of the fishery, from PNG to the Line Islands of Kiribati (**Figure 52**).

The Korean fleet gained a significant advantage on entry into the fishery through the purchase of ex-US superseiner class vessels in the late 1980s. Vessel operators quickly learned how to pursue and catch unassociated schools using similar technology as the US fleet. **Figure 53** indicates a significant reliance on LOG sets from 1994-1999, but unassociated sets remain the preferred fishing mode of the fleet. Catches indicated in the Figure between the Phoenix and Line Islands high in yellowfin represent unassociated schools of yellowfin and skipjack.

However, unassociated sets are in reality sets on tuna schools actively feeding on small baitfish, most commonly the ocean anchovy *Encrasicholina punctifer*. Tuna schools form large feeding aggregations that result in “boiling” or “foaming” schools that are more vulnerable to purse seining. Therefore, regional databases recognize a category of “baitfish associated” sets which are essentially the same as “unassociated” or “free” schools. Most unassociated sets made in the WCPO are actually actively feeding schools (Bailey et al. 1994). Productive areas of baitfish concentrations occur in the WCPO, but they are difficult to predict and subject to strong inter-annual variations in time and space. During times of low baitfish/tuna abundance, the Korean fleet may resort to fishing on more floating objects. Technical information from this fleet is not believed to be well documented or easily available. However, it can be assumed that a preference for targeting unassociated schools is related to the higher value of the catch per ton of storage space onboard and that vessels are well equipped to pursue school fish.

10.3.4 *Chinese Taipei purse seine*

Single and group purse seine technology was introduced to Chinese Taipei by the Japanese during the early 1980s with Japanese fishing masters and US technicians providing training (Wu and Wang 2001). Vessels entered the WCPO fishery in the early 1980s with construction of US style tuna seiners in Chinese Taipei commencing in 1984. After a steady increase in vessel numbers, the fleet was fully established by 1991. The fleet is currently composed of a mix of older <1000 GT vessels and very large, modern and fully equipped ships almost all of which are built in Chinese Taipei.

The fleet entered the region by fishing on LOGs and some DFADs in PNG but have expanded to operate in FSM, Nauru, Kiribati, Marshall Islands, Solomon Islands and neighboring high seas enclaves (Wu 2002). Catch distribution during 2005 concentrated in southern FSM, northern PNG and the high seas zone between (**Figure 54**). During the 1990s, the fleet became increasingly efficient at exploiting unassociated schools during which time catch composition of yellowfin increased. Floating object sets and the use of DFADs peaked in 1999 as for the US fleet and has declined since. However, sets on LOGs and DFADs still produce over half of the annual catch (**Figure 55**).

Little documented information on motivations for FAD use could be located. However, the high incidence of LOG fishing is probably linked to the westward area of operation by the fleet where natural floating objects are more abundant. It can be assumed that vessels will take advantage of baitfish associated schools when available but make floating object sets to maintain catch high rates.

Another aspect of FAD use by some fleets is linked to ability to market and fully utilize small fish. Depending on fleet and processing destination, some fleets will be able to retain and profit from very small fish while others need to meet a minimum size for commercial retention. It may be assumed that the Chinese Taipei fleet and vessels unloading or transshipping to Thailand and Philippine canneries can effectively market relatively small tuna for canning while the US fleet will not retain very small fish.

10.3.5 *Specific fleets operating on FADs*

There are other fleets for which information is less readily available but appear to favor fishing operations on floating object sets (LOGs or DFADs). Some of the older or smaller vessels can not effectively operate on unassociated schools due to technical factors, i.e. small net, slow pursing speed, outdated hydraulic systems. Other fleets listed here are very well documented and are known to rely heavily on AFADs, i.e. PNG, Philippine, Solomon Islands. More detailed information should be obtained on the operational practices of all purse seine fleets.

China – 8 vessels reporting in 2005, operating mostly in FSM and PNG, 48,660 t reported. Ten vessels participating in 2007. Recent logsheet data suggest about an even divide between unassociated vs floating object sets, but the technical parameters of the fleet have not yet been reported.

Indonesia domestic and distant-water – Numerous vessels, many of Philippine origin, operate on anchored FADs and floating objects within the Indonesia EEZ. Poorly reported and documented.

Kiribati – one vessel originating from a Japanese joint venture, no domestic. Reporting in 2005 for 7,105 t for 31.86 t/day operating in FSM, PNG and high seas. Very high catch rates suggest FAD use.

Marshall Islands – six vessels reporting in 2005 for 56,164 t at 43.54 t/day operating mostly within the Marshall Islands, Kiribati and Nauru EEZ. Most or all of fleet consists of ex-Chinese Taipei vessels flagged to Marshall Islands for operation under the FSM Arrangement. The fleet relies almost exclusively on floating object sets with a heavy reliance on DFADs (Muller 2006). (**Figure 56**)

Papua New Guinea – 22 domestic purse seine vessels, 14 of which are Philippine flag and operate with a domestic cannery. Most of the catch is taken within archipelagic waters on anchored FADs. Note the high concentration of anchored FAD catches inside archipelagic waters with high proportion of yellowfin and bigeye catch (**Figure 57**)**.** Nineteen larger locally based foreign vessels operate under the FSM Arrangement and operate in a variety of modes throughout the WCPO (Kumoru and Koren 2006). Well documented and observed. In total, 41 vessels reported 220,079 t in 2005.

Philippine domestic – numerous purse seine and ringnet vessels reporting, with a high proportion of yellowfin and bigeye. Known to rely almost exclusively on anchored FAD sets but operational details are poorly documented.

Philippine distant water – vessels operate in Indonesia, PNG and high seas. High proportion of yellowfin and bigeye is assumed as they rely heavily on anchored FADs and floating object sets. Poorly documented for operations in Indonesia but well reported from PNG. Under conditions of access to Indonesia, no catch data are required to be supplied and no logsheet data is available (Barut and Garvilles 2006).

Solomon Islands – 4 vessels reporting in 2005. Rely heavily on anchored FAD sets. High proportion of yellowfin and bigeye. Well reported.

Spain – 5 vessels reporting in 2005, catch reports not yet available. Thought to rely heavily on drifting FADs. High proportion of yellowfin and bigeye.

Vanuatu – 8 vessels reporting in 2005 for 73,232 t at 39.58 t/day. Concentrated effort in Marshall Islands and Kiribati in 2005. High catch rates suggest FAD use.

11 Summary

The increase in effort by WCPO surface fisheries that target tuna schools found in association with floating objects has contributed to declines in resource condition of yellowfin and bigeye stocks. This is particularly relevant for purse seine fisheries that have increased floating object directed effort by incorporating drifting FADs (DFADs) and anchored FADs (AFADs) into their normal fishing operations. The situation has resulted in a need to reduce fishing mortlity on small or juvenile sizes of yellowfin and bigeye tuna in the Convention Area. One proposed option is to direct management on FADs or all floating object-based effort. Numerous meetings and management related workshops have been convened to discuss these issues and more are inevitable.

A common understanding of technical FAD issues and fishing strategies by fleet is needed to make these deliberations as efficient as possible. This paper attempts to provide a basic understanding of yellowfin and bigeye behaviour in relation to floating objects and describe the technical terms and fishing strategies relevant to FAD-based fishing. Further work is clearly needed to better characterize the operational modes of different fleets and the spatial variability of bigeye catch and abundance throughout the region. Increased liaison and collaboration between scientists and the fishing industry should be encouraged to fill data gaps useful to evaluate FAD related management.

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13 FIGURES

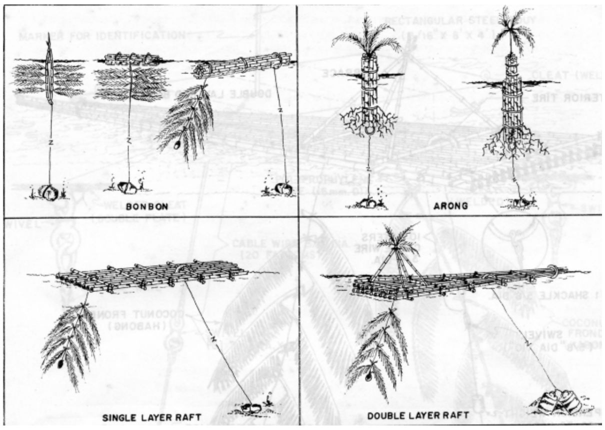


Figure 1. Philippine anchored FADs or payao constructed of bamboo (De Jesus 1982)

Figure 2. Bamboo rafts in the Philippines before and after deployment (photo Itano)

Figure 3. Philippine style handline boat tied to AFAD and crew unloading large handline caught tuna (photo Itano)

Figure 4. Indonesian pole and line boats fishing skipjack on an anchored FAD (photo Itano)

Figure 5. Small purse seine and ringnet vessels that operate on AFADs in the southern Philippines (photo Itano)

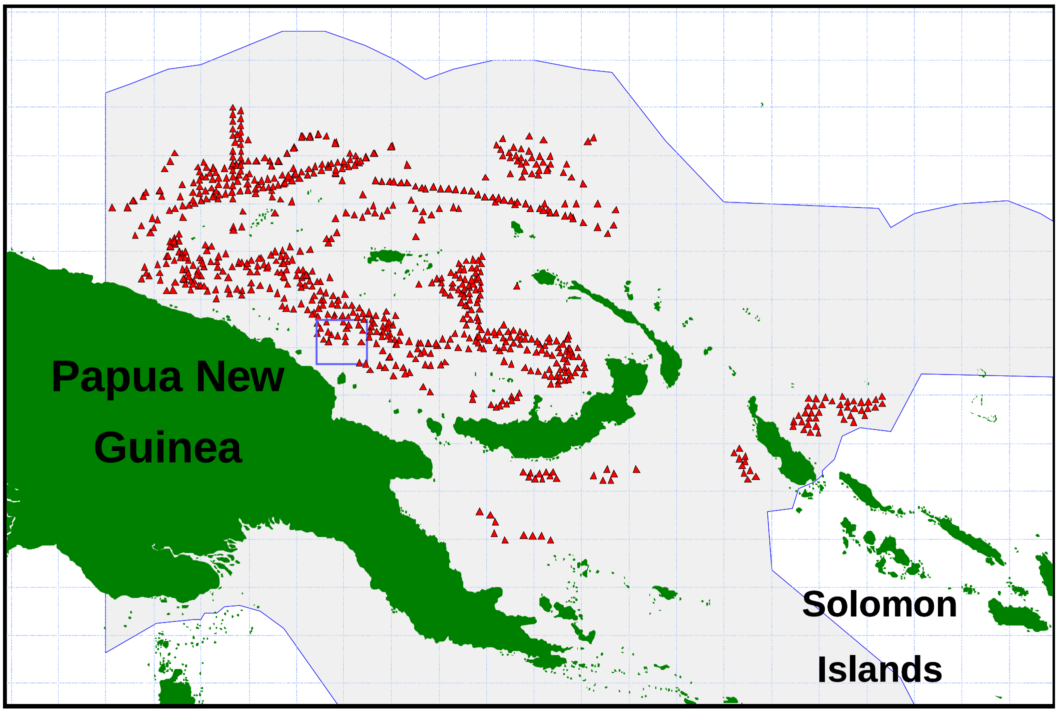


Figure 6. Some of the anchored FAD positions set in support of PNG domestic purse seine operations within the PNG EEZ (SPC)

Figure 7. Bamboo anchored FAD rafts used in the Solomon Islands and Fiji to support purse seine operations (photos Brogan, Itano)

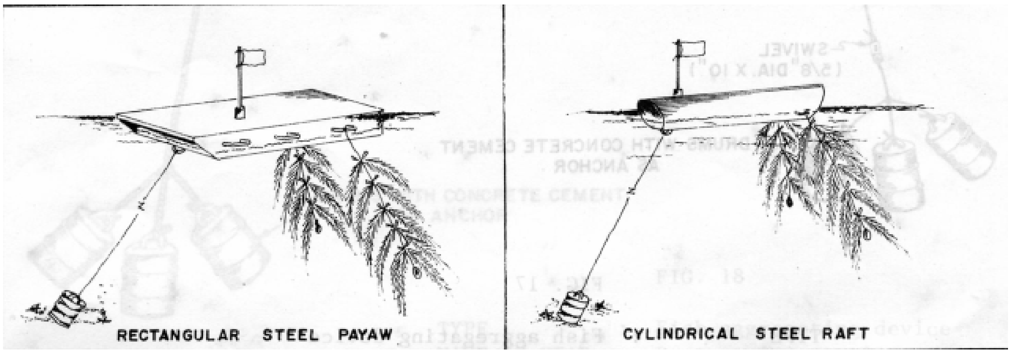


Figure 8. Steel anchored FAD types used to support purse seine and ringnet operations (De Jesus 1982)

Figure 9. Rectangular steel anchored FAD (photo Itano)

Figure 10. Philippine style cylindrical steel anchored FAD (photo Itano)

Figure 11. Newly constructed cylindrical steel anchored FAD floats (photos Fukofuka)

Figure 12. FAD anchors constucted of concrete filled steel drums and concrete anchors loaded on a ranger vessel ready for deployment

Figure 13. FAD mooring cable attached to FAD swivel with automobile tires

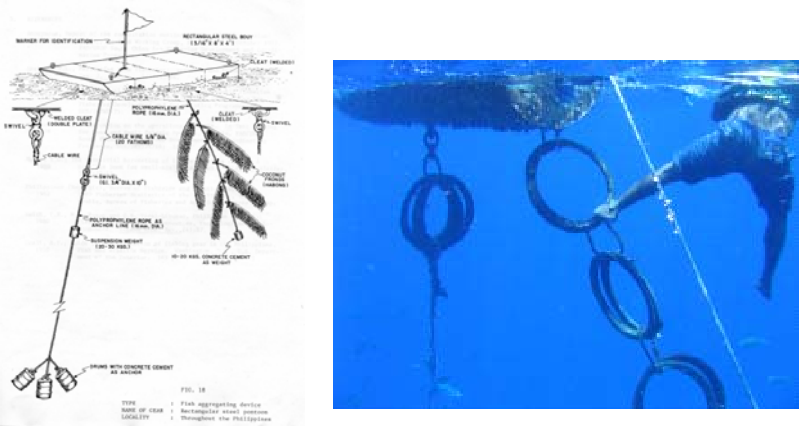


Figure 14. Diagram Philippine style anchored FAD mooring system and underwater view of cylindrical AFAD (photo Itano)

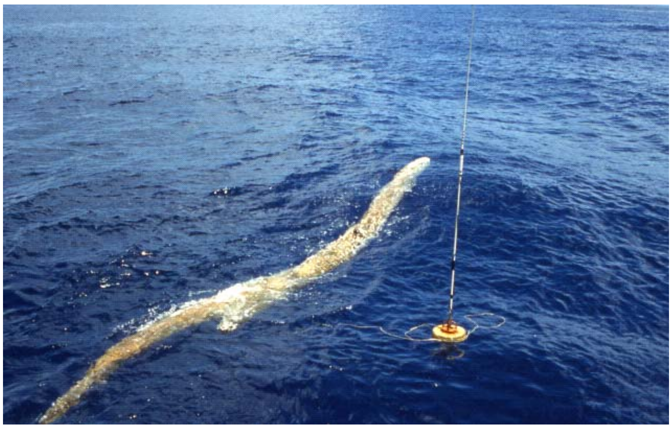


Figure 15. Typical LOG, or natural drifting object marked with a radio buoy to support purse seine operations (photo Itano)

Figure 16. Natural drift log enhanced with bamboo flotation and netting suspended beneath turning it into a drifting FAD (photo Itano)

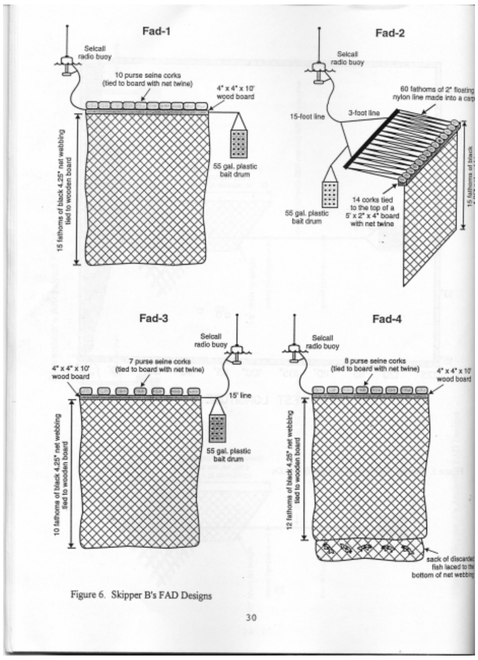


Figure 6. Skipper B's FAD Designs

Figure 17. Experimental drifting FAD designs tested in the Eastern Pacific Ocean (Armstrong and Oliver 1995)

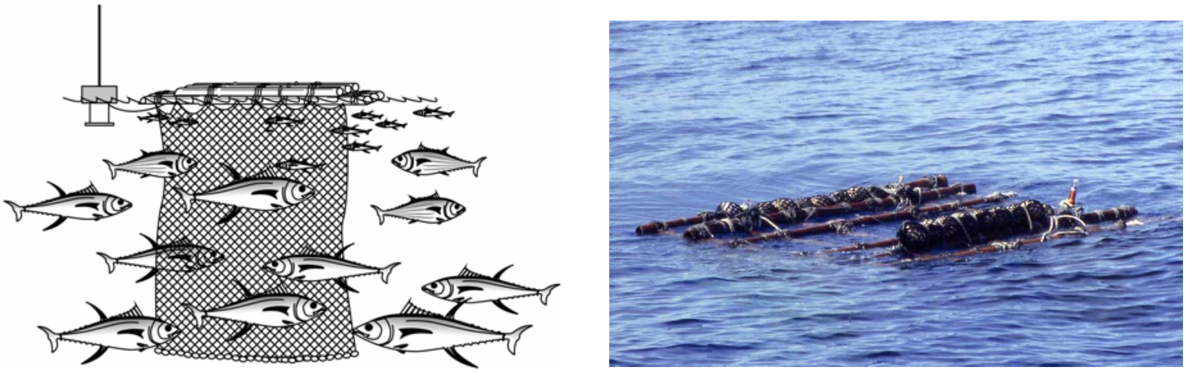


Figure 18. Graphic representation of a bamboo raft type drifting FAD an (SPC drawing for training sheets), and a Japanese drifting FAD in the WCPO (photo Fukofuka)

Figure 19. A stack of DFADs stored on a Chinese Taipei purse seine vessel and a DFAD from the Indian Ocean (photos Itano, Dagorn)

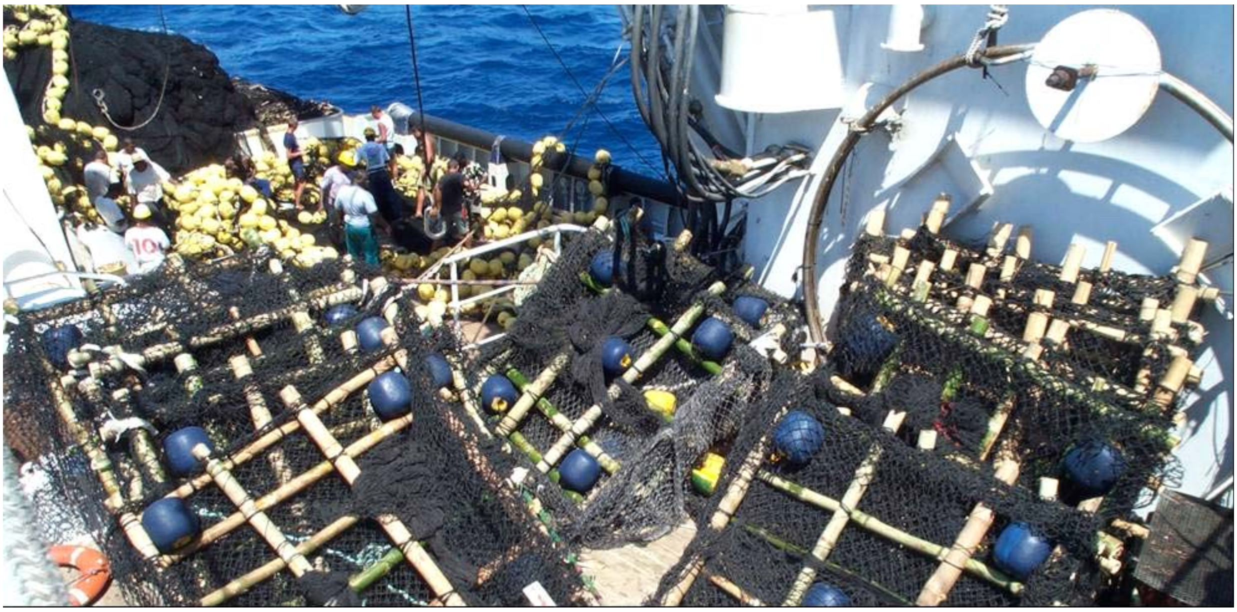


Figure 20. DFADs constructed of bamboo and purse seine netting on the deck of an EU purse seiner in the Indian Ocean (photo Fonteneau)

Figure 21. Underwater views of DRIFTING FADs in the Indian Ocean taken from 20 m depth (copyright FADIO/IRD-Ifremer/M. Taquet)

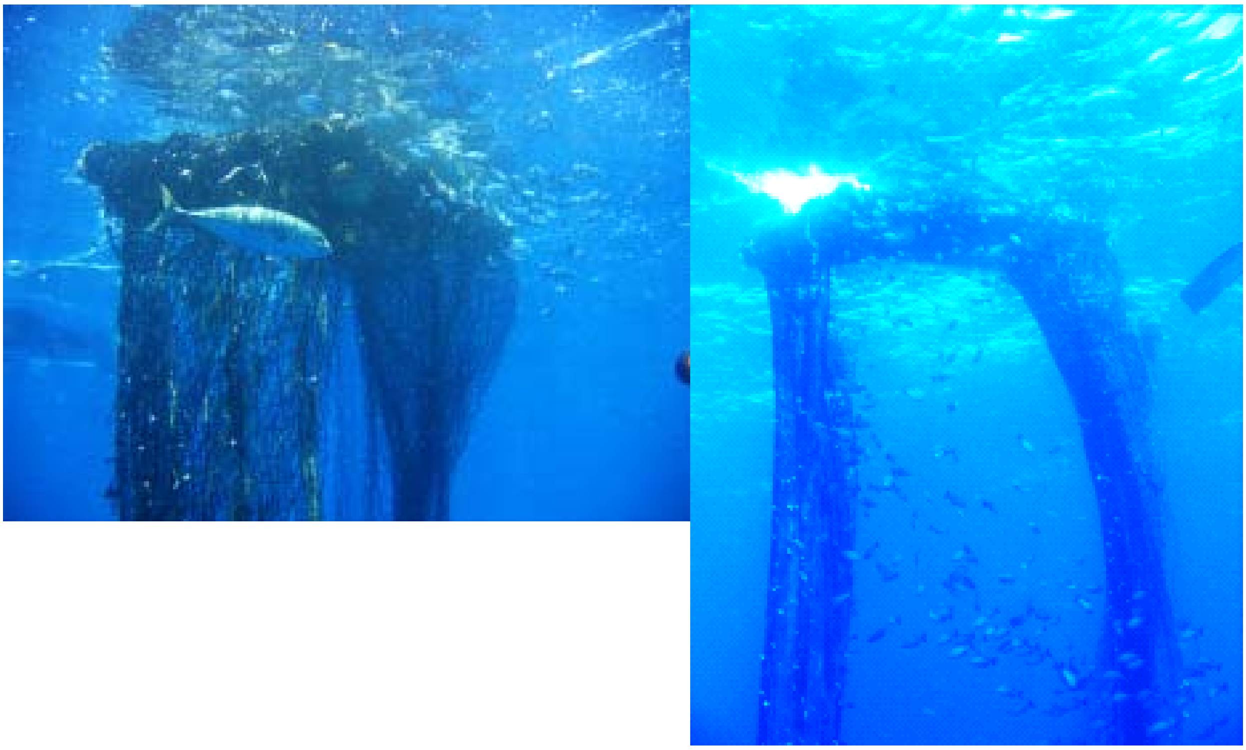


Figure 22. Underwater views of DFADs in the Indian Ocean showing associated finfish (copyright FADIO/IRD-Ifremer/D. Itano)

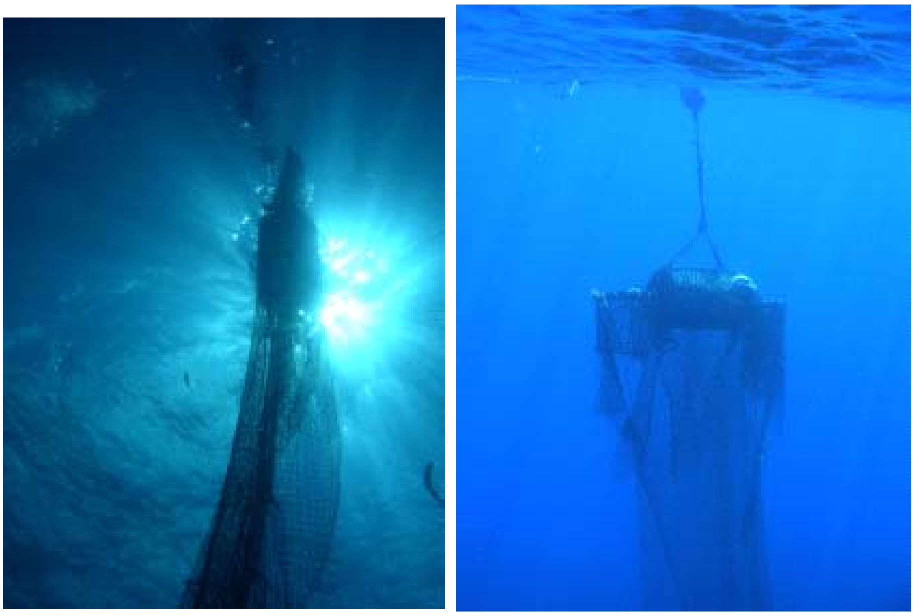


Figure 23. Two styles of sub-surface DRIFTING FADs used in the Indian Ocean for purse seine operations (copyright FADIO/IRD-Ifremer/D. Itano)

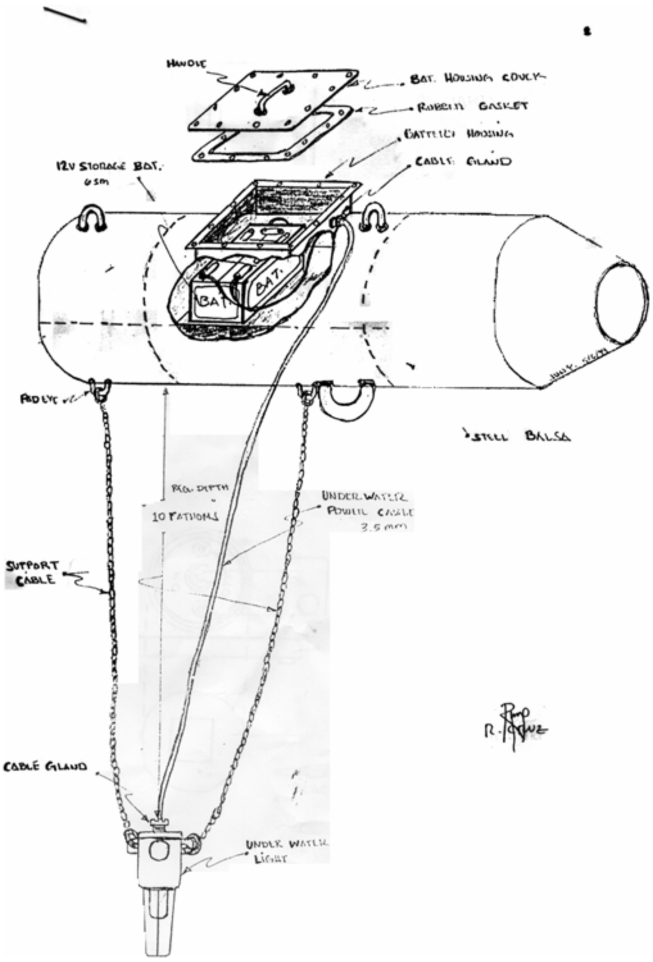


Figure 24. Experimental FAD with batteries and underwater bait/fish attraction light (Kumoru 2002)

Figure 25. Serpe type GPS tracking radio buoys and computer interface (Martec)

Figure 26. Low profile GPS and sonar transmitting buoys (Martec, Zunibal).

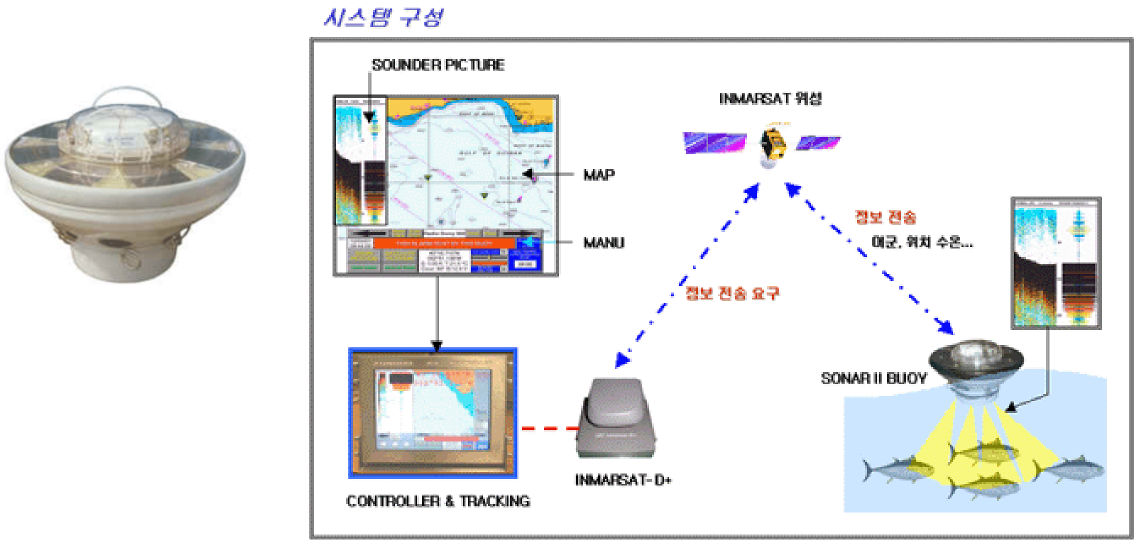


Figure 27. Satellite linked sonar transmitting GPS buoy (Zunibal)

Figure 28. A variety of low profile GPS radio buoys including sonar transmitting units used to mark DFADs (photo Itano)

Figure 29. Auxiliary towboat used to maneuver LOGs and DFADs (photo Itano)

Figure 30. Japanese search boat that works in a group seine operation to search, assess and aggregate tuna schools (photo Itano)

Figure 31. Generator equipped light boat used to aggregate baitfish and tuna on anchored FADs (photo Itano)

Figure 32. Ranger vessel loaded with FAD mooring lines and an AFAD float ready for deployment (photos Fukofuka)

Figure 33. FAD supply vessel used to support DFAD operations and an an anchored supply vessel on the Coco de Mer Seamount, Indian Ocean (photos Itano)

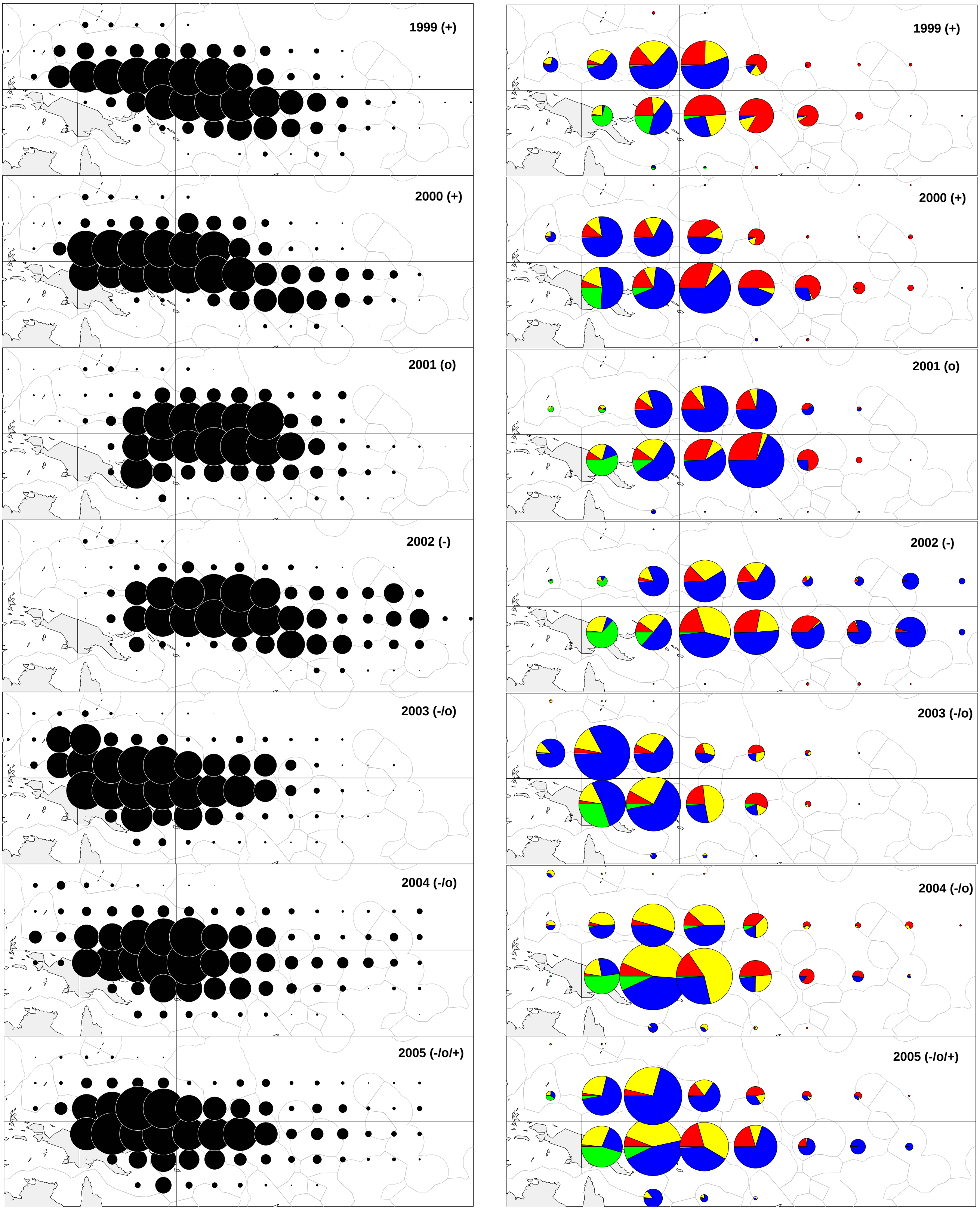


Figure 34. Distribution of purse-seine effort (days fishing – left; sets by set type – right), 1999–2005. (Blue–Unassociated; Yellow–Log; Red–Drifting FAD; Green–Anchored FAD).

(Figures 34 – 37 from Williams and Reid 2006)

ENSO periods are denoted by "+": La Niña; "-": El Niño; "--": strong El Niño; "o": transitional period.

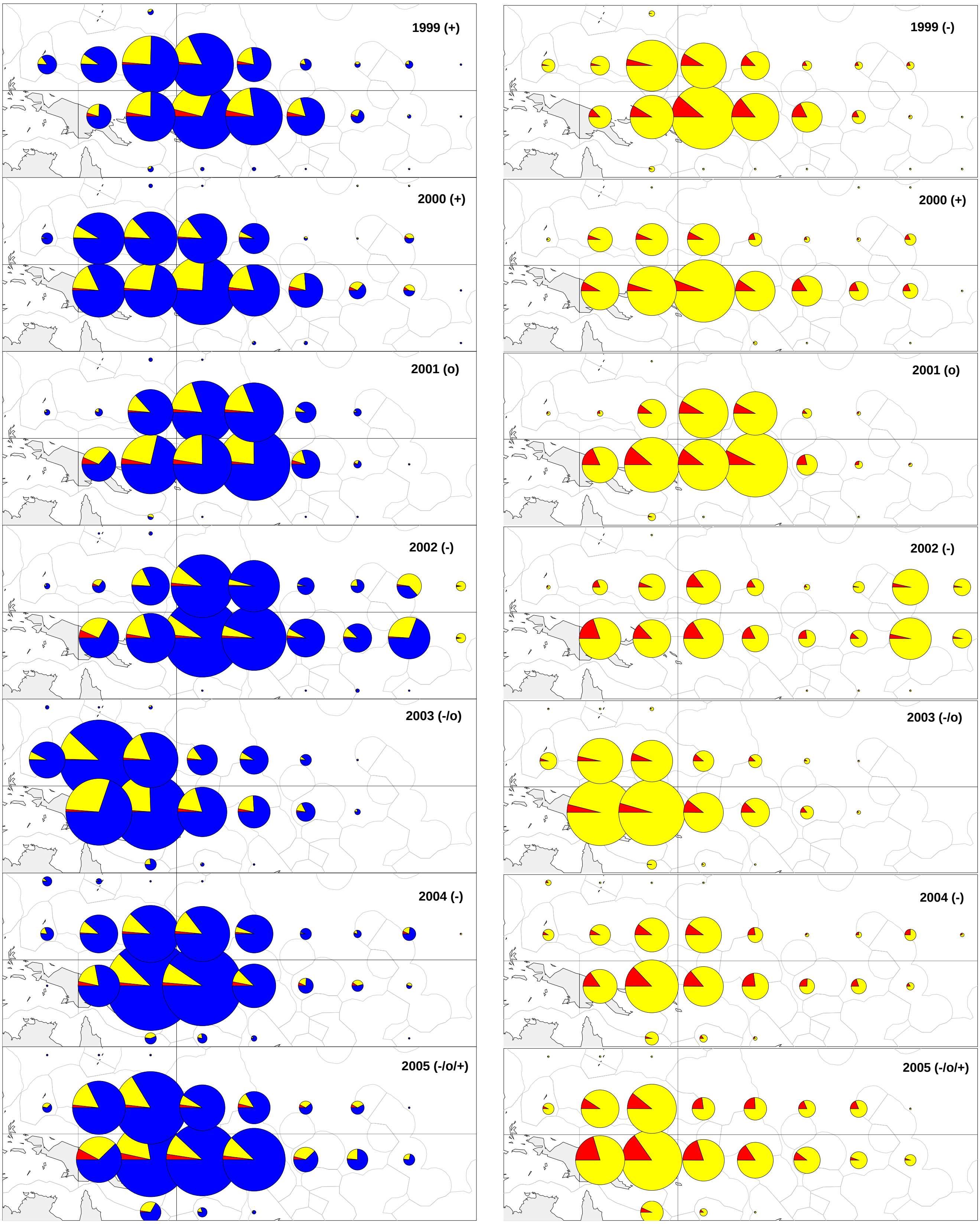


Figure 35. Distribution of purse-seine skipjack/yellowfin/bigeye tuna catch (left) and purse-seine yellowfin/bigeye tuna catch only (right), 1999–2005

(Blue–Skipjack; Yellow–Yellowfin; Red–Bigeye).

ENSO periods are denoted by "+": La Niña; "-": El Niño; "--": strong El Niño; "0": transitional period.

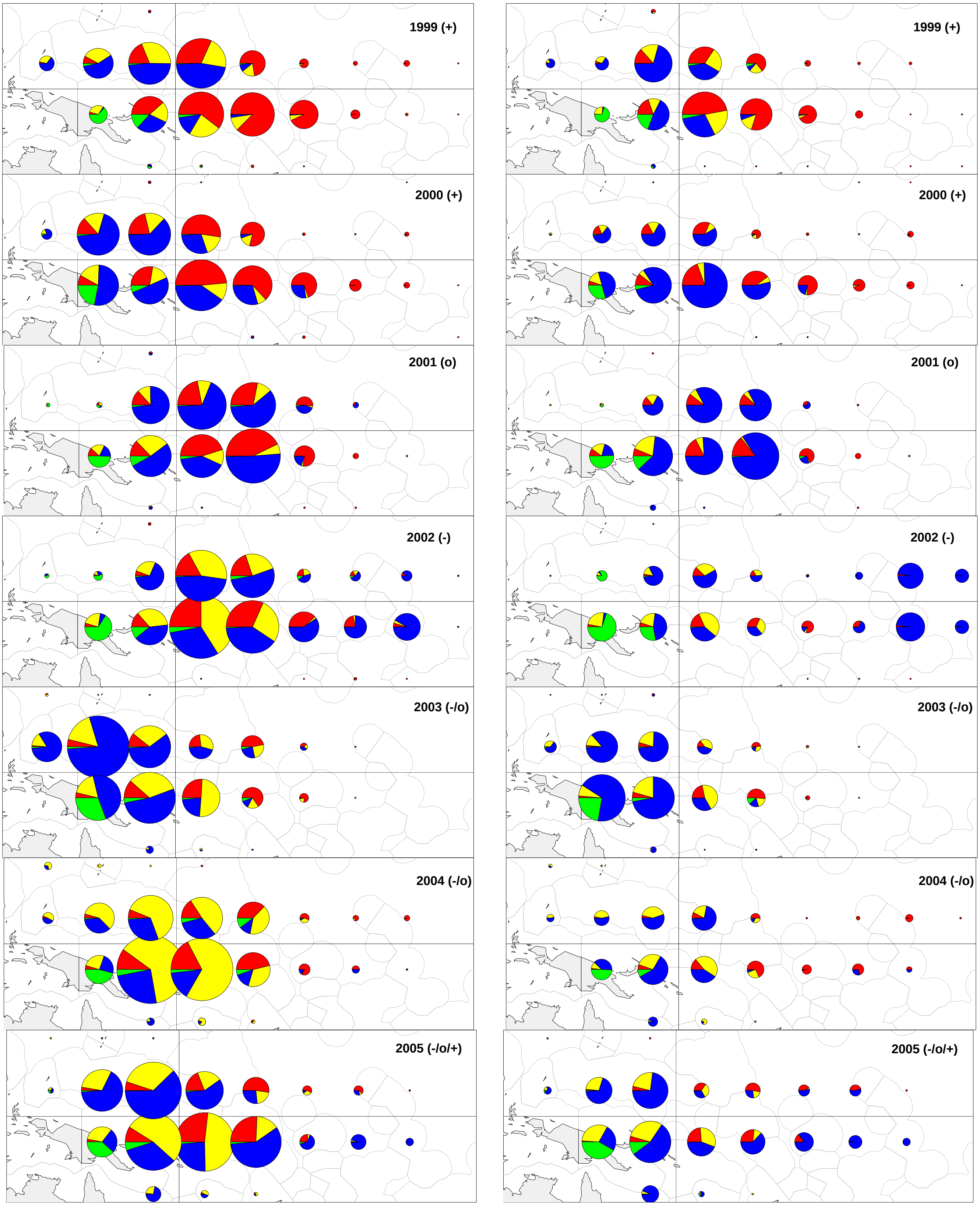


Figure 36, Distribution of skipjack (left) and yellowfin (right) tuna catch by set type, 1999–2005 (Blue–Unassociated; Yellow–Log; Red–Drifting FAD; Green–Anchored FAD).

ENSO periods are denoted by "+": La Niña; "-": El Niño; "--": strong El Niño; "o": transitional period.

Sizes of circles for all years are relative for that species only.

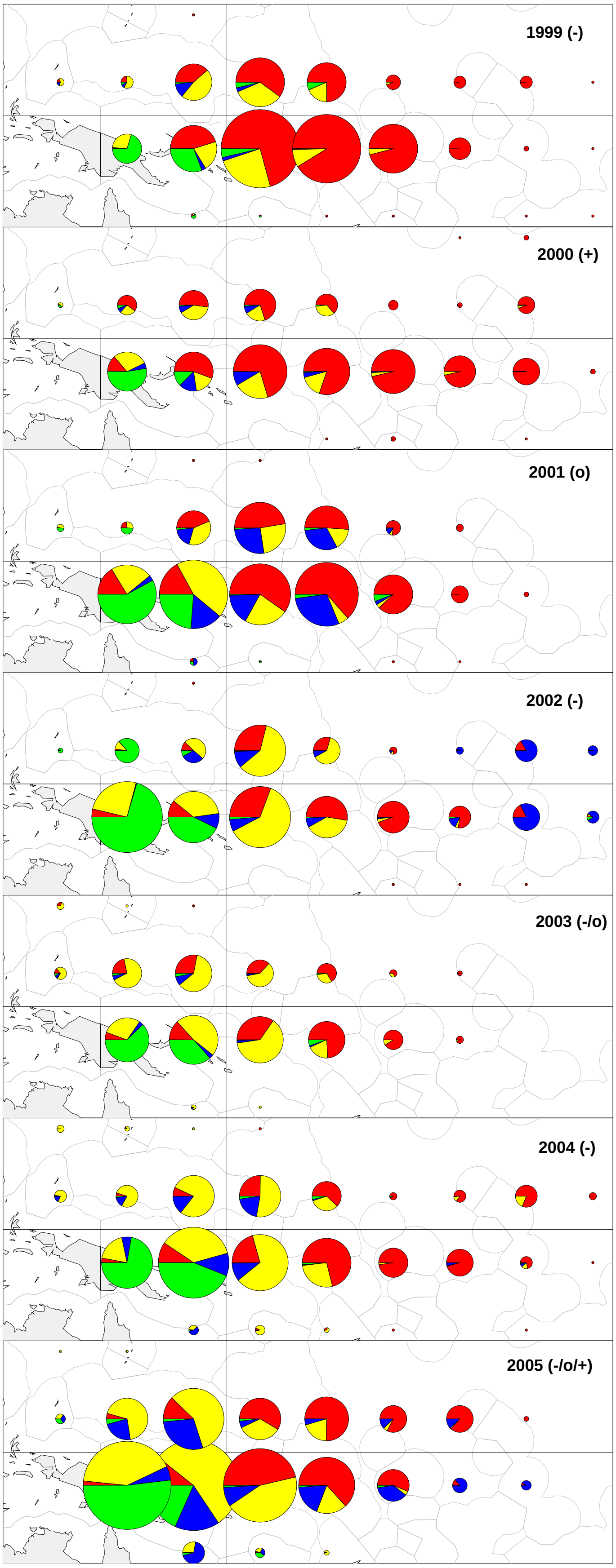


Figure 37. Distribution of estimated bigeye tuna catch by set type, 1999–2005 (Blue–Unassociated; Yellow–Log; Red–Drifting FAD; Green–Anchored FAD).

ENSO periods are denoted by “+”: La Niña; “-”: El Niño; “--”: strong El Niño; “0”: transitional period.

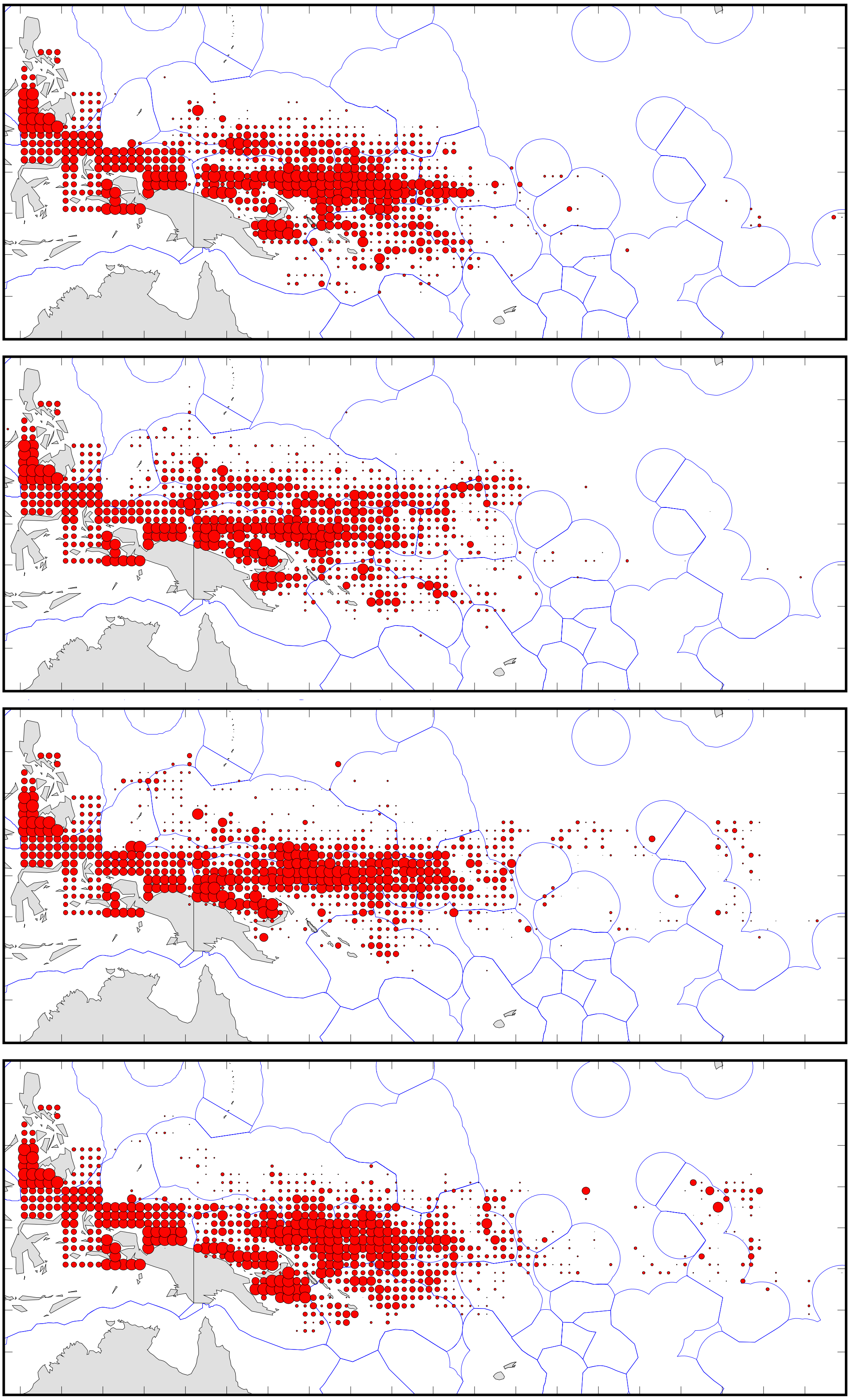


Figure 38. Distribution of quarterly purse-seine yellowfin catch by LOG SETS, 2001-2006, all years combined (Figures 49 – 54 from SPC data)

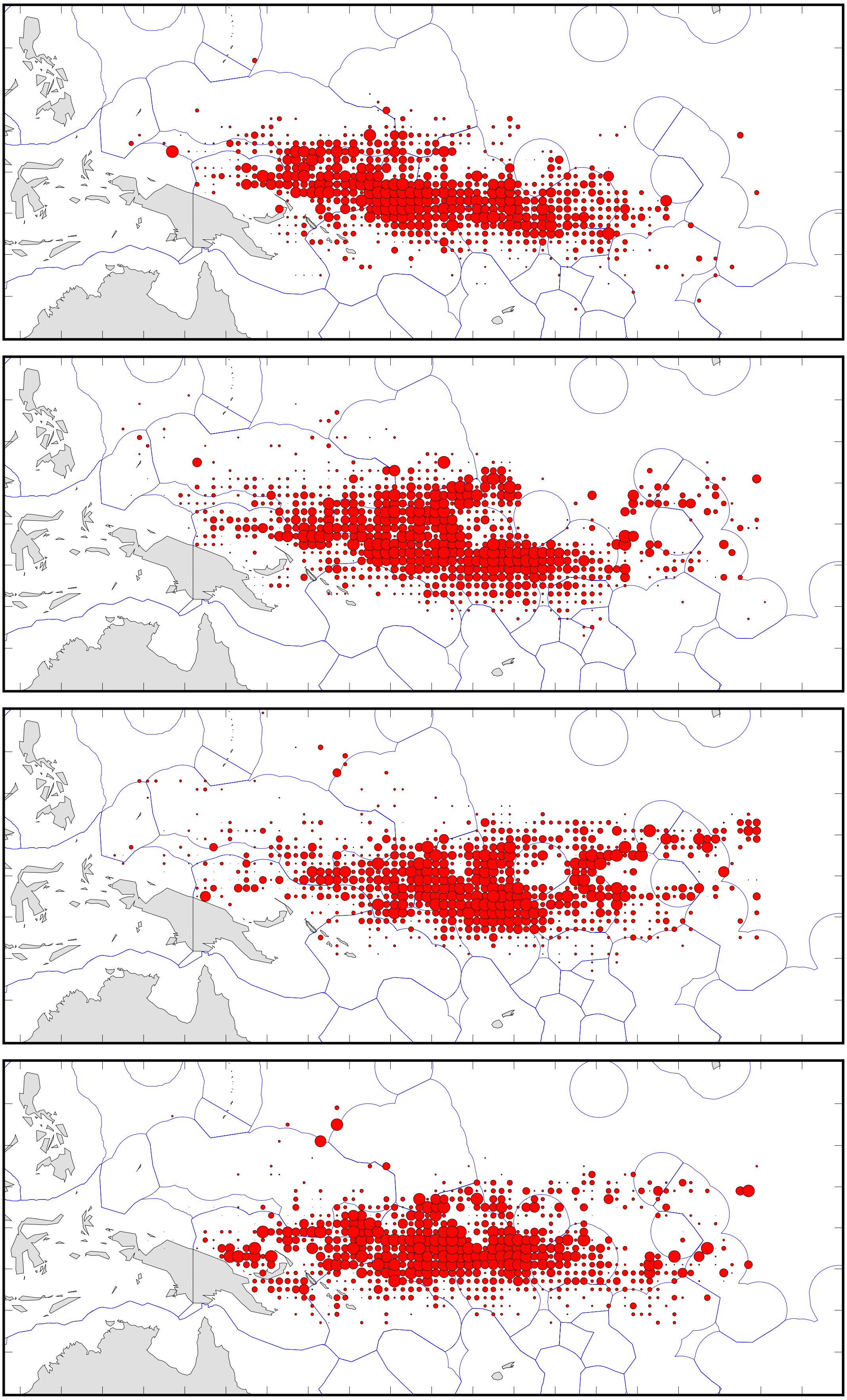


Figure 39. Distribution of quarterly purse-seine yellowfin catch by DRIFTING FAD SETS, 2001-2006, all years combined

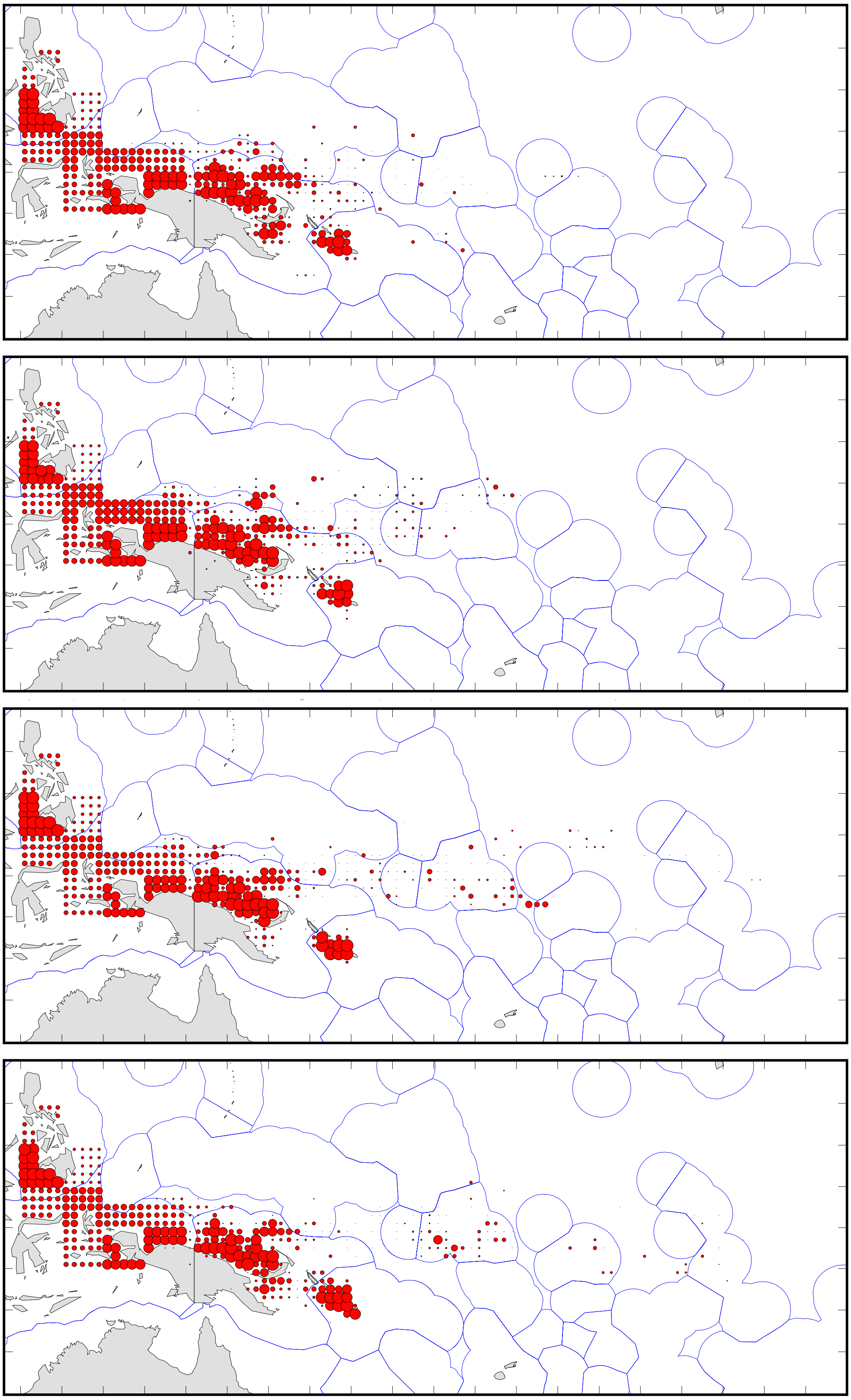


Figure 40. Distribution of quarterly purse-seine yellowfin catch by ANCHORED FAD SETS, 2001-2006, all years combined

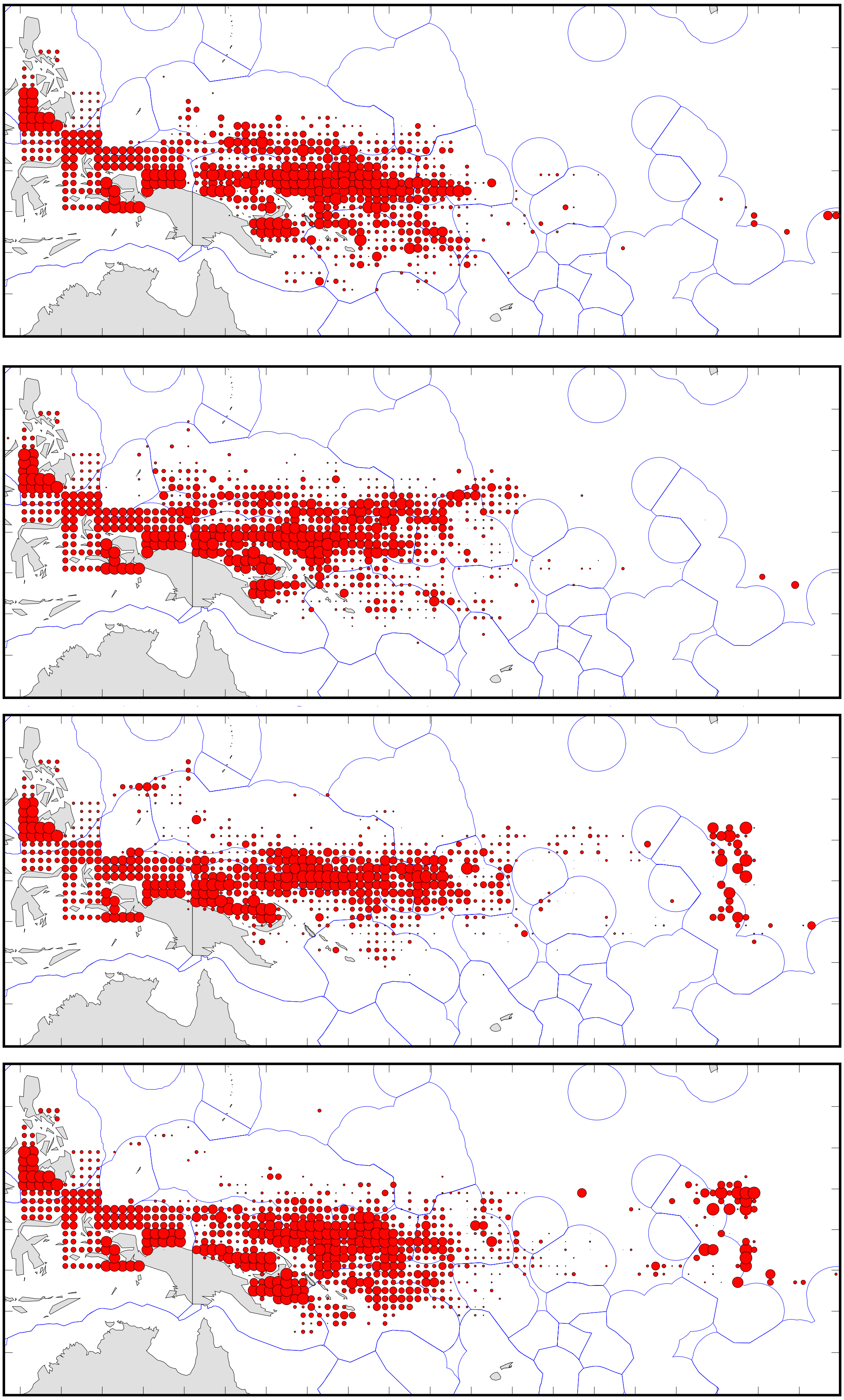


Figure 41. Distribution of quarterly purse-seine bigeye catch by LOG SETS, 2001-2006, all years combined (note: data plots for 3rd and 4th quarters near Line Islands represent DFADs from IATTC data)

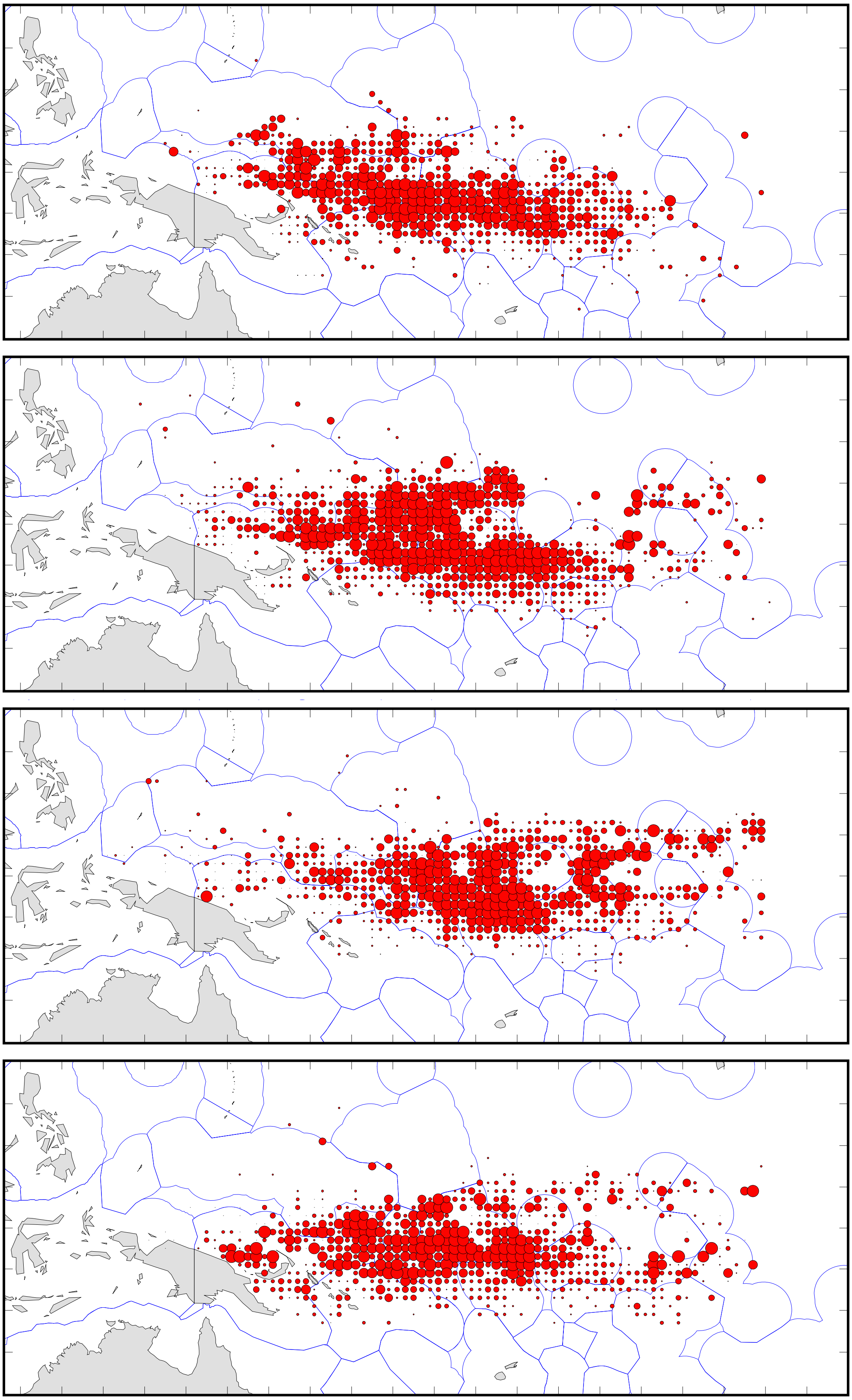


Figure 42. Distribution of quarterly purse-seine bigeye catch by DRIFTING FAD SETS, 2001-2006, all years combined

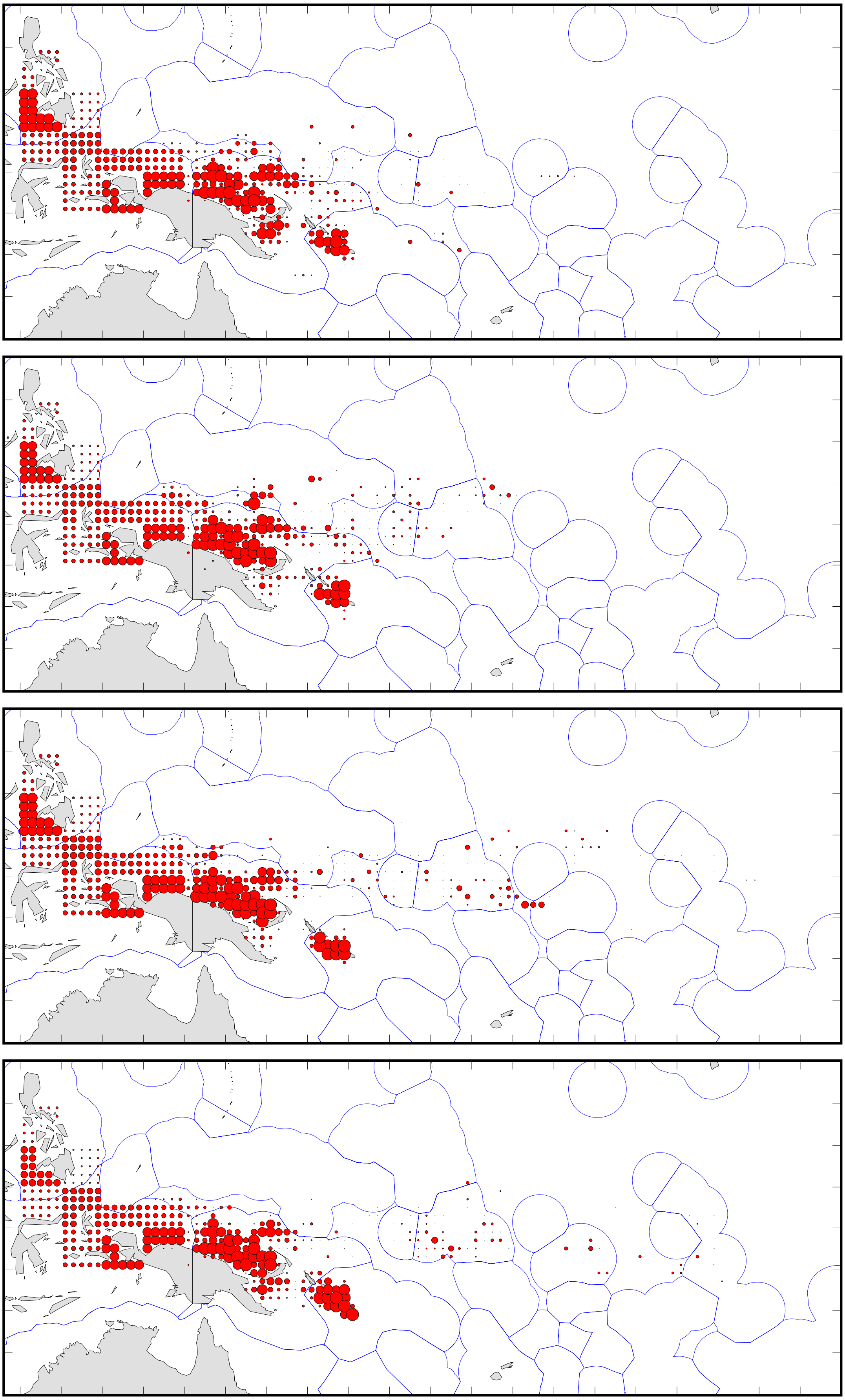


Figure 43. Distribution of quarterly purse-seine bigeye catch by ANCHORED FAD SETS, 2001-2006, all years combined

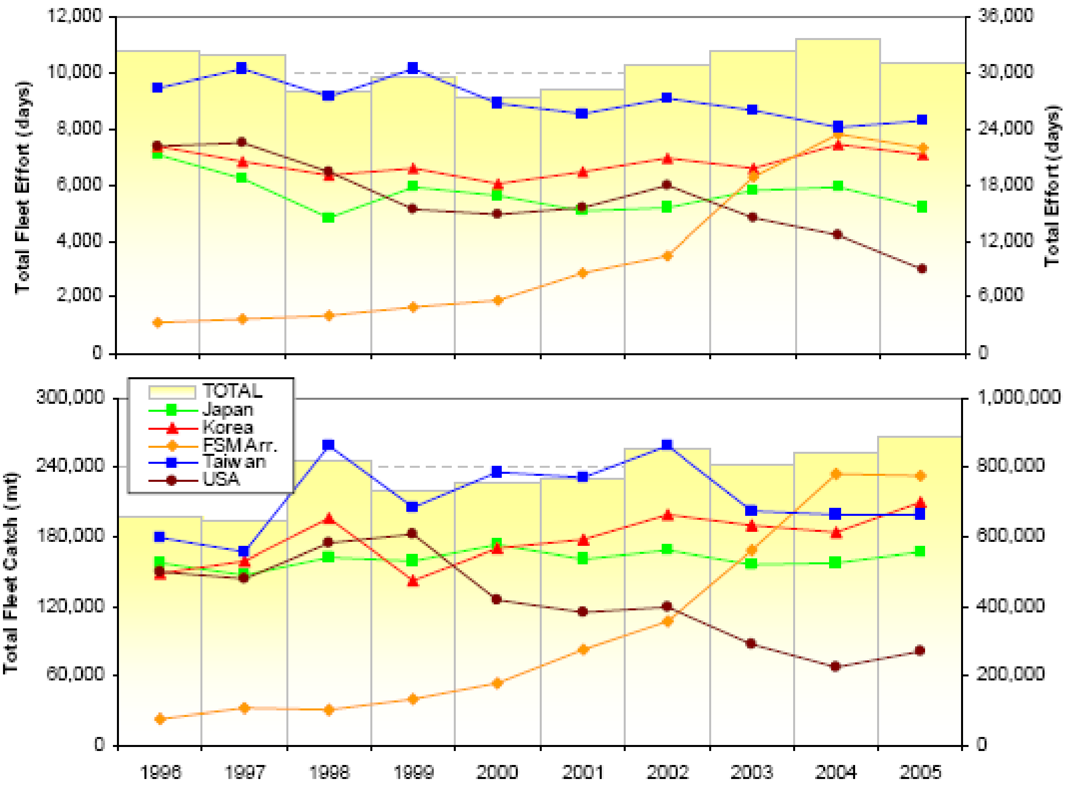


Figure 44. Trends in annual effort (top) and catch (bottom) estimates for the top five purse seine fleets operating in the tropical WCP–CA, 1996–2005. (from Williams and Reid 2006)

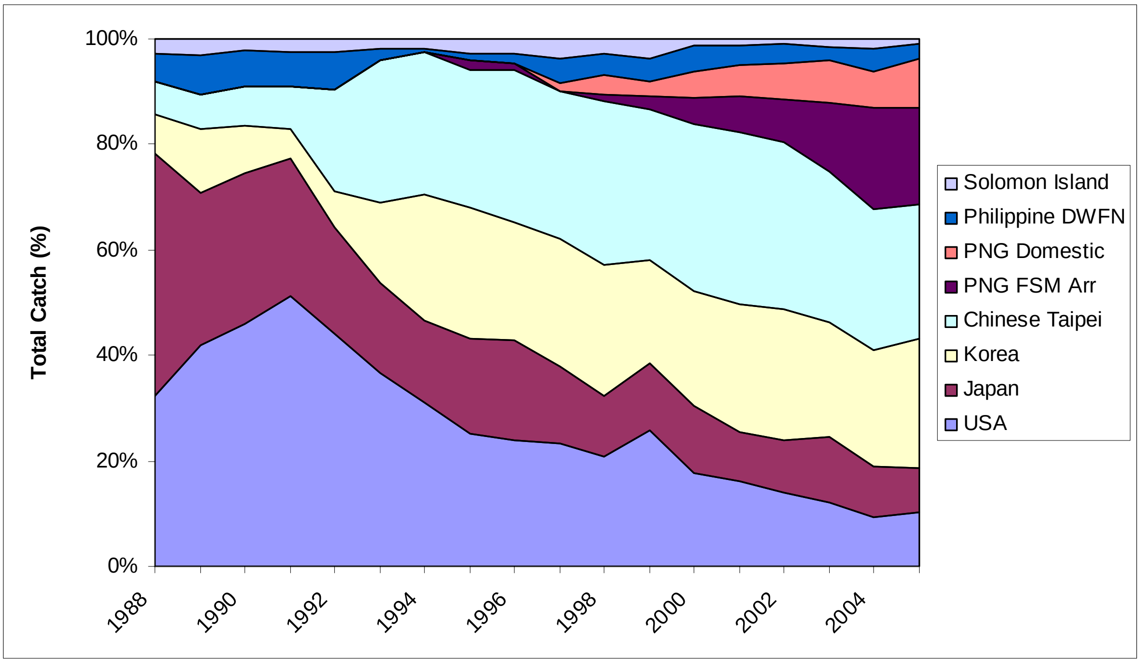


Figure 45. Per cent of total catch by eight purse seine fleets 1988 – 2005 (data SPC)

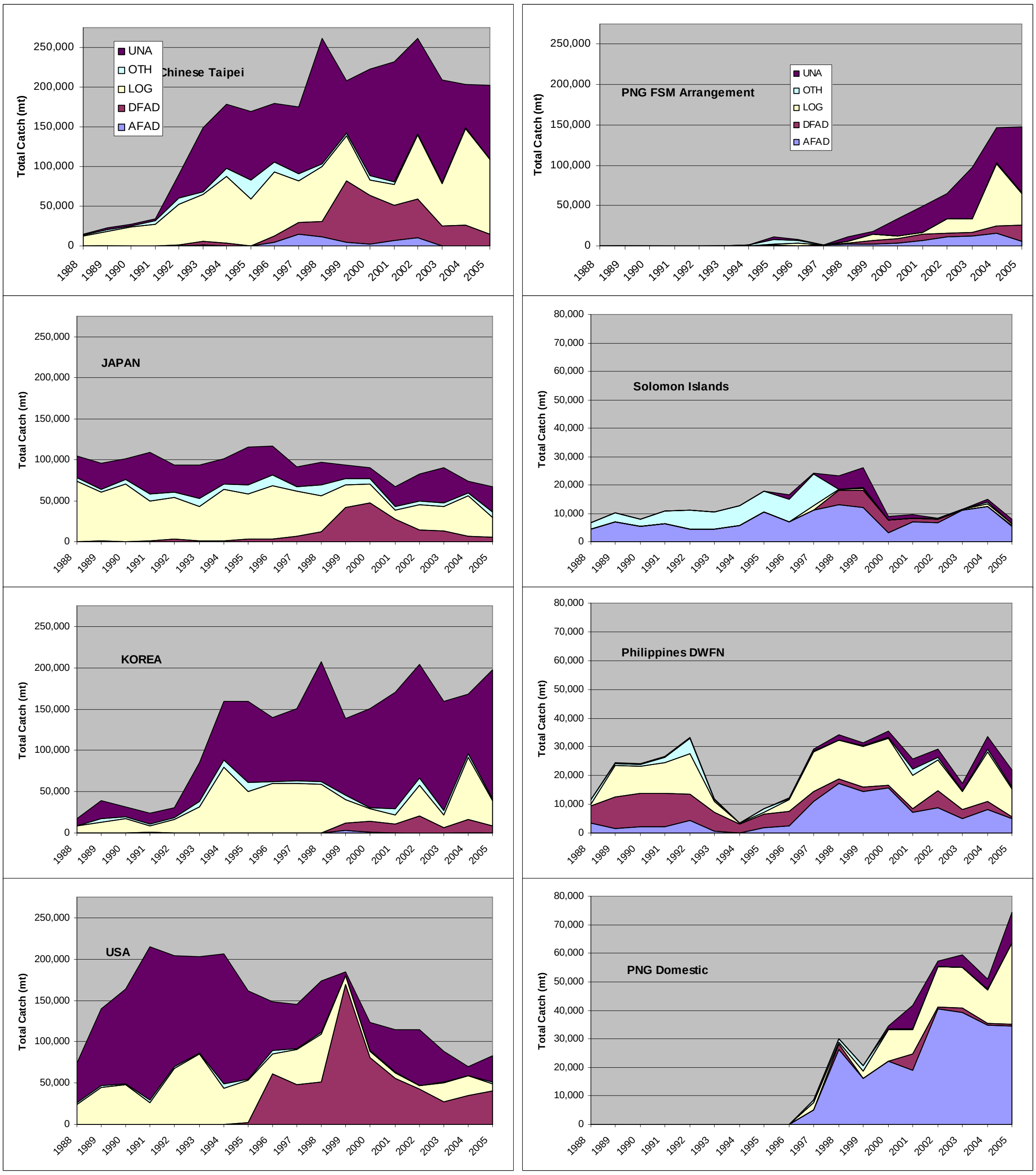


Figure 46. Total catch by major DWFN, FSM Arrangement and AFAD dependent fleets.

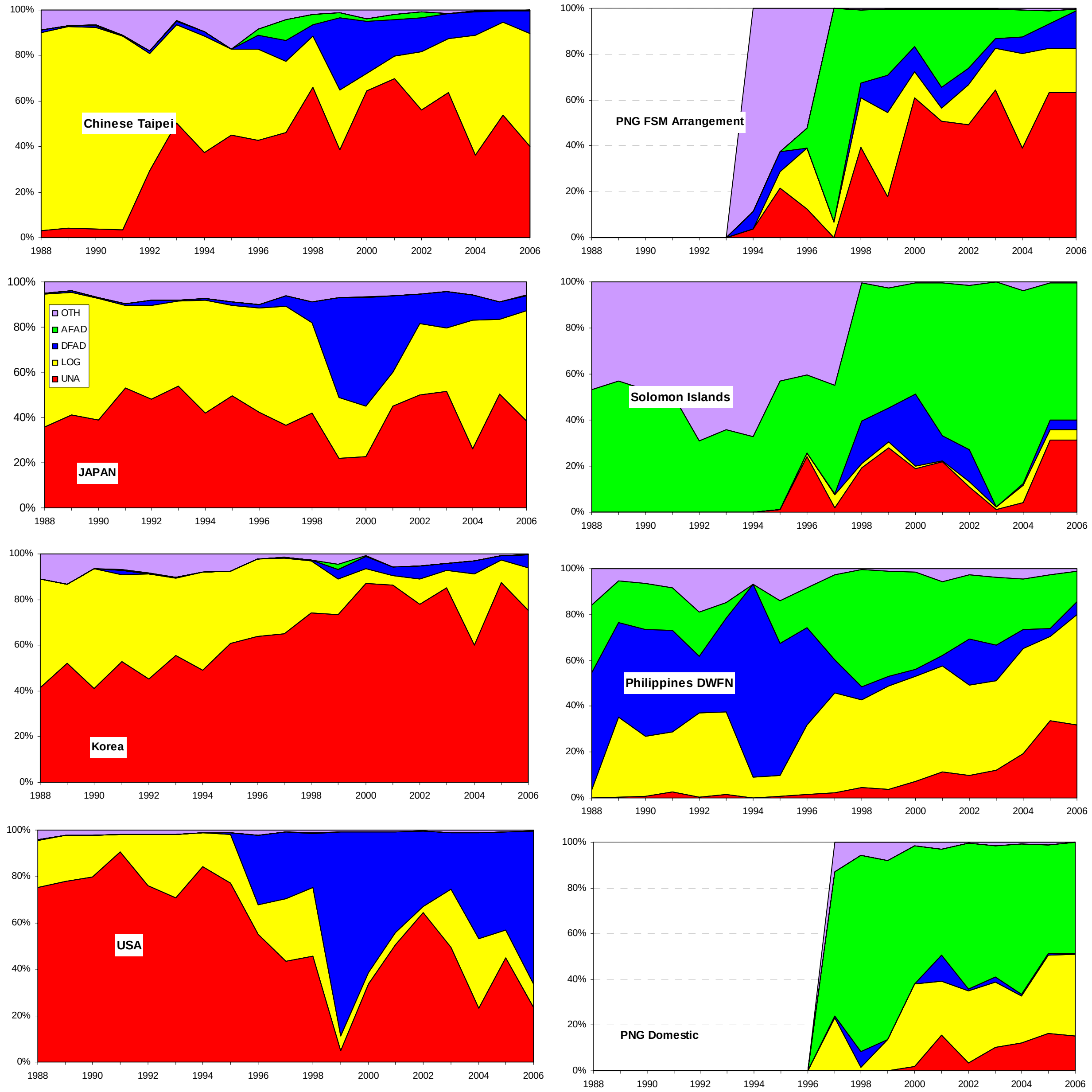
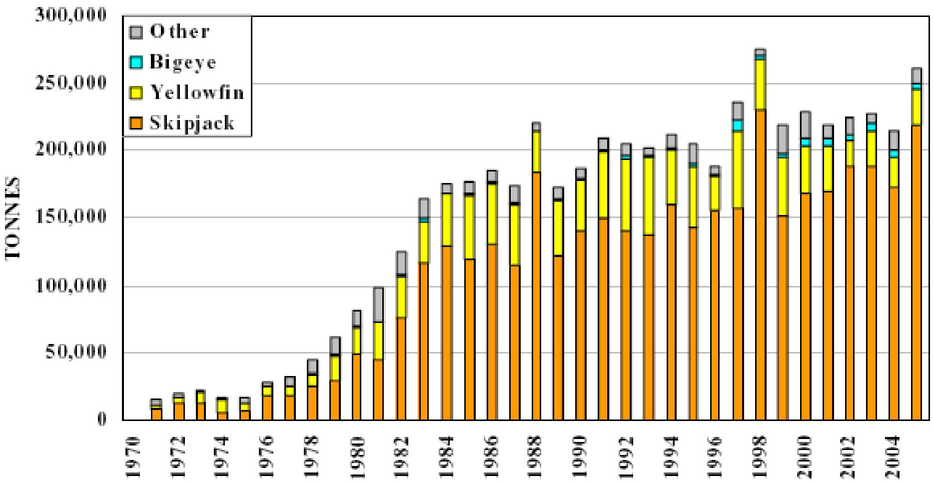


Figure 47. Percentage of catch by set type for major DWFN, FSM Arrangement and AFAD dependent fleets. (Unassociated=Red) (LOG=Yellow) (Drifting FAD=Blue) (Anchored FAD=Green)



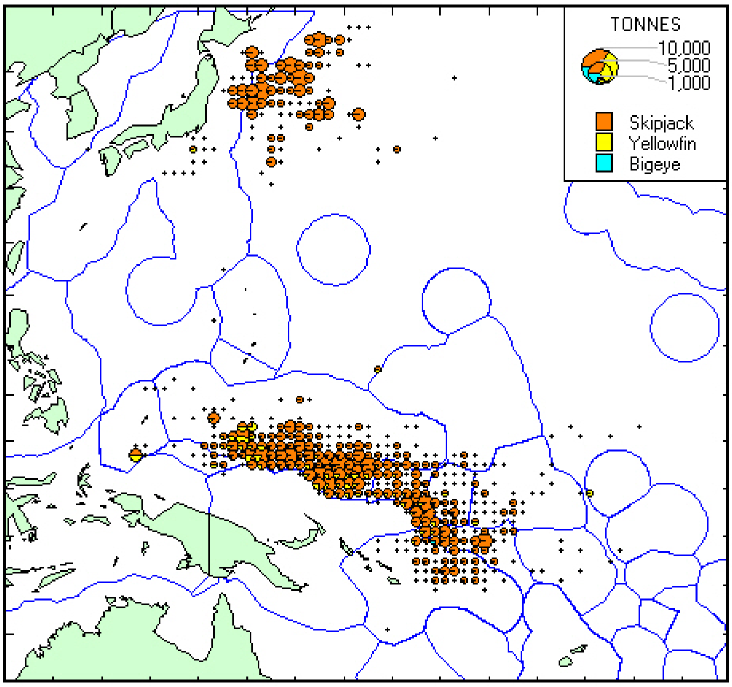


Figure 48. Japanese purse seine catch and 2005 spatial distritution (260,818 mt, 11,329 mt/day fished and searched, <35 vessels>)(WCPFC 2006b)

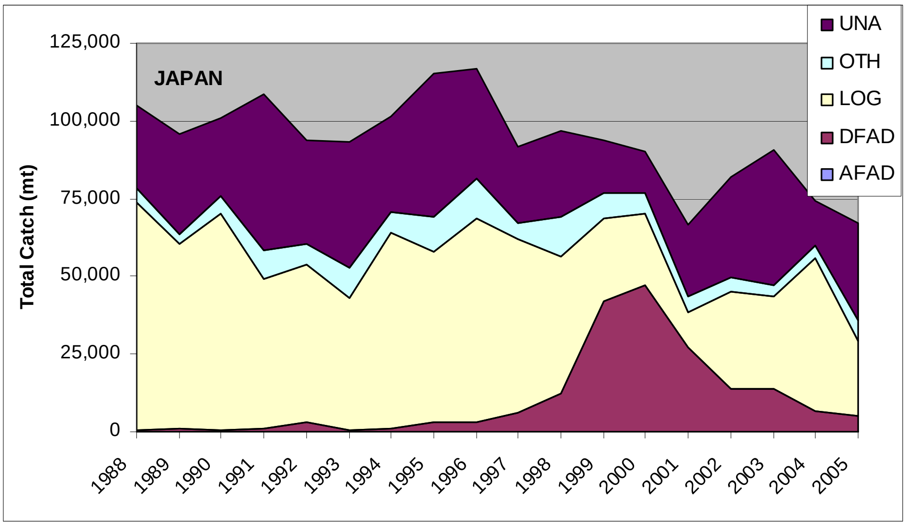


Figure 49. Catch by set type for Japanese purse seine 1988 – 2006 (SPC data)

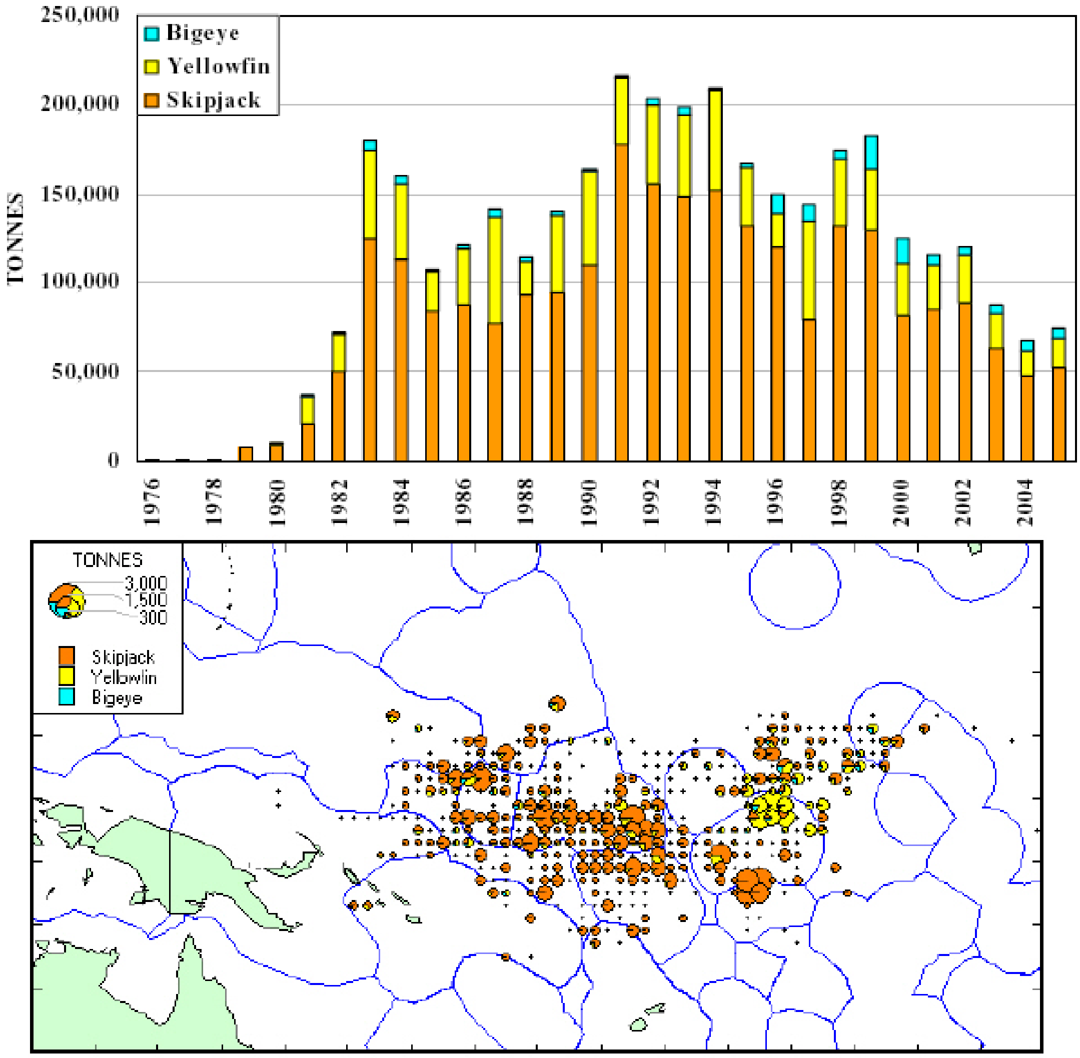


Figure 50. United Status purse seine catch and 2005 spatial distribution (74,287 mt, 27.17 mt/days fished and searched, 15 vessels)

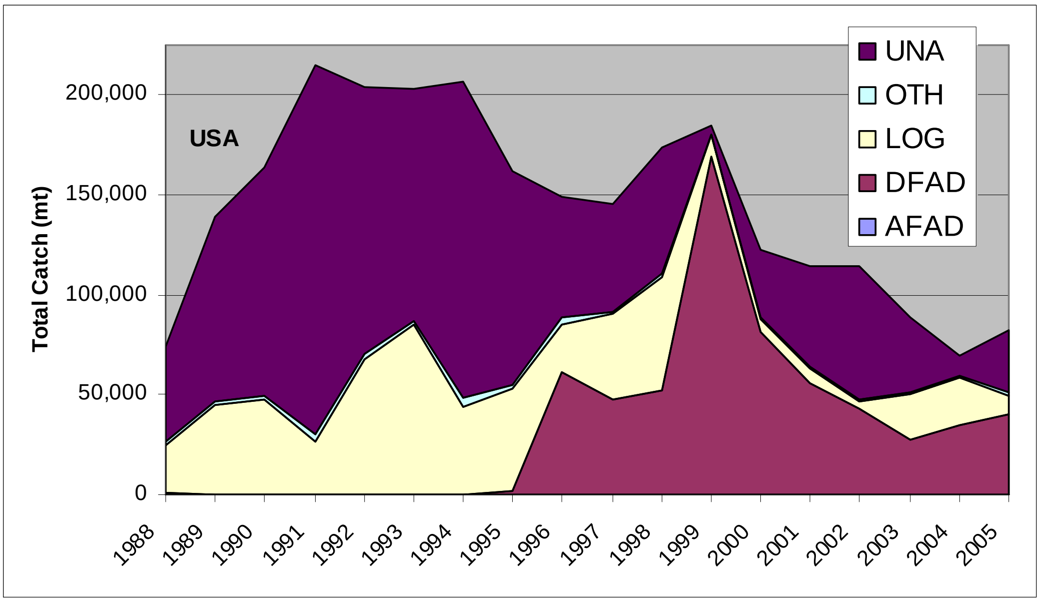


Figure 51. Catch by set type for US purse seine 1988 – 2006

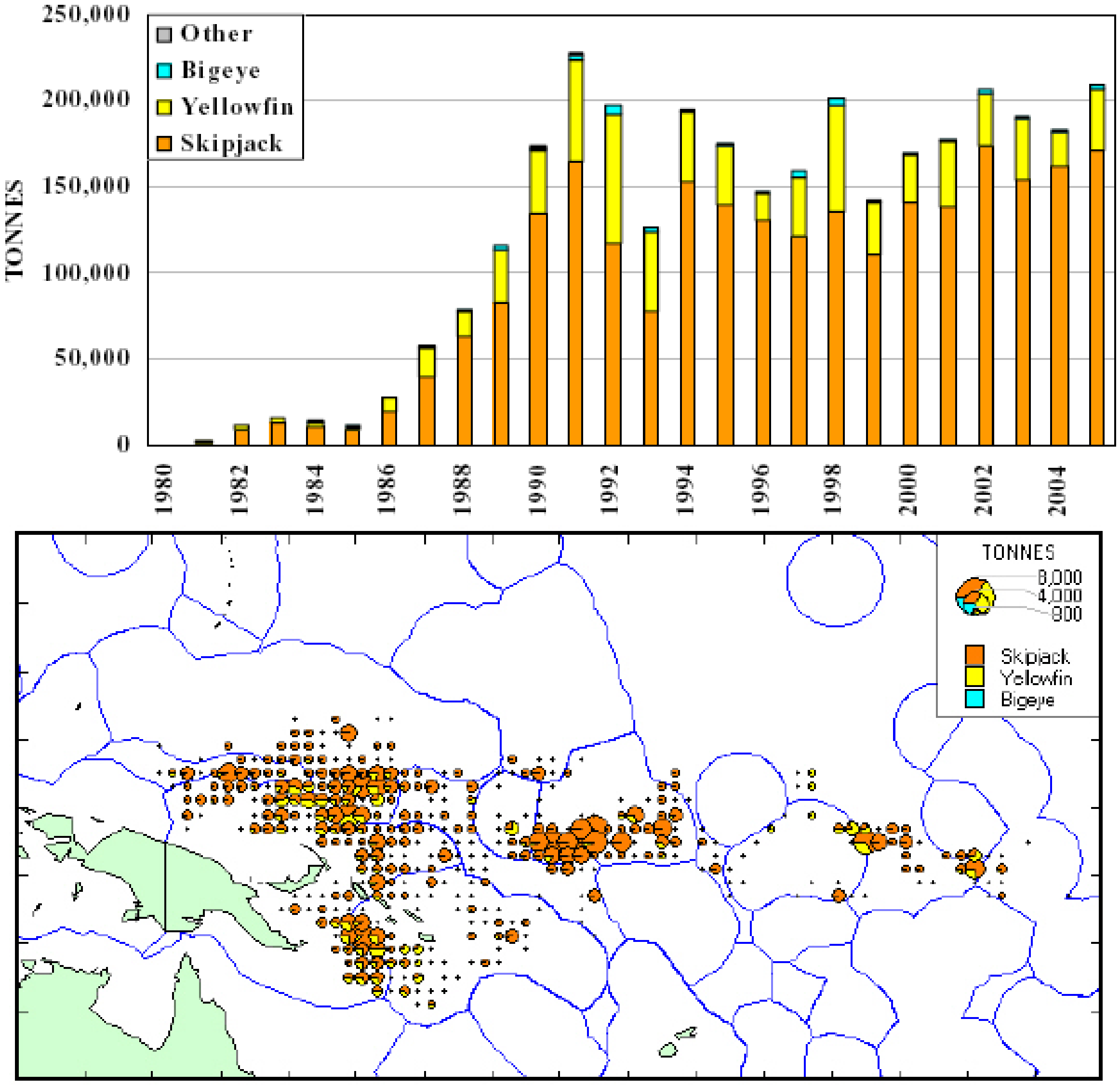


Figure 52. Korean purse seine purse seine catch and 2005 spatial distribution (209,808 mt, 29.85 mt/days fished and searched, 28 vessels)

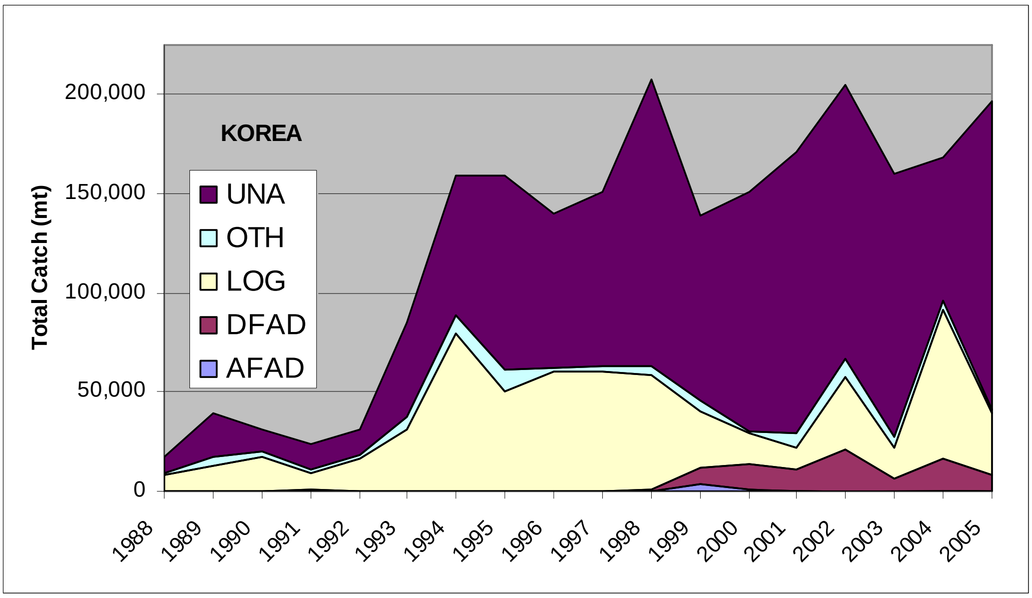
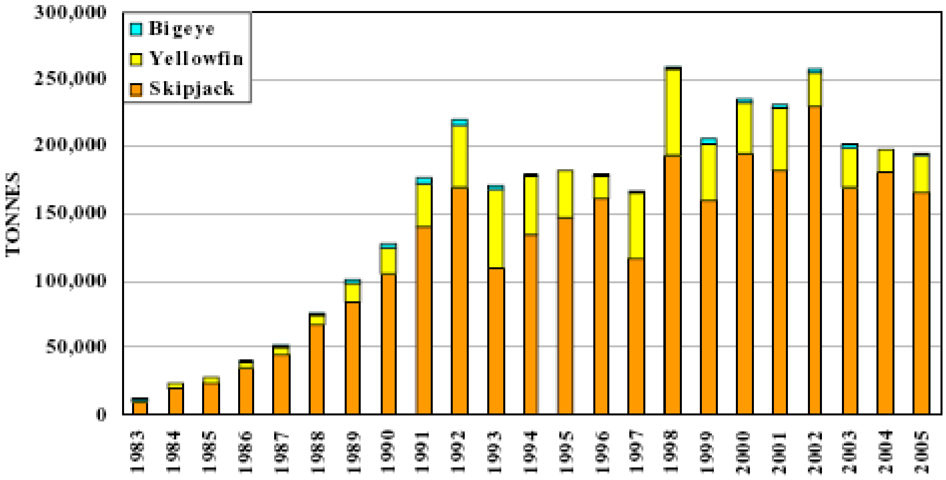


Figure 53. Catch by set type for Korean purse seine 1988 – 2006



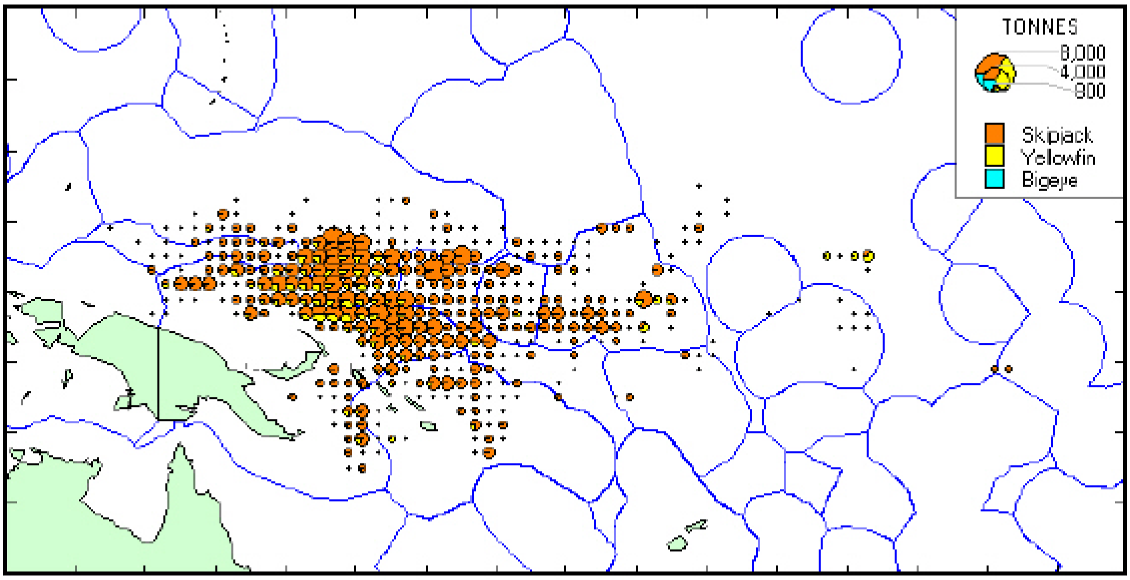


Figure 54. Chinese Taipei purse seine purse seine catch and 2005 spatial distribution (195,039 mt, 24.64 mt/days fished and searched, 34 vessels)

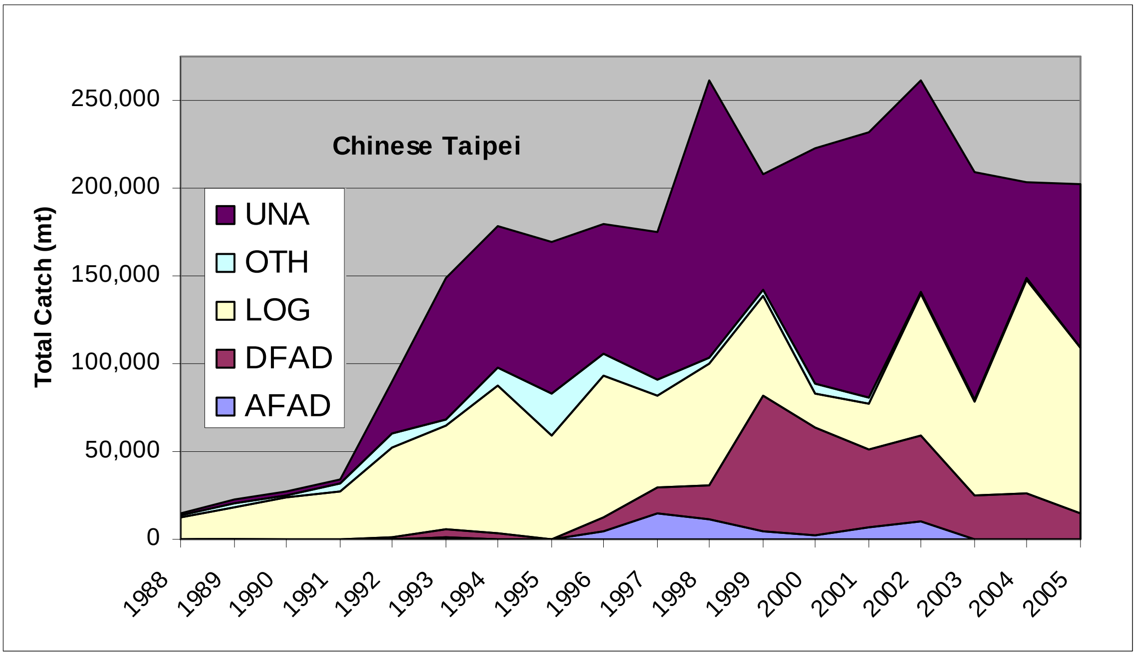


Figure 55. Catch by set type for Chinese Taipei purse seine 1988 – 2006

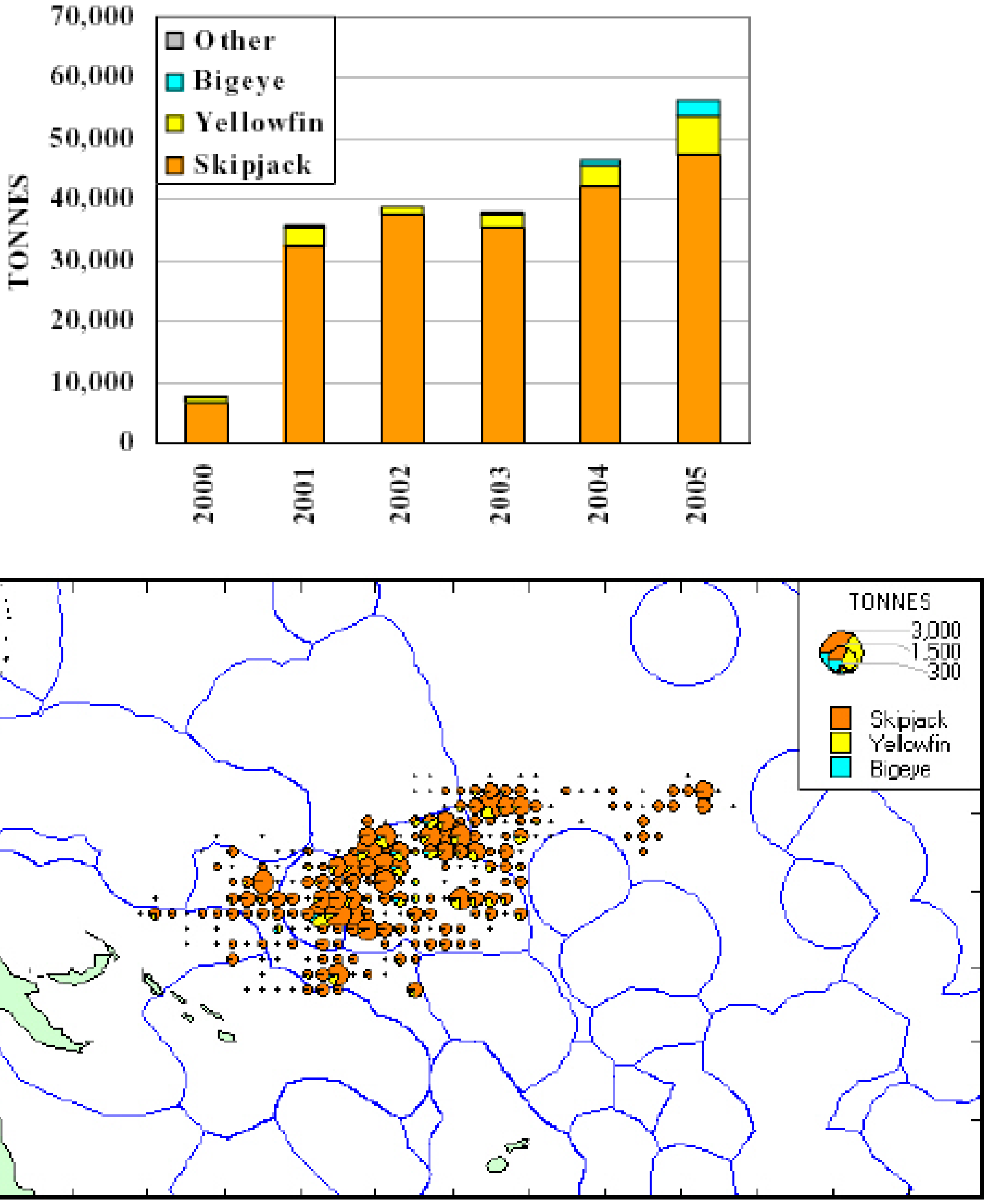


Figure 56. Marshall Islands purse seine purse seine catch and 2005 spatial distribution (56,164 mt, 43.54 mt/days fished and searched, 6 vessels)

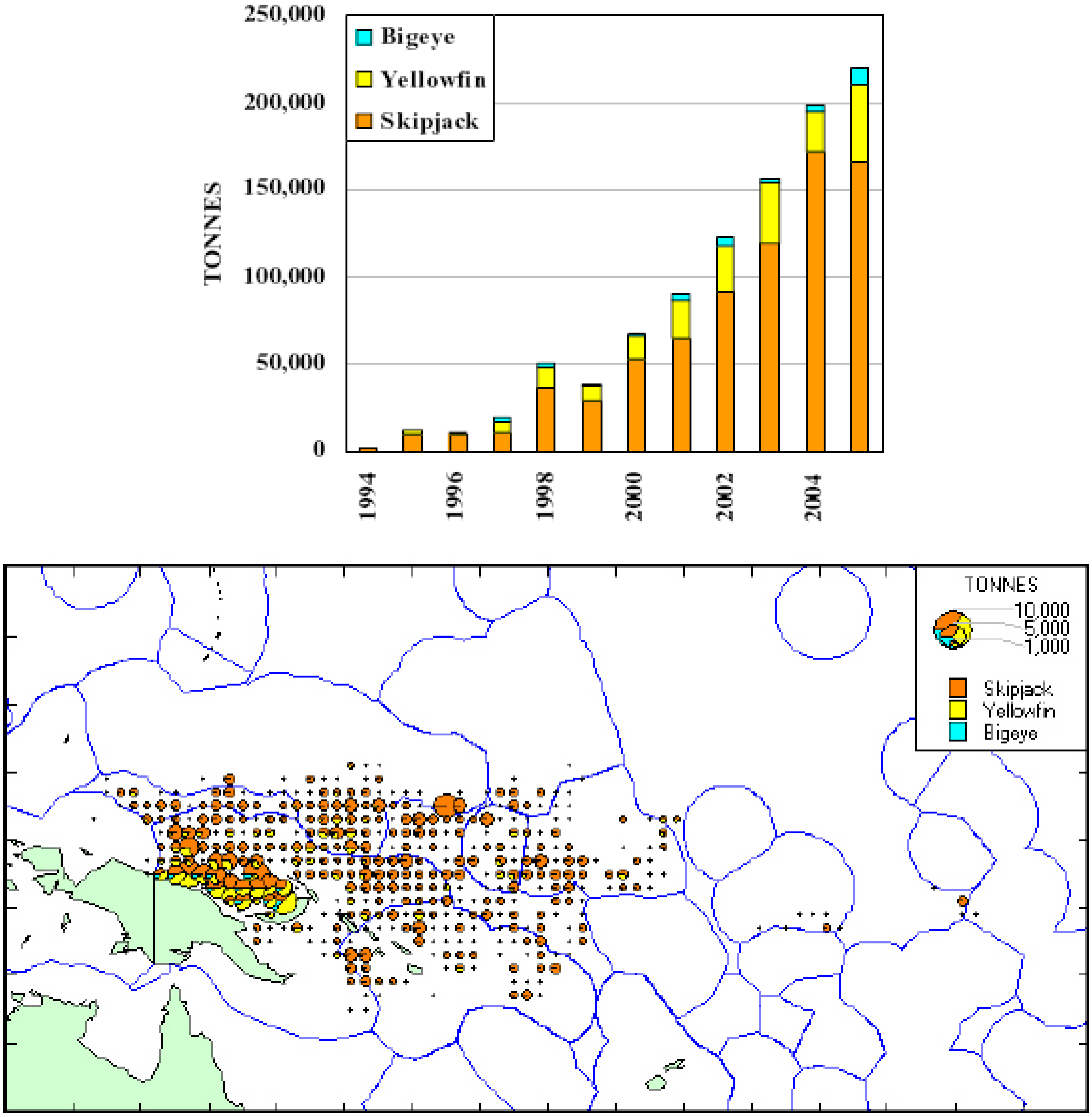


Figure 57. Papua New Guinea purse seine purse seine catch and 2005 spatial distribution (220,079 mt, 22.41 mt/days fished and searched, 41 vessels)