# The impact of FAD innovation on the performance of US tuna purse seine operations in the Pacific Ocean

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## Abstract

It is generally accepted that innovations in tuna purse seine technology have affected fishing operations and the traditional measurement of fishing effort, days fished including searching time. Not much is known, however, about the actual effects of the innovations on fishing performance. Data from the US tuna purse seine fishery in the Western Pacific Ocean were used to determine the impact of drifting Fish Aggregating Devices (FADs) on the performance of the US fleet. The results indicate, *inter alia*, a high rate of success (96%) in catching tuna and high yield rate (37 t/successful set) for FAD sets. Log sets were comparable in success rate (94%) and catch rate (36 t/successful set). Unassociated sets, on the other hand, had a higher catch rate (42 t/successful set) than FAD sets, but a low success rate, 53 per cent. FAD sets significantly improved the fleet's performance.

## Introduction

The purse seine revolution in tuna fishing for tropical tunas began in the late 1950s-early 1960s (McNeely, 1961) and continues unabated. It started with development of Nylon netting, and invention of the Puretic power block. Later, it advanced to improvements in deck equipment, introduction of helicopters, specially designed vessels, and procedures for fishing dolphin-associated schools (Green *et al.*, 1971). In the 1980s, further advances were made in net design, deck equipment, ship design as well as the introduction of electronic equipment, e.g. bird-radar, echosounders, satellite imagery, etc. (Fonteneau *et al.*, 1998; Ben-Yami, 1994). More recently, drifting Fish Aggregating Devices (FADs; Ben-Yami, 1994) were introduced and are radically changing purse seine fisheries for tropical tunas.

Although the generally accepted objective of these innovations has been to improve fishing efficiency, the actual effects of the improvements on fishing success have not been analysed. Instead, efficiency effects are assumed to be embedded in catch rates and have been evaluated with statistical tools (Fonteneau *et al.*, 1998). A different approach was used to study the effects of fishing efficiency and the results are reported in this paper. The author used standard fishery data from the US tuna purse seine fishery of the Pacific Ocean to determine the effects of FAD technology on the fishery. The approach compares detailed set-by-set data for periods before and after introduction of FAD technology.

## Overview of fishery

The US purse seine fishery for tropical tunas in the Pacific Ocean targets skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares*) tunas. Bigeye tuna (*T. obesus*) which is less abundant and frequently school with the target species, is caught as an incidental tuna species. The fishery is centered in roughly two separate regions, east and west of 150°W longitude (fig. 1). In the eastern region, the fishery has been well documented (Sakagawa, 1991) and, since 1950, managed through international agreement (Inter-American Tropical Tuna Convention (IATTC); Joseph & Greenough, 1979). In the western region, the US fishery began in the mid-1970s (Felando, 1987) and, since June 1988, has been managed through a fishing access agreement (South Pacific Tuna Treaty (SPTT) between the US and 16 Pacific Island nations (Coan *et al.*, 1997). The US fishery has undergone considerable changes over a period of some 50 years. Most significant is that the fleet has been gradually shrinking and the operations increasingly concentrated in the Western Pacific Ocean. This trend began in the early 1980s and accelerated in the 1990s owing mainly to changing business opportunities, discovery of better techniques for fishing tunas in the Western Pacific and the closing of the US market to tuna caught with dolphins (Sakagawa, 1991). Before this trend began, the US fleet was concentrated in the Eastern Pacific and was heavily dependent on dolphin-associated schools, which yield large-sized yellowfin tuna (Perrin, 1969).

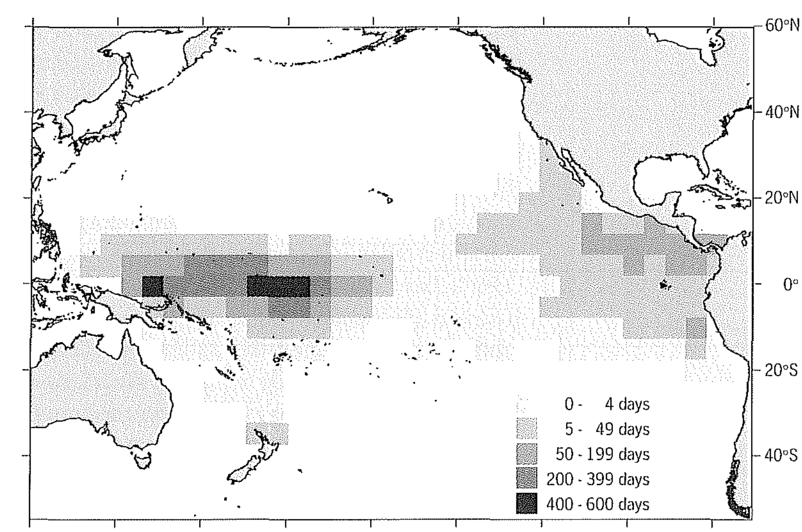



Figure 1
Geographic distribution of average fishing effort (days fished) for US tuna purse seine fishing in the Pacific Ocean, 1989-1998.

In 1982-1983, a strong, warm El Niño-southern oscillation (FFA; Philander, 1989) episode occurred in the Pacific. It reduced catchability of tunas in the eastern region and improved catchability in the western region. Fishing in the eastern region became unprofitable. For vessels to move their operations to the Western Pacific, costly investment was involved in deeper and lighter nets and new deck equipment for fishing conditions in the west. The heavy nets (Ben-Yami, 1994) for dolphin-associated schools used in the east were unsuitable for the western region where dolphin-associated schools are rare, and unassociated schools and log schools are common. Some vessels made the costly investment and shifted their operations while others tied up in port or were sold to foreign interests (Sakagawa, 1991). Later when the FFA abated, some vessels returned to the east and resumed fishing largely on dolphin-associated schools. This lasted until 1990 when US tuna processors adopted a policy of processing only tuna caught with dolphin-safe techniques. Vessels in the eastern fishery immediately lost their principal market for their catch, and faced the choices of converting to dolphin-safe techniques only, continuing with dolphin-associated fishing and finding new markets, selling their interests, or permanently moving to the Western Pacific. Most chose to permanently move to the Western Pacific. The few that remained in the Eastern Pacific gradually adopted dolphin-safe techniques. By 1996, the US fleet fishing east of 150°W had completely converted to utilizing only dolphin-safe techniques.

Fishery statistics for the fleet reflect this trend (tab. 1). For example, between 1989 and 1998, the number of purse seiners participating in the eastern fishery decreased 74%, from 31 vessels in 1989 to 8 vessels in 1995, then increased to 9 vessels, in 1996 and remained at that level. The US catch was 98,100 t in 1989 with 80% yellowfin tuna. By 1998, the US catch had decreased to 18,800 t and yellowfin tuna made up 35% of this catch. In the western fishery, the number of vessels is limited by the SPTT (currently, up to 50 vessels), and fluctuates because some vessels participate in both eastern and western fisheries in some years.

Table 1 - Catch for the US tuna purse seine fishery in the Pacific Ocean.

| Year | Western[1] | | | | | Eastern[1] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. of Seiners[2] | Catch (t) Skipjack | Yellowfin | Bigeye | Total | No. of Seiners[2] | Catch (t) Skipjack | Yellowfin | Bigeye | Total |
| 1989 | 35 | 95,000 | 42,900 | 2,400 | 140,300 | 31 | 19,300 | 78,700 | 100 | 98,100 |
| 1990 | 43 | 110,000 | 52,100 | 1,800 | 163,900 | 30 | 11,500 | 53,800 | 100 | 65,400 |
| 1991 | 43 | 177,400 | 37,300 | 1,600 | 216,300 | 15 | 12,700 | 21,300 | (3) | 34,000 |
| 1992 | 44 | 155,900 | 43,700 | 3,500 | 203,100 | 10 | 13,700 | 22,200 | 1,600 | 37,500 |
| 1993 | 42 | 148,400 | 46,000 | 3,700 | 198,100 | 11 | 18,900 | 19,800 | 1,800 | 40,500 |
| 1994 | 49 | 151,500 | 56,400 | 1,700 | 209,600 | 13 | 11,100 | 12,100 | 4,300 | 27,500 |
| 1995 | 44 | 132,500 | 31,800 | 3,200 | 167,500 | 8 | 18,500 | 7,900 | 7,100 | 33,500 |
| 1996 | 39 | 120,100 | 19,400 | 9,900 | 149,400 | 9 | 13,300 | 9,800 | 4,500 | 27,600 |
| 1997 | 35 | 84,700 | 50,200 | 9,100 | 144,000 | 9 | 15,700 | 8,200 | 5,300 | 29,200 |
| 1998 | 39 | 135,000 | 36,200 | 5,500 | 176,700 | 9 | 8,700 | 6,500 | 3,600 | 18,800 |

1. The dividing line for eastern and western fisheries is 150°W longitude.
2. Vessels that fished in both eastern and western fisheries are counted for both fisheries.
3. Less than 100 tons.

The number increased from 35 vessels in 1989 to 49 vessels in 1994 and then fluctuated lower to 39 vessels in 1998. The catch increased from 140,300 t in 1989 to a peak of 216,300 t in 1991 and then fluctuated lower to 176,700 t in 1998. Skipjack tuna has been the predominate species caught in the western fishery (76% in 1998).

## Data and sources

The operations of the US tuna purse seine fleet are monitored and fishery data are collected jointly by the National Marine Fisheries Service (NMFS) and the Forum Fishery Agency (FFA) for the western fishery and by the IATTC for the eastern fishery. Data collection requirements are different for the two fisheries, but in general, involve all vessels maintaining and submitting detailed daily fishing log books and unloading information for each trip. Vessels are also required to provide access for sampling of their landings for fish sizes, species composition and for other biological information at landing ports. Furthermore, vessels are required to accommodate at sea observers who monitor fishing activity and collect data on the catch. In the Eastern Pacific, all large vessels (>363 t tuna carrying capacity) are required to carry IATTC observers. In the Western Pacific, 20% of the fishing trips are monitored with observers by the FFA and all of the vessels are characterised as large.

### Western fishery

For the western fishery, detailed log book and port sampling data, (1989-1998), from NMFS files were used and served as the principal data source for the study. Since June 1988, NMFS has collected data for each fishing trip made by licensed vessels in the Western Pacific fishery. The number of days fished by the fleet ranged from 6,057 in 1998 to 8,236 in 1993 (tab. 2).

Table 2 - Fishing effort and number of sets for the US tuna purse seine fishery in the Pacific Ocean.

| Year | Western[1] | | Eastern[1] | |
|---|---|---|---|---|
| | Days Fished | Nb of Sets | Days Fished | Nb of Sets |
| 1989 | 6,598 | 6,436 | 4,900 | 4,051 |
| 1990 | 6,555 | 6,294 | 3,221 | 2,575 |
| 1991 | 7,261 | 9,245 | 1,945 | 1,219 |
| 1992 | 7,562 | 7,440 | 1,808 | 1,253 |
| 1993 | 8,236 | 7,416 | 1,738 | 1,036 |
| 1994 | 8,224 | 8,483 | 882 | 430 |
| 1995 | 7,956 | 6,873 | 973 | 507 |
| 1996 | 7,161 | 6,002 | 1,047 | 634 |
| 1997 | 6,952 | 5,671 | 1,208 | 565 |
| 1998 | 6,057 | 4,795 | 722 | 301 |

1. The dividing line for eastern and western fisheries is 150°W longitude.

Vessel captains are required to record in log books the mode of activity, such as travelling to fishing area or port, searching, and breakdown, and the midday position for each day at sea. When fishing takes place, information is recorded on a set-by-set basis including the coordinates where the set was made, time of set, and type of set. If a set is successful, the captain records estimated tonnage of tuna caught by species, estimated tonnage of by-catch (usually discarded at sea), and estimated tonnage of tuna discarded. Records for by-catch species and discards are considered less reliable than those for target species owing to the relative recording priorities of vessel operators.

Codes are provided for captains to use in recording type of set. Virtually all codes used are limited to the following: (1) "unassociated", or school usually feeding close to the surface and unassociated with a floating object, whale shark or other live animal; (2) "log", or school associated with a naturally occurring floating object, such as a tree trunk, tree frond, coconut, or debris; and (3) "FAD", or school associated with a Fishing Aggregating Device, which can be a modified naturally occurring floating object or a raft constructed from bamboo, plywood, etc. and set adrift with a radio-beacon for monitoring location. When log and FAD sets are summarised and pooled, they are collectively referred to as "drifting object" sets. Total number of sets represented in the data ranged from 4,795 in 1998 to 9,245 in 1991 (tab. 2).

Catches are recorded as estimated tonnages by species. Catches of less than 0.5 t are seldom reported; consequently, sets with reported catches of tuna greater than 0.5 t are considered successful sets. The reported tonnages for skipjack tuna are generally accurate with none to insignificant amounts of other tuna species included. The reported tonnages for yellowfin tuna, on the other hand, could include bigeye tuna because US fishermen do not make a distinction between these species. This practice is largely due to the landed price for both species being the same, so there being no incentive for separating this catch by species and for keeping separate tonnage records.

Separating yellowfin and bigeye tunas, however, is performed by NMFS. This is done with data collected through a port sampling scheme, which involves statistically sampling landings for species composition. Each year, more than 55,000 fish are identified by species. The results are used to verify the purity of skipjack tuna landings and to prorate mixed yellowfin tuna landings. Proration is done according to set type and sizes of fish in the landings (Coan *et al.*, 1995). The sampling design is largely for estimating catch by species in the fleet's aggregate catch by time-area strata and not in single trip catches.

The NMFS port sampling scheme is also used to collect information on sizes of fish in the landings. Each year, several thousand fish of each species are measured (tab. 3). In 1998, for example, approximately 20,600 yellowfin tuna, 25,200 skipjack tuna and 9,600 bigeye tuna were measured. As with the design for species composition sampling, the design for size sampling is largely for estimating sizes of fish in the fleet's aggregate catch by time-area strata and not in single trip catches.

The FFA manages an observer programme for the US fleet in the western region. The programme is designed for gathering scientific and compliance information for the FFA; consequently, records are treated as confidential. Summaries of catches of incidental species and discard information gathered by observers in 1998 were reported by Coan *et al.* (1999).

Table 3 - Number of fish examined for species identification and measured for size from landings of US tuna purse seiners fishing in the Western Pacific Ocean.

| *Year* | *Skipjack* | *Yellowfin* | *Bigeye* | *Total* |
|---|---|---|---|---|
| 1989 | 26,932 | 40,093 | 6,290 | 73,315 |
| 1990 | 30,099 | 30,783 | 3,893 | 64,775 |
| 1991 | 44,324 | 32,893 | 3,731 | 80,948 |
| 1992 | 31,434 | 42,486 | 8,657 | 82,577 |
| 1993 | 30,176 | 37,678 | 6,047 | 73,901 |
| 1994 | 28,829 | 27,435 | 4,435 | 60,699 |
| 1995 | 31,065 | 30,768 | 6,294 | 68,127 |
| 1996 | 26,872 | 23,362 | 15,519 | 65,753 |
| 1997 | 25,816 | 31,873 | 12,991 | 70,680 |
| 1998 | 25,216 | 20,582 | 9,579 | 55,377 |

## Eastern fishery

US data for the eastern fishery were obtained from the IATTC. The IATTC provided data aggregated for all vessels and sets combined, in conformity with its policy of not releasing individual set-by-set data of vessels. The data were unsuitable for the set-by-set analyses of the study, but were useful for general information about the fishery.

Log book data were aggregated by 5°x5° area blocks and month for each year, from 1989 to 1998. They included catch by species, type of set, and fishing effort, which represented from 722 days fished in 1998 to 4,900 days fished in 1989, and from 301 sets in 1998 to 4,051 sets in 1989 (tab. 2). Data on fish sizes were available, but were not used because the sample sizes appeared to be inadequate. Observer data were also available aggregated by 5°x5° area and month and used as supplemental information as follows.

Captains were not required to record log and FAD sets separately in IATTC log books. Typical set type codes used were unassociated, drifting object (log or FAD) and dolphin-associated schools. Observers, on the other hand, recorded log and FAD sets separately. Observer records were, therefore, used to prorate drifting object sets from log books into log and FAD sets. The IATTC requires captains to report bigeye tuna catches separately from yellowfin tuna catches in log books. The reports may not be accurate for bigeye tuna catches because of economic reasons noted above, but log book catches were used in this study rather than observer estimates.

## Changing types of sets

The number of sets by type was tabulated for each year and fishery. The results clearly show a shift to greater dependence on FADs by the fleet. In the western fishery, approximately 80% of the sets involved unassociated schools and 20% involved logs before 1995 (fig. 2). FAD technology in this fishery gained a foothold in 1994-1995 (Coan *et al.*, 1997) and spread rapidly. Since 1995, about 25% of the sets involved FADs, 50% involved unassociated schools and 25% involved logs. FAD sets, hence, increased while unassociated sets largely decreased in the western fishery.

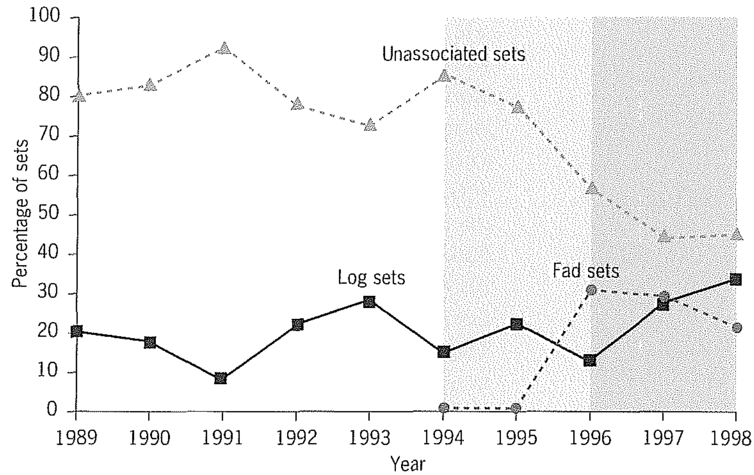



Figure 2
Percentage of sets by type for the US tuna purse seine fishery in the Western Pacific Ocean. Three periods based on FAD usage are shown with shading:
• 1989-1994 pre-FAD period
• 1995 a transition period
• 1996-1998 FAD period.

This same pattern holds for the eastern fishery, but is more pronounced and with greater variability (fig. 3). In 1989, about 75% of the sets involved dolphin-associated schools and about 12% each involved unassociated and log schools. With adoption of a dolphin-safe policy by processors in 1990, dolphin-associated sets declined rapidly to zero in 1996. Log and unassociated sets replaced the declining dolphin-

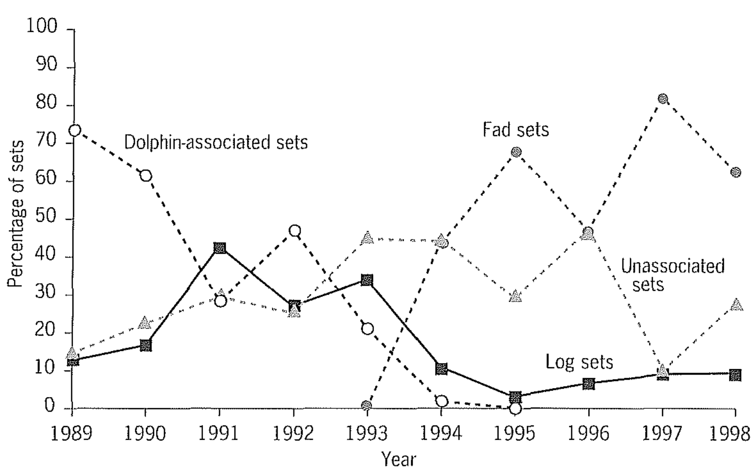



Figure 3
Percentage of sets by type for the US tuna purse seine fishery in the Eastern Pacific Ocean.

associated sets until 1994, when FAD technology took hold. FAD technology rapidly became the preferred method of fishing for the fleet, averaging 61% of all sets executed in 1994-1998. Unlike the western fishery, FAD sets in the eastern fishery replaced mainly log sets. The percentage of log sets declined from an average of 34% in 1991-1993 to 9% in 1994-1998.

Associated with this shift to FAD sets are changes in fishing operations and fishing areas. Data from the western fishery show that the frequency distribution of time of set (time when set commenced) is identical for log and FAD sets (fig. 4). Log and FAD sets are executed largely under cover of darkness in the early morning hours between 2 am and 6 am. Most of the sets are before daybreak, when light conditions are minimal for safe setting of the purse seine net and for minimizing escape of fish schools from the encircling net (Hampton & Bailey, 1999). This early morning activity requires a vessel to conduct searching operations and to locate suitable drifting objects the day before the set is made. Typically, a promising drifting object is located late in the day and the vessel drifts with the object over night in order to be in a position for setting on it the next morning. The drifting object is moored to the seiner and at dusk, special fishing lights are turned on to attract forage species and tuna. About 4 am, an auxiliary boat equipped with fishing lights is launched, ties to the object and takes over the light attracting task from the seiner. The lights on the seiner are gradually turned off, the seiner drifts away from the lightboat and drifting object and commences setting of the net before daybreak.

In contrast, unassociated sets are executed at all times during the day, from daybreak (around 4 am) to about 6 pm (fig. 4). Sets are spread evenly throughout the day, except for a peak at about 4 pm. This peak appears to be related to the practice of locating potential unassociated schools towards evening and remaining with the school in order to execute the last set for the day during hours of waning light at sunset. Schools are believed to be less skittish during that time of the day.

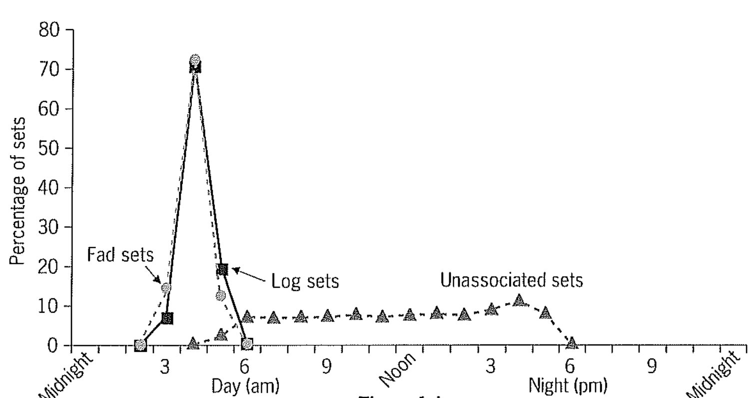



Figure 4
Time of set (beginning of set) by set type for sets made by US purse seiners fishing in the Western Pacific Ocean, 1996-1998.

In the eastern fishery, FAD technology resulted in a significant shift in the area fished. In 1989, 8% of the fishing effort was south of 5°N; whereas in 1997 92% of the effort was south of 5°N. Virtually all of this fishing effort in 1997 was devoted to FAD sets and concentrated primarily in the offshore area south of the equator and west of 100°W (IATTC, 1999).

The percentage of successful sets, or sets with catches greater than 0.5 t, shows a change since the introduction of FAD technology. In the western fishery, before the significant introduction of FAD technology in 1994-1995, the fleet averaged about 55% successful sets. After introduction of FAD technology, the percentage increased to more than 70 per cent.

## Before and after introduction of FAD technology

Fishery data from the western fishery were tabulated for two different periods, 1989-1994 (pre-FAD) and 1996-1998 (FAD), for comparison. These periods straddle 1995, the transition year, and represent years before and after the introduction and significant use of FAD technology. Both periods contain years of warm ENSO conditions, e.g. 1991-1992 and 1997-1998, which influenced fishing operations.

### Success rate and days fished

Comparison of the success rate for the periods indicates no difference between periods for each type of set (tab. 4). Log and FAD sets had a high success rate of more than 90% for each period. Unassociated sets, in contrast, had a low success rate of about 50% for each period.

The catch rate of successful sets indicates a significant difference (Mann-Whitney test) between periods for types of sets (tab. 4). The average catch rate for log sets during the FAD period (35.7 t/set) was significantly lower ($Z = 8.23$) by 16% compared to the pre-FAD period (42.8 t/set). For unassociated sets, the average rate was similarly significantly lower ($Z = 4.65$) in the FAD period (42.0 t/set versus 44.9 t/set) but by a smaller margin (1%). Overall the catch rate for the different types of sets and different periods averaged approximately 40 t/set.

Table 4 - Success and catch rates by set type for different periods of FAD innovation for US tuna purse seiners fishing in the Western Pacific.

| | Type of Set | | |
|---|---|---|---|
| | Log | FAD | Unassociated |
| Success Rate (%) | | | |
| Pre-FAD (1989-1994) | 94.0 | - | 49.8 |
| FAD (1996-1998) | 94.2 | 95.7 | 53.1 |
| Catch Rate (t/successful set)[1] | | | |
| Pre-FAD (1989-1994) | 42.8 (43.1) | - | 44.9 (41.8) |
| FAD (1996-1998) | 35.7 (36.1) | 37.3 (38.3) | 42.0 (38.8) |

1. Standard deviation for catch rate is shown in parentheses.

The frequency profile of sizes of successful sets for the two periods is quite similar (fig. 5, 6). The frequency distribution is skewed towards many sets with small catches and a few with very large catches (over 100 t). For all set types and for both periods, about 70% of the sets had less than 50 t each and about 50% had less than 30 t each. Sets with very large catches made up about 8 to 10% of the total successful sets.

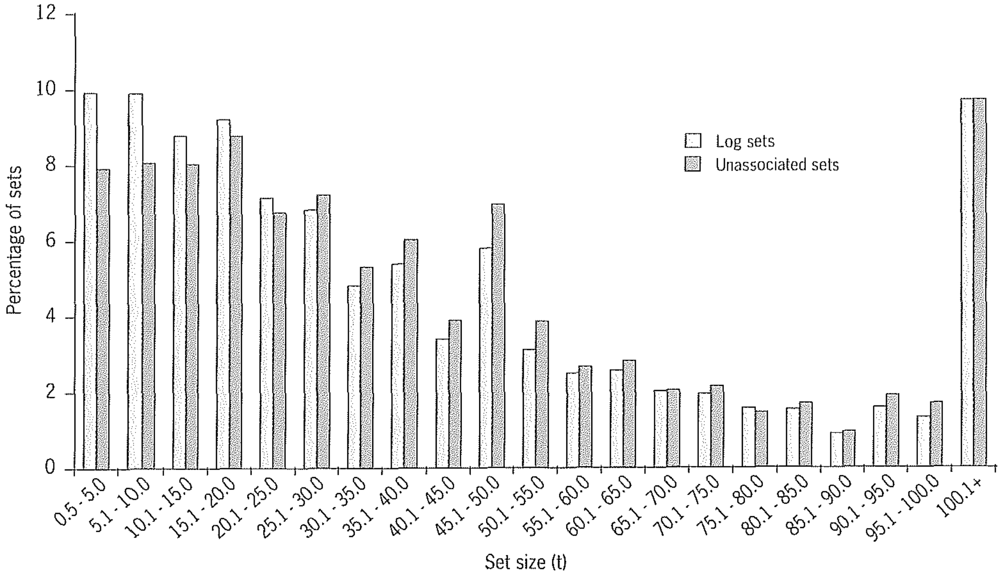



Figure 5 - Average frequency distribution of sets by set size (catch) for the US purse seine fishery in the Western Pacific Ocean, 1989-1994.

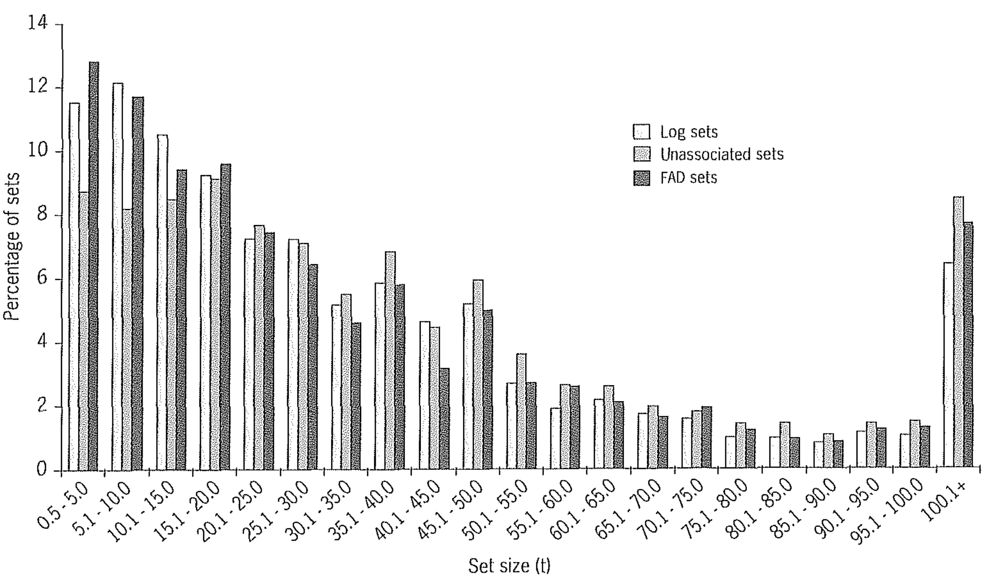
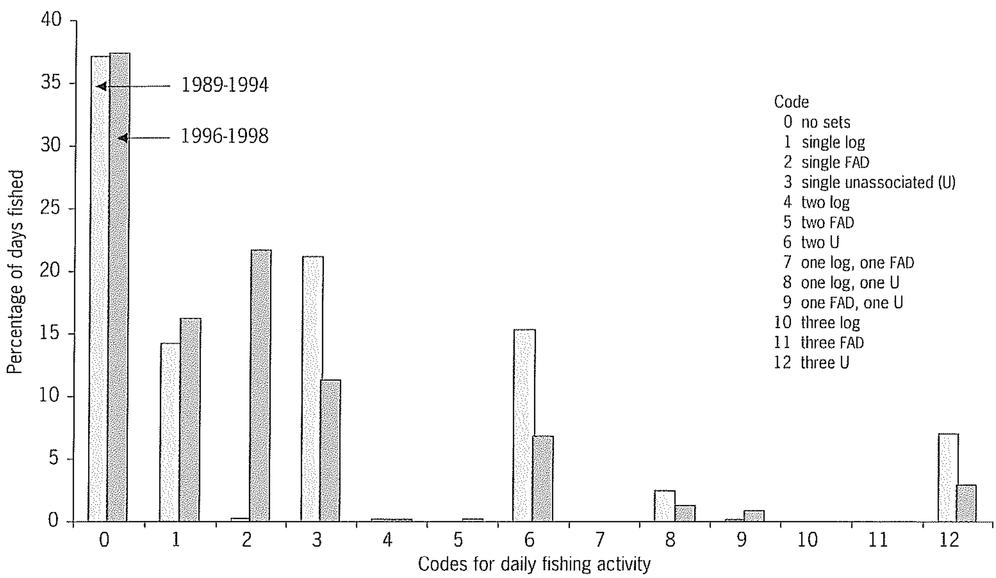



Figure 6 - Average frequency distribution of sets by set size (catch) for the US purse seiners fishery in the Western Pacific Ocean, 1996-1998.

The day-by-day fishing operations of the fleet were examined and there are similarities between the two periods (fig. 7). The results indicate that the percentage of days utilized for searching and that resulted in no sets was about the same for the two periods, about 37% of the total days fished for each period. The fleet rarely executed multiple FAD or log sets in a single fishing day, probably because the time, i.e. just before daybreak, for successful completion of such sets allow for only one to be executed per day. Single unassociated sets in a fishing day, on the other hand, were common (22% of days fished in the pre-FAD period and 10% of days fished in the FAD period). Combinations of unassociated sets and other set types, during a day were less common (2% of days fished in both pre-FAD and FAD periods).

Figure 7
Comparison of days fished by combination of set types in the pre-FAD period (1989-1994) and FAD period (1996-1998) for the US purse seine fishery in the Western Pacific Ocean.




There are also striking differences in fishing operations between periods. In the pre-FAD period, about 46% of the days fished involved unassociated schools whereas in the FAD period, only 23% of total days fished involved unassociated schools and 22% involved FADs. For both periods, log sets were involved in about 14% of the days fished.

## Species composition

Species composition of the catch by set type shows that log and FAD sets are more alike than unassociated sets (tab. 5). That is, log and FAD sets have a high percentage of skipjack tuna, modest percentage of yellowfin tuna and a small percentage of bigeye tuna. In contrast, unassociated sets have a moderate to high percentage of skipjack tuna, a modest percentage of yellowfin tuna and only trace amounts of bigeye tuna. Species proportions in log sets are similar for the two periods (tab. 5). However, during the FAD period, the proportion of bigeye tuna (6%) was considerably higher than that in the pre-FAD period (1%).

Table 5 - Species composition (%) of catches by set type for different periods of FAD innovation for the US tuna purse seine fishery in the Western Pacific.

| | Species | | | |
|---|---|---|---|---|
| | Skipjack | Yellowfin | Bigeye | Total |
| Log Set | | | | |
| Pre-FAD (1989-1994) | 72 | 27 | 1 | 100 |
| FAD (1996-1998) | 71 | 23 | 6 | 100 |
| FAD Set | | | | |
| Pre-FAD (1989-1994) | - | - | - | - |
| FAD (1996-1998) | 79 | 12 | 9 | 100 |
| Unassociated Set | | | | |
| Pre-FAD (1989-1994) | 73 | 27 | <1 | 100 |
| FAD (1996-1998) | 67 | 33 | <1 | 100 |

For unassociated sets, the proportion of yellowfin tuna was much higher in the FAD period (33%) than in the pre-FAD period (27%). As a result, the proportion of skipjack tuna was lower during the FAD period (67%) than during the pre-FAD period (73%). This high percentage of yellowfin tuna in the FAD period may be due to enhanced availability owing to the strong ENSO of 1997-1998.

Species composition was examined in a slightly different way with data for the 1996-1998 period only. Tuna species caught in each set were tabulated by set type (tab. 6). The results show that log and FAD sets are alike with respect to involving predominantly mixed-species schools containing yellowfin tuna and skipjack tuna (61-63%) and containing all three species, yellowfin, skipjack and bigeye tunas (6-8%). Schools of skipjack tuna only were also frequently involved in both log and FAD sets (16-20%). Schools of yellowfin tuna only were less frequently involved, but more than twice as often involved in log sets (16%) than in FAD sets (7%). Schools of mixed bigeye tuna and skipjack tuna were twice as often involved in FAD sets (2%) than in log sets (1%).

Table 6 - Frequency of sets by school type (species composition of school) for US tuna purse seiners fishing in the Western Pacific Ocean, 1996-1998.

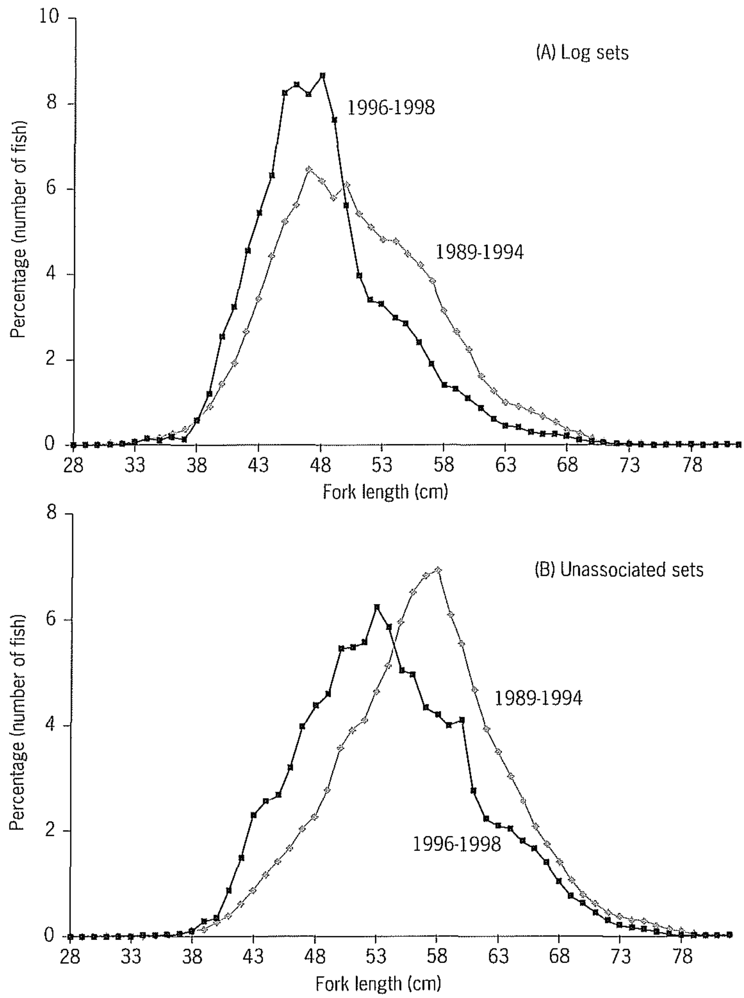
| Species Composition | Log | | FAD | | Unassociated | |
|---|---|---|---|---|---|---|
| | Number of Sets | Percentage | Number of Sets | Percentage | Number of Sets | Percentage |
| Yellowfin only | 564 | 15.8 | 327 | 7.1 | 1,124 | 25.7 |
| Bigeye only | 10 | 0.3 | 8 | 0.2 | 0 | 0.0 |
| Skipjack only | 583 | 16.3 | 893 | 19.5 | 2,498 | 57.2 |
| Yellowfin + Bigeye | 15 | 0.4 | 11 | 0.2 | 3 | 0.1 |
| Yellowfin + Skipjack | 2,160 | 60.6 | 2,878 | 62.9 | 731 | 16.7 |
| Bigeye + Skipjack | 36 | 1.0 | 90 | 2.0 | 2 | 0.0 |
| Yellowfin + Bigeye + Skipjack | 198 | 5.6 | 373 | 8.1 | 13 | 0.3 |
| Total | 3,566 | 100.0 | 4,580 | 100.0 | 4,371 | 100.0 |

In contrast, unassociated sets are quite different from the other set types. The predominate composition was schools of skipjack tuna only (57%) and of yellowfin tuna only (26%). Mixed-species schools accounted for only 17% of the sets.

### Sizes of fish

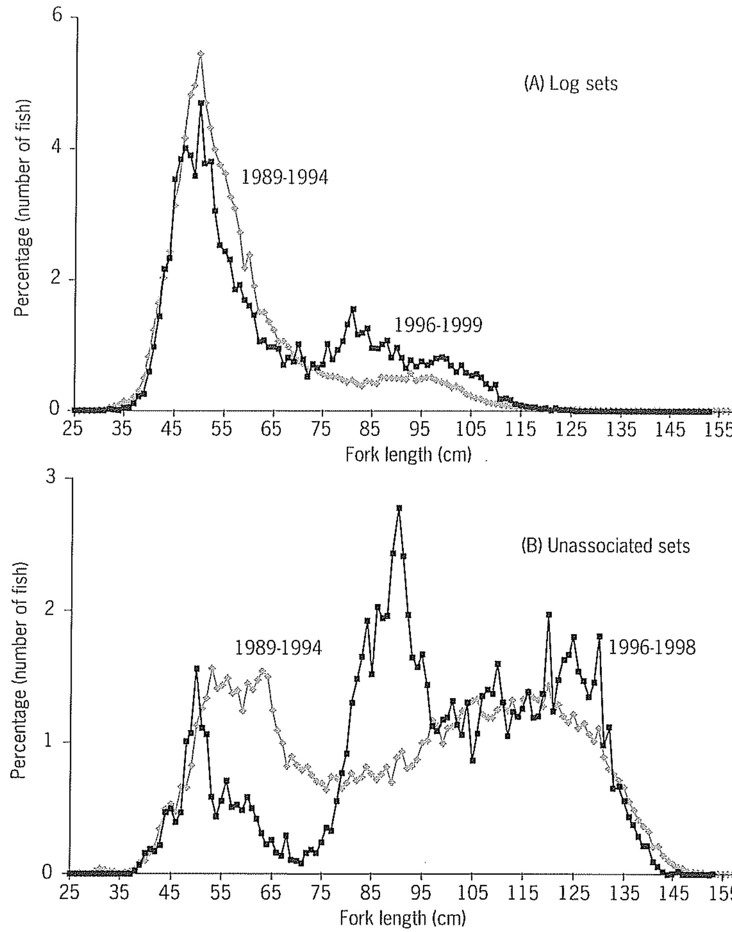
Size frequency distributions were computed for each species by set type for the two periods (fig. 8, 9, 10) and comparisons evaluated using the Kolmogorov-Smirnov test with $\alpha = 0.05$.

Figure 8
Comparison of sizes of skipjack tuna caught in the pre-FAD period (1989-1994) and the FAD period (1996-1998) in the Western Pacific Ocean for log sets (A) and unassociated sets (B).




Comparing sizes of fish caught within periods, the results show that skipjack tuna and yellowfin tuna are, on the average, larger in unassociated sets than in log sets. For example, in the FAD period, the average size of yellowfin tuna in unassociated sets was 97 cm FL and in log sets, 65 cm FL (fig. 9). Skipjack tuna in unassociated sets were 54 cm FL and in log sets, 48 cm FL (fig. 8). For bigeye tuna, there is generally no difference in sizes caught in the different types of sets and the sizes tend to be predominantly within the size range of skipjack tuna (fig. 10).

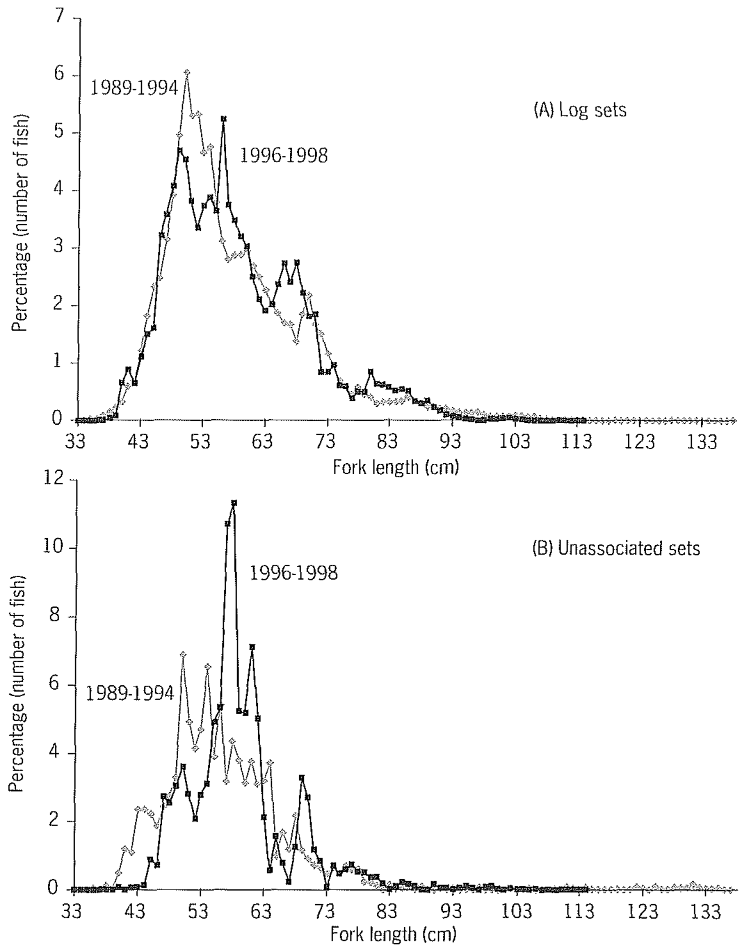
Figure 9
Comparison of sizes of yellowfin tuna caught in the pre-FAD period (1989-1994) and the FAD period (1996-1998) in the Western Pacific Ocean for log sets (A) and unassociated sets (B).




Comparing sizes of fish between periods, there is no significant difference in average sizes of bigeye tuna (fig. 10). For skipjack tuna, the size distributions are significantly different between periods for both log (D = 0.1768) and unassociated (D = 0.2130) sets (fig. 8). A higher frequency of small skipjack tuna was caught in the FAD period than in the pre-FAD period. This is consistent with comments made by fishermen that more schools consisting of small skipjack tuna have been recently observed in the Western Pacific.

For yellowfin tuna, a higher frequency of large fish (>75 cm FL) was caught in both log and unassociated sets in the FAD period than in the pre-FAD period (fig. 9). However, only for unassociated sets is the size distribution between periods significantly different (D = 0.1978). The average size of yellowfin tuna in log sets was 64 cm FL for the FAD period and 59 cm FL for the pre-FAD period. In unassociated sets, the average size was 97 cm FL for the FAD period and 91 cm FL for the pre-FAD period.

Figure 10
Comparison of sizes of bigeye tuna caught in the pre-FAD period (1989-1994) and the FAD period (1996-1998) in the Western Pacific Ocean for log sets (A) and unassociated sets (B).




## Insight and outlook

FAD technology has gained wide acceptance in the US purse seine fleet for tropical tunas because it increases fishing efficiency. FADs are easily deployed, tracked and located with radio-beacon devices. Locating unassociated schools is more difficult and requires long hours of searching and exceptional knowledge of the fishing areas.

The deployment of drifting FADs basically augments the supply of naturally occurring drifting objects that attract forage animals and tunas under them in the open ocean. FAD performance is thus similar to log performance, but quite different from the performance of unassociated sets. In the US tuna purse seine fishery in the Western Pacific Ocean, both FAD and log sets are executed before daybreak and have a very high success rate for catching tunas, more than 90 per cent. This is about double the success rate of unassociated sets (about 50%), which are executed at all hours of the day.

The species composition of a FAD or log set typically is mixed and with about 71-79% skipjack tuna, 12-27% yellowfin tuna and 1-9% bigeye tuna in the Western Pacific fishery. Frequently, this catch consists of mostly small sizes of tuna.

For unassociated sets, the catch composition tends to have greater amounts of yellowfin tuna and less bigeye tuna than in log and FAD sets. The sizes of fish in unassociated sets also tend to be larger than in log or FAD sets in the western fishery. This is particularly noticeable in the size distribution of yellowfin tuna. Typically, more than 60% of the catch are large fish (>75 cm FL) in unassociated sets whereas, more than 60% are small fish (< 75 cm FL) in log and FAD sets (fig. 9). This size distribution for log and FAD sets is similar to the size distribution of yellowfin tuna caught in unassociated sets in the eastern fishery (IATTC, 1999). Also, the size distribution of yellowfin tuna in unassociated sets in the western fishery is similar to the size pattern for yellowfin tuna typically caught in dolphin-associated sets in the eastern fishery. Unique oceanographic conditions in some of the areas in the Western Pacific appear to increase the availability of large yellowfin tuna to the purse seine gear, whereas in the eastern fishery dolphins serve that purpose.

Catches of bigeye tuna have recently increased significantly in all oceans (Fonteneau, 1998) and coincidentally with expansion of FAD fishing by purse seiners. For the US purse seine fishery in the Western Pacific, the bigeye tuna catch markedly increased from an average of 2,400 t/yr in the pre-FAD period to an average of 8,200 t/yr in the FAD period (tab. 1). This increase may be partially the result of increased availability of bigeye tuna to drifting objects during the FAD period than to solely the FAD technology. For instance, bigeye tuna in log sets increased from 1% in the pre-FAD period to 6% in the FAD period. It is clear, though, that FAD sets generally catch a higher proportion of bigeye tuna (9%) than log or unassociated sets.

Although FAD technology is widely used by the US fleet, its full potential has not yet been achieved. Currently in the western fishery, the fleet devotes 37% of the days fished for searching that result in no sets. An additional 21% of the days fished had sets on unassociated schools of which only 50% produced catches. Approximately 48% of the days fished, therefore, produce no catch. With increased deployment of FADs, the fleet could reduce this percentage of non-productive fishing days and increase overall production and efficiency. For example, if FADs were used in all days fished, the catch would have averaged 53% higher, or 240,000 t/yr, than 156,700 t/yr during the FAD period.

With increased deployment of FADs by the fishery, however, there would be increased risk of undesirable efforts with effects such as increased catches and discarding dead of undersized tunas and by-catch species. For the western fishery, Coan *et al.* (1999) reported discard rates for 1998. The discard rate for undersized tunas was 0.4 t/set for FAD sets, 0.3 t/set for log sets and 0.2 t/set for unassociated sets. The respective discard rate for by-catch was 0.4 t/set, 1.1 t/set and 0.1 t/set.

Because FAD sets also tend to produce smaller sizes of tunas, increased FAD sets would likely increase the landings of smaller sizes of tunas. Finally, with large number of FADs deployed in the Western Pacific, the migratory behaviour of tunas might be affected. FADs might retain tuna in areas where they would otherwise quickly pass through, and not be enticed by concentrated forage to remain. This could affect their biological parameters (growth, maturity, survival) and population dynamics. These potential effects on the population biology of tunas and on their ecosystem are currently largely unknown and require research attention.

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