

Movement and vulnerability of bigeye (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) in relation to FADs and natural aggregation points

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Abstract – In Hawaii, a variety of small- and medium-scale pelagic fisheries target fishing effort on a network of coastal moored FADs, natural inshore tuna aggregation points, offshore seamounts and offshore weather monitoring buoys. Large-scale longline vessels also operate in the Hawaii exclusive economic zone (EEZ) and beyond. These circumstances provide an ideal setting for tag-and-release experiments designed to elucidate the movement patterns, residence times, exchange rates and vulnerability of bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) within the Hawaiian EEZ. Preliminary recapture data indicate that FADs, island reef ledges and seamounts exert an overwhelming influence on the catchability of tuna. Recapture rates from these locations vastly outweigh tag returns from open water areas. As of August 31, 1999, a total of 15 387 bigeye and yellowfin tuna ranging in size from 29 to 133 cm fork length (FL) and from 26 to 143 cm FL respectively (mean 59.8 ± 14.1 cm; 58.4 ± 17.3 cm) have been tagged and released throughout the Hawaii EEZ. Recapture rates for both species have been similar with an overall recapture rate of 10.3 %. The location of tag releases reflects the importance of associative behavior and schooling to the vulnerability of tuna; seamounts and FADs accounted for 72.4 % and 23.5 % of all tag releases. Within the main Hawaiian Island group (excluding the offshore seamounts and buoys), 83.1 % of all recaptures have been made on anchored FADs and 11.9 % of recaptures have come from ledges or tuna aggregation areas close to the islands where bigeye and yellowfin tuna become vulnerable to hook and line gear. As these studies continue, additional and longer-term recaptures will provide increasingly detailed information on the movement patterns and vulnerability of bigeye and yellowfin tuna as they grow, move and recruit to different fisheries. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

aggregation / FAD / seamount / tag / yellowfin tuna / bigeye tuna / *Thunnus albacares* / *Thunnus obesus* / vulnerability / Pacific Ocean / Hawaii

Résumé – Déplacements et vulnérabilité du thon obèse (*Thunnus obesus*) et de l'albacore (*Thunnus albacares*) en relation avec les DCP et les points d'agrégation naturels. A Hawaï, diverses flottilles de pêche artisanale ou semi-industrielle concentrent leur effort de pêche sur des DCP mouillés près des côtes, sur des points d'agrégation naturels dans la zone côtière, sur des monts sous-marins au large, ou encore sur des bouées météorologiques situées au large. Les palangriers de gros tonnage opèrent également dans la zone économique exclusive (ZEE) d'Hawaï et au-delà. Ces conditions fournissent un cadre idéal pour des expériences de marquage/recapture afin d'étudier les déplacements, les temps de résidence, les taux d'échanges et la vulnérabilité du thon obèse (*Thunnus obesus*) et de l'albacore (*Thunnus albacares*) dans la ZEE d'Hawaï. Des données préliminaires de recapture indiquent que les DCP, les plateaux récifaux des îles, ainsi que les monts sous-marins exercent une très forte influence sur la capturabilité des thons. Les taux de recapture provenant de ces sites sous-estiment largement les retours des thons dont le marquage a été effectué au large. Ainsi, le 31 août 1999, un total de 15 387 thons obèses et albacores, respectivement de 29 à 133 cm et 26 à 143 cm (longueur à la fourche), soit une moyenne respective de $59,8 \pm 14,1$ cm et $58,4 \pm 17,3$ cm, ont été marqués et relâchés dans la ZEE d'Hawaï. Les taux de recapture pour les deux espèces sont similaires, avec un taux de recapture total de 10,3 %. Le lieu des marquages reflète l'importance du comportement associatif et grégaire des thons sur leur vulnérabilité ; monts sous-marins et DCP comptent pour 72,4 % et 23,5 % de l'ensemble des remises en liberté. Dans le groupe d'îles principales d'Hawaï (à l'exception des monts sous-marins et des bouées océanographiques), 83,1 % de toutes les recaptures ont été faites sous les DCP ancrés et 11,9 % des recaptures viennent du plateau corallien ou des zones de regroupement des thons, à proximité des îles où ces deux espèces deviennent vulnérables aux palangres « à main » (verticales). Ces études n'étant pas terminées, de nouvelles recaptures à long terme apporteront de plus en plus d'informations sur les déplacements et la vulnérabilité du thon obèse et de l'albacore pendant leur croissance, leurs déplacements et leur recrutement dans les différentes zones de pêche. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

agrégation / DCP / mont sous-marin / marquage / albacore / thon obèse / *Thunnus albacares* / *Thunnus obesus* / océan Pacifique / Hawaï

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1. INTRODUCTION

The Hawaiian Ridge system forms an extensive mid-Pacific feature composed of high islands, coral atolls, reefs, submerged banks and seamounts. These features aggregate several economically important pelagic fish, including tropical and sub-tropical tunas, billfish, dolphin fish (*Coryphaena hippurus*) and wahoo (*Acanthocybium solandri*). Several Hawaii-based fisheries have developed to exploit these resources. In addition, the state of Hawaii maintains a large network of moored fish aggregation devices (FADs) close to the inhabited islands to enhance small and medium-scale pelagic fisheries (Holland et al., 2000) while four offshore weather monitoring buoys provide productive offshore fishing locations. Submarine features such as ledges and banks close to the main islands also aggregate tuna where they are sought by different fisheries.

The strong association of tuna to seamounts, drifting objects and moored buoys is well known (Fonteneau, 1991; Hampton and Bailey, 1993) but the duration of these associations are not well documented or understood. An improved understanding of retention rates, vulnerability and movement patterns of tuna between different fishing grounds and school association types would greatly assist user groups and sound management. Two research programs, the Pelagic Fisheries Research Program, of the University of Hawaii and the State of Hawaii's FAD Administration Program, have conducted mark and recapture experiments on bigeye and yellowfin tuna to address these questions. Preliminary data from these experiments are presented here.

1.1. Physical characteristics of the region: geology and oceanography

The Hawaiian Ridge stretches over 21 500 km from the island of Hawaii (19° N, 155° W), west-northwest to just beyond Midway and Kure Atolls (30° N, 179° W). The Hawaiian Ridge system is commonly sub-divided into the eight main Hawaiian Islands (MHI) and the northwest Hawaiian Islands (NWHI), which consists of basalt outcroppings, submerged banks and coral atolls. Extensive seamount fields border the Hawaiian Ridge, including the Musicians Seamounts to the northwest of the MHI around 25°–29° N and 158°–163° W and the Navigator Seamounts located between 18°–20° N and 156°–160° W which contain the Cross Seamount to the south of the islands (figure 1).

Below a depth of 2 000 meters, the island chain forms a nearly continuous mid-Pacific barrier, exerting a dramatic influence over oceanic current patterns in this area. The Hawaiian Islands are positioned within the North Pacific subtropical gyre, subject to northeast Trade Winds and the westward flowing North Equatorial Current (NEC). Eastward of the MHI, the NEC flows due west, bifurcating near the island of Hawaii with the southern portion continuing westward to the south of the islands. The northern portion flows

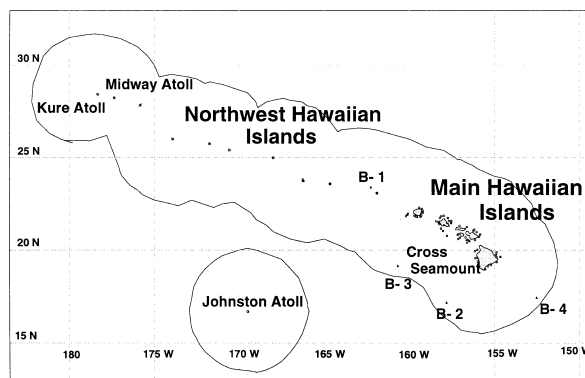


Figure 1. The main Hawaiian Island (MHI) and northwest Hawaiian Island (NWHI) groups.

northwest along the Hawaiian Ridge (Mysak and Magaard, 1983; White, 1983). Large-scale eddies form in the lee (westward) of the main Hawaiian Islands as a result of wind driven surface currents flowing between the islands and the islands blocking the westward flow of the NEC (Patzert, 1969; Patzert and Wyrski, 1974). Qiu et al. (1997) proposed the existence of an eastward flowing Hawaiian Lee Counter Current (HLCC) at the interface between two elongated gyres set up in the lee of the MHI between 170°–158° W and forming the HLCC along 19° N. Sea surface temperatures in the Hawaii zone range from 23–30 °C but normally remain within the range of 24–28 °C. The extreme northwestern region of the island chain can experience slightly cooler water temperatures and become influenced by the Kuroshio Extension system that circulates throughout the western North Pacific to Japan (Mizuno and White, 1983). Sea surface temperatures remain within the optimal habitat range for bigeye and yellowfin tuna throughout the year.

1.2. Hawaiian tuna fisheries

Tuna are harvested in Hawaii by troll, handline, pole and line, and longline gear, with commercial landings in the range of 13 000–15 000 mt during recent years (Anonymous, 1998). Target species in decreasing order of importance by weight and value include bigeye, yellowfin, skipjack, albacore and northern bluefin tuna.

Pelagic longline fishing in the Hawaiian region is regulated by a vessel-permitting system, with 164 permit holders and approximately 114 active vessels operating both within and outside Hawaii's 200 nautical mile exclusive economic zone (EEZ). A small domestic pole and line fleet targets skipjack close to the main Hawaiian Islands (Boggs and Kikkawa, 1993). Close to the MHI, small-scale troll and handline fisheries concentrate on yellowfin tuna, skipjack, dolphin fish and wahoo. Boggs and Ito (1993) summarized the history and recent status of Hawaii pelagic fisheries.

Small-scale handline fishing for tuna in Hawaii takes many forms. Three main categories exist. The *ika shibi* handline fishery is a night handlining technique that originated on the island of Hawaii and evolved from an *ika*, or squid fishery. Each boat carries a crew of one or two persons operating two to four lines baited with squid or small coastal pelagic fishes. Underwater bait attraction lights are used to attract wild squid and baitfish (Yuen, 1979). The fishery peaks during the summer months and focuses on large yellowfin tuna (approximately 40–80 kg) caught close to the main Hawaiian Islands. Medium to large bigeye tuna also contribute to *ika shibi* landings in some years but are likely to have been misreported as yellowfin tuna and are under-represented in catch statistics (Boggs and Ito, 1993).

Palu ahi is a daytime handline technique that is a modern adaptation of the ancient Polynesian 'drop stone' fishing method. A weighted handline and single baited hook is lowered in an area where sub-surface tuna are believed to be concentrated. Yellowfin and bigeye are taken but of a smaller size than is typical of the night-time *ika shibi* fishery. With the exception of fishing efforts focused on the seamounts and offshore weather buoys, *ika shibi* and *palu ahi* techniques are only employed in nearshore areas and around nearshore FADs, as described by Rizutto (1983).

In recent years, a third category of handline fishing has developed, which concentrates on tuna found in association with offshore moored weather buoys and the certain seamounts. This fishery employs a variety of fishing methods (*ika shibi*, *palu ahi*, jigging, trolling, pole-and-line) to target juvenile bigeye and yellowfin tuna, with most of the catch by weight composed of juvenile bigeye ranging between 6–25 kg whole weight. The vessels are quite small (typically between 12–18 m in length, with two- to four-man crews) but range up to 330 km offshore. Catch rates from the fishery are relatively high with landings often ranging between 2 000–5 000 kg for 2 to 5 days of effort.

1.3. Tuna fishing grounds

1.3.1. Longline grounds

Pelagic longline gear is prohibited from inshore waters surrounding the main Hawaiian Islands and from within 50 nautical miles of the NWHI to reduce impacts on protected species (sea birds, sea turtles, marine mammals), and to minimize gear conflict with inshore recreational and small-scale fisheries. Hawaii-based longliners travel great distances in search of swordfish but most of the vessels targeting tuna tend to operate close to the island chain or on deep seamounts a short distance outside the longline closed zones or bordering the Hawaii EEZ. Longline landings of bigeye tend to occur south of 30° N and peak during the first and fourth quarters close to the main Hawaiian Islands (Curran et al., 1996). Higher catch rates of yellowfin in the longline fishery occur in warmer

waters south of 20° N and peak during the second and third quarter. Isolated, oceanic islands are also targeted, with high catch rates of bigeye and yellowfin occurring seasonally near Johnston Atoll (16° 30' N, 169° 25' W) and due south of Hawaii near Palmyra Atoll, between 7–12° N latitude.

1.3.2. Offshore handline areas

The offshore handline fishery is based on high catch rates of juvenile bigeye and yellowfin tuna found in association with offshore weather monitoring buoys and the Cross Seamount. This deep sea feature is located at 18° 42' N, 158° 16' W and rises from depths greater than 4 000 m to 330 m and is located approximately 290 km south of Honolulu. Several other seamounts of the Navigator group surround the Cross Seamount but none rise to depths shallower than 600 m. None of the other seamounts aggregate concentrations of bigeye and yellowfin tuna vulnerable to surface gear, although many are fished by longline vessels.

Handline vessels operating on the Cross Seamount also target bigeye and yellowfin tuna found in association with four weather monitoring buoys moored in the outer Hawaii EEZ, referred to here as B1, B2, B3, and B4. The buoys are moored in depths ranging from 3 200–5 200 m and located 270–340 km offshore and have become de facto fish aggregation devices that are known to concentrate large schools of bigeye and yellowfin tuna.

1.3.3. Inshore fishing grounds: FADs, banks and ledges

The state of Hawaii maintains a network of moored FADs around all inhabited main Hawaiian Islands to enhance the fishing success and profitability of Hawaii based small boat fishermen (Holland et al., 2000). The program holds permits for 60 surface and four subsurface FAD sites, about 53 of which are actively maintained. Deployment depths range from a few hundred to 2 761 m and most are located within 15 km from the shore. The majority of inshore FADs are set in depths of 900–1 650 m.

Most trolling or inshore handline trips include a visit to one or more FADs. In a collective sense, the inshore FAD network forms one of the most frequently visited inshore 'fishing grounds' for the diverse small boat fleet that operates around the main Hawaiian Islands. Fishing methods on or near FADs include surface trolling, sub-surface slow trolling, live baiting, jigging and handlining. Hawaii-based commercial pole and line vessels also fish for mixed species schools of tuna on the inshore FADs. *Figure 2* depicts the inshore FAD locations and popular tuna fishing grounds of the main Hawaiian Islands referred to in this paper.

Troll and handline fishing trips that do not visit an inshore FAD usually fish near some sort of structure, such as near banks, ledges or isolated pinnacles, such as the Penguin Banks in the central main Hawaiian Islands, or near Kaula Rock (*figure 2*). Trolling and

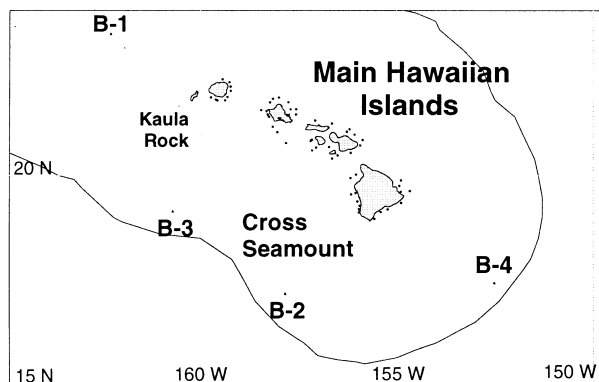


Figure 2. Inshore and offshore FADs and tuna fishing grounds.

some handline trips also concentrate near the 1 000 fathom (1 829 m) depth contour surrounding the MHI, which is believed to be a productive area for large tuna and marlin. Trollers also search for current lines containing flotsam to target tuna and other pelagic species found in association with drifting objects. Smith (1993) provides a detailed description of near-shore geography and fishing locations within the main Hawaiian Islands. As in other areas of the Pacific, there are certain nearshore areas in Hawaii that traditionally yield higher tuna catches than other adjacent areas. These *ahi koa* or ‘tuna holes’ are targeted by troll and handline fishermen.

2. METHODS

2.1. Hawaii Tuna Tagging Project/Objectives

In August 1995, conventional tag and release activities were initiated on bigeye and yellowfin tuna to address issues related to movement patterns, aggregation, catch rates and fisheries interaction. The initial focus was on the fisheries active near the Cross Seamount but the program was subsequently expanded to cover the entire Hawaii EEZ. With additional time, longer-term and long-distance movements should contribute towards knowledge on stock structure, exchange rates, and interactions throughout the Central Pacific. The objectives of the tagging project are to examine:

- movements of bigeye and yellowfin within the Hawaii EEZ and between major fishing grounds,
- interactions:
 - direct gear interaction, i.e. concurrent interaction between competing fisheries in the same time-area strata for the same-sized fish, including surface and sub-surface gear types,
 - sequential or progressive interactions, i.e. interactions which occur as fish grow and recruit to different fisheries,

- spatially segregated interaction, i.e. interactions where fish move between fishing grounds and enter new fisheries remote in time and space,
- exploitation rates and differential vulnerability (local fishing mortality) of tuna around seamounts and Fish Aggregation Devices (FADs),
- aggregation effects: retention rates of bigeye and yellowfin tuna around seamounts, FADs and local fishing grounds.

2.2. Study design

Following an early emphasis on the Cross Seamount, the HTTP expanded its scope and volume of operation, tagging and releasing bigeye and yellowfin tuna throughout the Hawaiian Islands during the 1998–2000 period. As much as possible, equal numbers of bigeye and yellowfin were tagged and released throughout the Hawaii EEZ in as broad a size range as possible. Four main release areas were chosen based on their modeled value to discerning movement, exploitation patterns (Bills and Sibert, 1997), and practical considerations of where significant quantities of releases could be made:

- Inshore areas of the main Hawaiian Islands,
- Cross Seamount,
- Central Northwest Hawaiian Islands,
- Midway Atoll.

2.3. Tagging methodology

The project utilized commercial troll, handline, and pole-and-line vessels for the release of tagged fish. Serially numbered plastic dart tags in two sizes were used, marked with a reward message and a toll-free telephone number for reporting recapturers. The tags, manufactured by Hallprint, Pty were either 11-cm, orange tags for tuna greater than 40 cm fork length, or yellow 9-cm dart tags for tuna measuring 20–40 cm fork length, and applied with appropriately sized tubular stainless steel applicators. Reward posters printed in English, Japanese, Korean and Chinese language providing details of tag recapture and reporting mechanisms were distributed widely and on a continuous basis. A variety of non-cash rewards were given to persons providing tags from recaptured tuna with a letter detailing release data of the fish and information on time at liberty, growth at liberty and distance between release and recapture.

All tagging was conducted by a small pool of trained technicians to maintain a uniform quality and condition of releases with all tags securely set through the pterygiophores located below the second dorsal fin. Tuna with any damage to the eyes, gill area or exhibiting significant bleeding were rejected for tagging. Each fish was captured with a barbless hook and line gear, placed on a wetted, padded vinyl mattress, measured to the nearest centimeter, tagged and released. The tag number, species, fork length and capture gear type were recorded and entered to a

Table I. Summary statistics of tagged and released bigeye and yellowfin tuna ($n = 15\,122$).

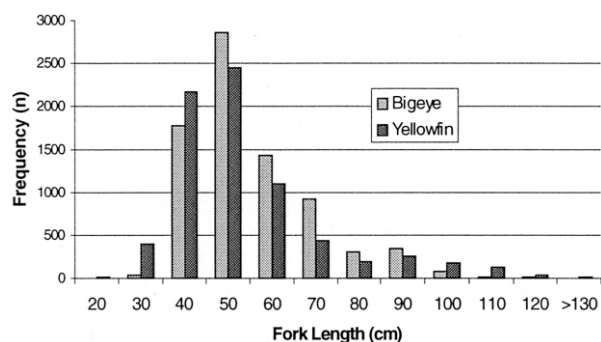
Species	Range (cm)	Median	Mode	Mean	Standard Deviation	count
Bigeye	29–133	56.0	53.0	59.78	14.12	7 762
Yellowfin	26–143	55.0	48.0	58.42	17.25	7 360

database containing the associated date, location and school association data.

2.4. Tag releases – interim status

2.4.1. Tag releases by species and area

As of 31 August 1999, a total of 15 397 tag releases consisting of 7 959 bigeye (51.7 %) and 7 440 yellowfin (48.3 %) had been tagged and released at the Cross Seamount and other areas of the Hawaii EEZ. The size distributions of tag releases were similar for both species, with mean fork lengths of 59.8 and 58.4 cm for bigeye and yellowfin respectively (standard deviation of 14.12 and 17.25 cm respectively). The size range of tag releases is quite broad; 29–133 cm fork length and 26–143 cm for bigeye and yellowfin respectively, but most tag releases fall within the range

**Figure 3.** Length frequency distribution of bigeye and yellowfin tag releases to August 31, 1999 ($n = 7\,762$ bigeye, 7 360 yellowfin).**Table II.** Tag releases by area and species as of 31 August 1999.

Area	Bigeye	% of BE	Yellowfin	% of YF	Total	% of total
Midway	8	0.1	1 506	20.2	1 514	9.8
NWHI	14	0.2	670	9.0	684	4.4
B1	5	0.1	197	2.6	202	1.3
B2	835	10.5	340	4.6	1 175	7.6
B3	748	9.4	137	1.8	885	5.7
B4	285	3.6	153	2.1	438	2.8
Cross	5 958	74.9	3 604	48.4	9 562	62.1
MHI FAD	81	1.0	833	11.2	914	5.9
MHI unassociated	23	0.3	0	0.0	23	0.1
	7 957	100	7 440	100	15 397	100

of 45 to 70 cm fork length with mean fork length values of 59.78 and 58.42 cm (*table I*). The length frequency distributions of tagged bigeye and yellowfin are shown in *figure 3*.

The majority of tag releases were made on the Cross Seamount, accounting for 62.1 % of all releases and 74.9 % of all bigeye tagged. The distribution of yellowfin releases differs from bigeye, as yellowfin are more abundant (or vulnerable) in comparison to bigeye near the main and northwest Hawaiian Islands, and bigeye dominate in catches from the Cross Seamount. The significance of fish aggregation devices as important locations for tagging tuna is clear, with the offshore FADs combined (B1, B2, B3, B4) and MHI FADs accounting for 2 700 and 914 tag releases respectively, or 23.5 % of all tag releases. Relevant data on tag releases achieved by area are given in *table II*.

2.4.3. Releases by school/association type

Tag releases have been mainly achieved through tagging efforts directed at tuna schools associated with seamounts (72.4 %) and FADs (23.5 %). Total seamount releases are greater than the number of releases made on the Cross Seamount alone because other seamounts in the northwest Hawaiian Islands have been visited on tagging cruises. The category ‘Island or reef’ *table III* lists tuna caught near isolated small islands and reefs such as the atolls and banks of the northwest Hawaiian Islands. Only 23 tag releases were made on ‘unassociated’ schools, which were large longline-caught bigeye tuna implanted with archival data logging tags by the National Marine Fisheries Service and externally marked with HTTP dart tags.

3. RESULTS

The results presented in this report, based on tag recapture rates and locations are preliminary. Further tag releases and recaptures may contribute to or alter these findings, but general trends in recaptures by area and school association types should remain consistent.

Table III. Tag releases by species and school association type.

Association	Bigeye	% of BE	Yellowfin	% of YF	Total	% of total
Seamount	6 009	75.5	5 146	69.2	11 155	72.4
Anchored FAD	1 923	24.2	1 691	22.	3 614	23.5
Island or reef	2	0.0	603	8.1	605	3.9
Unassociated	23	0.3	0	0.0	23	0.2
Total	7 957	100	7 440	100	15 397	100

3.1. Recaptures

3.1.1. Recapture rates

As of August 31, 1999, A total of 1 580 (10.3 %) tuna of both species had been recaptured. Yellowfin tuna have been recaptured at a slightly higher rate (10.8 %) than bigeye (9.7 %). *Table IV* lists tag recapture numbers and recapture rates from releases made at specific areas or locations in the Hawaii EEZ. A high proportion (12.7 %) of tag returns resulted from short-term recaptures of releases made in the Cross Seamount. However, recapture rates of bigeye and yellowfin released at the inshore, MHI FADs have been very high at 22.2 % and 19.3 % respectively. To date, returns of tuna tagged in the northwest Hawaiian Islands and near Midway Atoll have been very low.

3.1.2. Recaptures by area

Table V lists tag recaptures by area or location, where a reliable recovery location was reported ($n = 1 560$). Three recaptures have been reported by Japanese commercial fishing vessels at locations to the west of the International Date Line. Two were in international waters and one was caught within the Japanese EEZ. A single recapture has been reported from the Eastern Pacific Ocean; a yellowfin tuna released on the Cross Seamount and recaptured six months later by a purse seine vessel near the northern coast of Mexico. Excluding the 19 yellowfin released and quickly recaptured on Buoy 1 (B1), only one

tagged tuna has been recaptured within the northwest Hawaiian Islands (NWHI) to date.

Recaptures in the category 'Longline areas' (*table V*) include bigeye and yellowfin taken by pelagic longline vessels operating to the north and south of the longline exclusion zones that surround the main Hawaiian Islands. Some of these recaptures came from longline sets made near deep seamounts, such as those belonging to the Musicians and Navigator Seamount fields described earlier, or from scattered isolated seamounts south of the Hawaii EEZ. Other longline recaptures came from so-called 'open water' areas. Several longline recaptures were made directly on the Cross Seamount and are reported in the 'Cross Seamount' category.

Recaptures within the main Hawaiian Islands come primarily from anchored FADs, which account for an overwhelming 83.1 % of all recaptures in the MHI group. *Table V* lists tag recaptures made within the main Hawaiian Islands for those with known school or association type. Twenty-eight recaptures were classified as 'island- or reef-associated', meaning that the fish were caught in a location near a small island, reef, ledge or *ahi koa* as described previously. These fish were generally larger than FAD-associated recaptures and were taken with *palu ahi* or *ika shibi* handline gear. Only ten of all the recaptures were categorized as 'unassociated', and these usually came from small troll vessels operating in open water areas between the main Hawaiian Islands (*table VI*).

Table IV. Recapture numbers and recapture rates from releases made at certain areas/locations.

Area	BE releases	BE recapture	BE return (%)	YF release	YF recapture	YF return %	Total releases	Total recapture	Recapture %
Midway	8	0	0	1 506	5	0.3	1 514	5	0.3
NWHI	14	0	0	670	5	0.7	684	5	0.7
B1	5	0	0	197	32	16.2	202	32	15.8
B2	835	74	8.9	340	21	6.2	1 175	95	8.1
B3	748	22	2.9	137	9	6.6	885	31	3.5
B4	285	9	3.2	153	5	3.3	438	14	3.2
Cross	5 958	649	10.9	3 604	569	15.8	9 562	1 218	12.7
MHI FAD	81	18	22.2	833	161	19.3	914	179	19.6
MHI unassociated	23	1	4.3	0	0	0	23	1	4.3
Total	7 957	773	9.7	7 440	807	10.8	15 397	1 580	10.3

Table V. Tag recaptures by area or location with reliable recovery location.

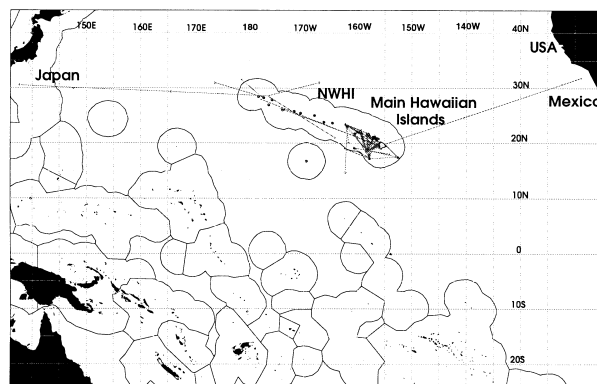
Area	Bigeye	Yellowfin	Total
East longitude	0	3	3
NWHI	0	1	1
B1	0	19	19
B2	84	11	95
B3	18	9	27
B4	11	9	20
MHI FAD	24	174	198
MHI other areas	4	35	39
Cross Seamount	603	532	1 135
Longline areas	14	8	22
Eastern Pacific	0	1	1
Total	758	802	1 560

3.2. Movements patterns of tagged tuna

3.2.1. Long distance movements

To date the only recaptures that have demonstrated long-distance displacements on an ocean basin scale have come from yellowfin tuna releases. One yellowfin tuna, tagged near Midway Atoll was recovered approximately 4 410 km to the west by a longline vessel operating within the Japan EEZ. Another yellowfin tuna, tagged on the Cross Seamount was recovered after six months at liberty approximately 4 200 km to the east, near the coast of northern Mexico (figure 4) few scattered longline recoveries of yellowfin and bigeye tuna have been made short distances outside the Hawaii EEZ but by far, the majority of recoveries have been made close to the points of release and well within the EEZ (figures 4, 5).

Two yellowfin tagged and released near Midway Atoll were later recaptured 450 km west of the Hawaii EEZ in the region where the northwest Hawaiian Island chain and the Emperor Seamounts meet. Two others released near Midway Atoll in the spring of 1998 and winter of 1999 were recaptured with *ika shibi* handline gear at a nearshore tuna aggregation area off the west coast of the island of Hawaii in August 1999. That is, they had traversed from Midway at the western end of the NWHI to the eastern most part of the chain.

**Figure 4.** Yellowfin recaptures to August 31, 1999.

3.2.2. From Offshore Buoy 1

Nineteen short-term recaptures were made on Buoy 1 from releases at the same location ('point of release'). Four yellowfin tagged on Buoy 1 were later recaptured on the Cross Seamount and one in an open water area by a Hawaii-based longliner. The remaining recaptures of yellowfin tagged at Buoy 1 were later caught on anchored FADs surrounding the main Hawaiian Islands or on handline gear at nearshore aggregation areas (figure 6).

3.2.3. From Offshore Buoys 2, 3, 4

Recaptures of Buoy 2 releases with significant movement away from that buoy were made on the Cross Seamount, Buoy 3, Buoy 4, and at inshore MHI FADs and inshore handline areas, such as Kaula Rock and on ledge near Kaena Point, off the western point of Oahu in the central MHI (figure 7). Ten of the yellowfin recaptures at Buoy 2 had been tagged at the same buoy from three days to nine months previously. Seventy-four bigeye recaptures were made from releases at Buoy 2, most of which were recaptured on Buoy 2 (point of release) within a month of release. The only documented movements of bigeye away from Buoy 2 were recaptured on the Cross Seamount between three and seven months at liberty. A single longline recapture to the west of Buoy 3 was reported.

Buoy-3 recaptures away from Buoy 3 came from the Cross Seamount for both yellowfin and bigeye tuna.

Table VI. Tag recaptures from within the main Hawaiian Islands with known school association type.

	Bigeye	% of BE	Yellowfin	% of YF	Total	% of total
Unassociated	2	7.1	8	3.8	10	4.2
Island or reef	2	7.1	26	12.5	28	11.9
Drifting FAD	1	3.6	1	0.5	2	0.8
Anchored FAD	23	82.1	173	83.2	196	83.1
Total	28	100	208	100	236	100

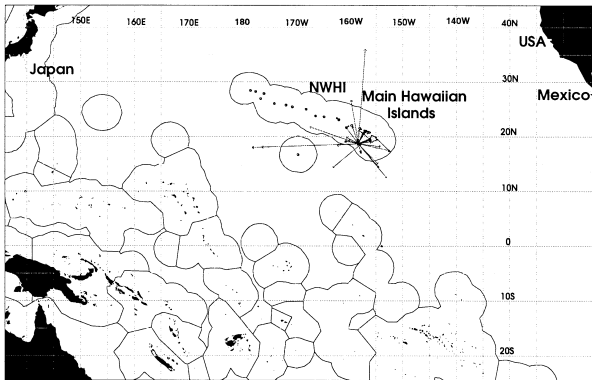


Figure 5. Bigeye recaptures to August 31, 1999.

One bigeye and one yellowfin released at Buoy 4 were later recaptured with handline gear at a productive *ahi koa*, or tuna aggregation point near the eastern point of the island of Hawaii (figure 7).

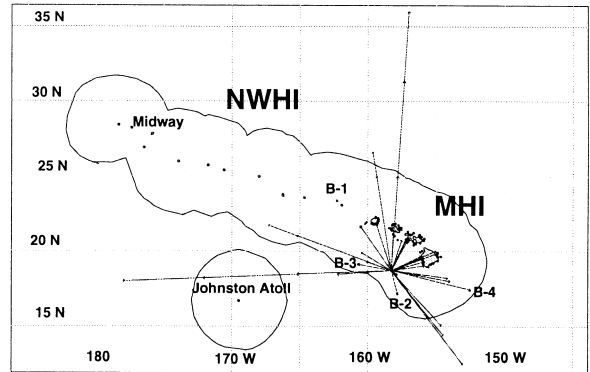


Figure 8. Recaptures of bigeye tuna from tag releases made on the Cross Seamount.

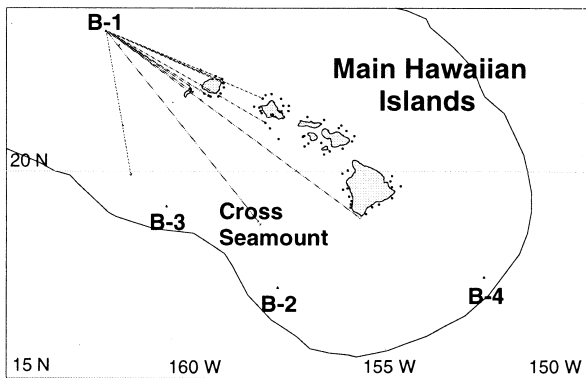


Figure 6. Recaptures of yellowfin tuna from tag releases from B1.

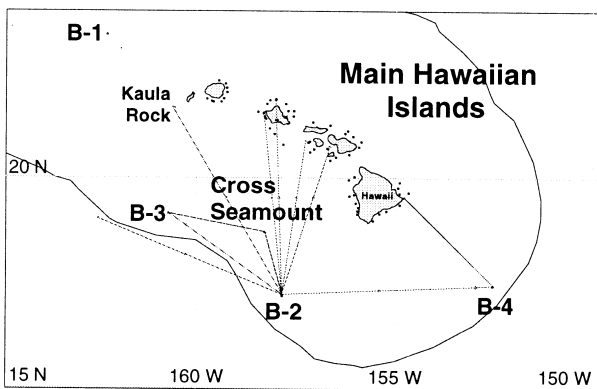


Figure 7. Recaptures of yellowfin and bigeye tuna from tag releases made at B2, B3, B4.

3.2.4. From Cross Seamount

Large numbers point-of-release-captures have been made for yellowfin and bigeye released on the Cross Seamount — primarily by offshore handline boats. Movements of tagged fish away from Cross Seamount have fallen into four main categories: (1) to offshore buoys B2, B3, B4; (2) to offshore longline areas; (3) to inshore MHI FADs; and (4) to nearshore tuna aggregation points within the MHI (figures 8, 9). Seventeen bigeye released on the Cross Seamount were later recaptured by longline vessels to the north, south east and west of the main Hawaiian Islands, including fish caught as far south as 12.5° N and as far north as 36° N latitude. Only one yellowfin tagged on the Cross Seamount has been recaptured by a longline vessel working away from the seamount, and this fish was caught only 58 km to the northwest on the Brigham Seamount. For the tunas recaptured at buoys, more bigeye were recaptured at offshore buoys while yellowfin were more commonly recaptured near the inshore MHI FADs and at nearshore tuna aggregation points.

3.2.5. From Inshore FADs

To date, over 900 tag releases have been made at inshore FADs with an overall recapture rate of 19.6 % (table II). Over half of these releases (81 bigeye, 434 yellowfin) were made at BO FAD during a single-month period in 1998 when a pole and line vessel was available to the tagging project. Recaptures from this single buoy are representative of movements and recapture points of tuna within the main Hawaiian Islands.

Twenty-one percent of bigeye releases from BO FAD were recaptured with all but one being recaptured on the same FAD. The single bigeye recapture away from BO FAD was caught on F FAD, 280 km to the southeast and off the west coast of the island of Hawaii. By contrast, 74.1 % of the yellowfin recaptures were made at other locations away from BO FAD. Of these twenty-eight yellowfin that were tagged

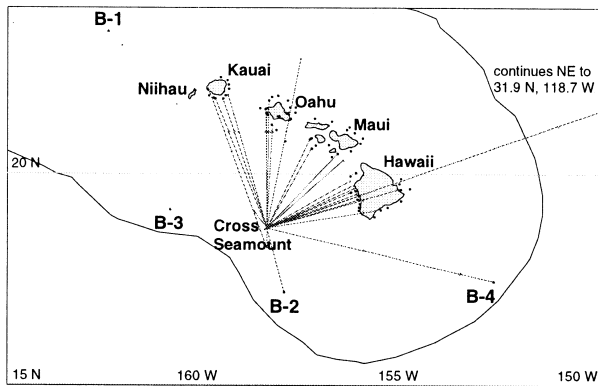


Figure 9. Recaptures of yellowfin tuna from tag releases made on the Cross Seamount.

on BO FAD and recaptured elsewhere, fourteen were caught to the west and fourteen were recaptured to the east and all from within the main Hawaiian Islands. Twenty-five of these recaptures were taken from various anchored MHI FADs or from inshore tuna aggregation areas. Only three recaptures were recovered from open water (unassociated) schools. Six recaptures were made at inshore *ahi koa*, or handline areas off Oahu and the island of Hawaii. The handline recaptures were made between one and eleven months at liberty resulting in a larger size at recapture compared to the FAD recoveries.

3.2.6. To Cross Seamount

Some movement of tagged fish to the Cross Seamount have been documented. For bigeye, seven fish tagged and released at Buoy 2 and four bigeye from Buoy 3 were later recaptured on the Cross Seamount. Similar movements have been recorded for tagged yellowfin, including four yellowfin tagged on Buoy 1 and later recaptured on the Cross Seamount. Yellowfin released on Nihoa Bank in the southern NWHI and a MHI FAD near the island of Hawaii were recaptured on the Cross Seamount.

3.2.7. To inshore aggregation areas

Figures 10 and 11 indicate movements of yellowfin and bigeye to the island of Hawaii. All recaptures in this category were made either on anchored FADs or at nearshore handline fishing areas. Yellowfin recaptures include two fish tagged at the Nero Seamount west of Midway and at an unnamed bank in the northern NWHI (figure 10). These fish were recaptured during the summer handline fishery for yellowfin off the west coast of the island of Hawaii. Yellowfin tagged on Buoy 1, Buoy 4, BO FAD and the Cross Seamount were also taken in the nearshore handline fishery off Hawaii. The majority of FAD recaptures were of small yellowfin that had been tagged and released on other anchored FADs on the northwest coast of Hawaii.

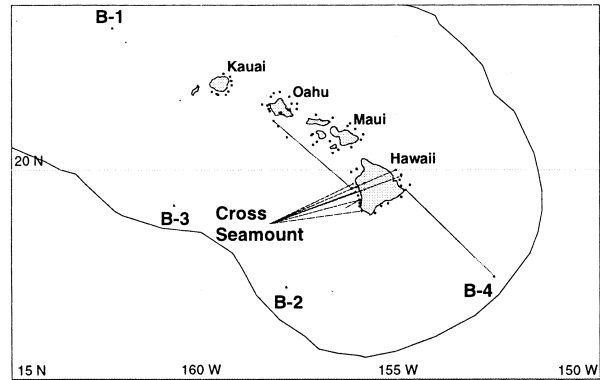


Figure 10. Recaptures of yellowfin tuna near the island of Hawaii.

Bigeye recaptures near the island of Hawaii were made at anchored FADs, and inshore *palu ahi* and *ika shibi* tuna aggregation areas (figure 11). Bigeye recaptures near the island of Hawaii came from the Cross Seamount Buoy 4, BO FAD and a release made off the west coast of Hawaii that had been implanted with an archival data-logging tag by the National Marine Fisheries Service.

4. DISCUSSION

Preliminary results of tagging research in Hawaii highlight the overwhelming influence of natural and man-made structures to the aggregation and vulnerability of bigeye and yellowfin tuna. These associative behaviors form the foundation of searching and fishing strategies for all Hawaii tuna fisheries, including offshore longline and handline vessels that often target fishing effort close to seamounts.

For example, 96 % of tag releases achieved by the program have been made on seamounts, offshore buoys and anchored FADs. Within the main Hawaiian Islands, 95.8 % of tag recaptures have been made on

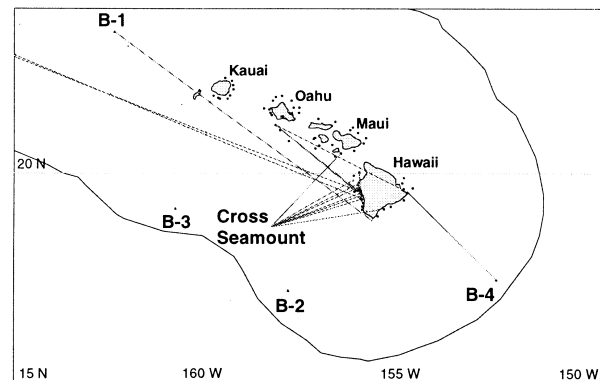


Figure 11. Recaptures of bigeye tuna near the island of Hawaii

tuna schools found in association with these structures. Anchored FADs alone have accounted for 83.1 % of all tag recaptures reported within the main Hawaiian Islands. These results parallel the analysis of Kleiber and Hampton (1994) who showed that FAD deployments strongly influence recapture rates and movement patterns of skipjack tuna near the Solomon Islands where a large FAD network is maintained.

In general, yellowfin recaptures indicate movement or vulnerability towards and near the main Hawaiian Islands, whereas bigeye recaptures have remained more offshore in nature from within and outside the EEZ. Interesting differences in movement patterns of juvenile and adult tuna around Hawaii are also emerging. Recaptures of juvenile yellowfin suggest they are highly vulnerable at the Cross Seamount as well as on the inshore FAD network, and by a variety of hook and line gear types. Longer-term recaptures of yellowfin, representing significantly larger-sized fish are starting to be taken at nearshore tuna aggregation points and recruit to offshore longline fisheries, offering supporting data to size-related differentials in vulnerability by aggregation type. Yellowfin tuna in Hawaii appear to exhibit an island-associated, inshore-spawning run, peaking in the June–August period (Itano, 2000; June, 1953). The relative importance of inshore and offshore spawning grounds and the degree of ‘resident’ spawning will be further addressed as tagged yellowfin reach maturity and are recaptured by regional fisheries. To date, most of the recaptures of both species have been made relatively close to their points of release, while the island of Hawaii appears to be a major tuna aggregation point for the entire region, particularly for yellowfin tuna. However, a few long-distance movements of yellowfin have been recorded by the program. Recaptures of yellowfin released near Midway Atoll and recovered west of the Date Line are particularly interesting, and may support significant mixing of tuna resources of the Western Pacific and Hawaii. However, more recaptures are needed to further examine these hypotheses.

In addition to longer residence times in comparison to yellowfin at the Cross Seamount (Holland et al., 1999), bigeye tuna appear to prefer offshore areas, moving between and becoming vulnerable at offshore aggregation points, such as near seamounts and the offshore weather buoys. Where bigeye travel between release and recapture remains a mystery, as pelagic longline gear and most of the inshore tuna fishing gears do not effectively sample juvenile bigeye tuna. The collection of fishery-independent data, such as provided by archival or sonic tagging may help to address these questions. As longer-term recaptures of both species become available, greater confidence in estimates of size-dependent vulnerability, movement patterns and recruitment rates should result. Ongoing tagging work on tuna associated with the main Hawaiian Island FADs will also facilitate the calculation of two-way exchange rates between inshore and offshore fisheries.

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References

- Anonymous, 1998. Pelagic Fisheries of the western Pacific region, 1997 Annual Report. Western Pacific Regional Fishery Management Council, Honolulu, Hawaii, USA.
- Bills, P.J., Sibert, J.R., 1997. Design of tag-recapture experiments for estimating yellowfin tuna stock dynamics, mortality, and fishery interactions. SOEST Publication JIMAR Contr.97-313.
- Boggs, C.H., Ito, R.Y., 1993. Hawaii’s pelagic fisheries. Mar. Fish. Rev. 55, 69–82.
- Boggs, C.H., Kikkawa, B.S., 1993. The development and decline of Hawaii’s skipjack tuna fishery. Mar. Fish. Rev. 55, 61–68.
- Curran, D.S., Boggs, C.H., He, X., 1996. Catch and effort from Hawaii’s longline fishery summarized by quarters and five degree squares. NOAA Technical Memorandum NMFS. NOAA-TM-NMFS-SWFSC-225.
- Fonteneau, A., 1991. Seamounts and tuna in the Tropical Eastern Atlantic. Aquat. Living Resour. 4, 13–25.
- Hampton, J., Bailey, K., 1993. Fishing for tunas associated with floating objects: a review of the western Pacific fishery. SPC Tuna and Billfish Assessment Programme Tech. Rep. 31. South Pacific Commission, Noumea, New Caledonia.
- Holland, K.N., Jaffe, A., Cortez, W., 2000. The Hawaii FAD system. Actes de Colloques Ifremer, 28.
- Holland, K.N., Kleiber, P., Kajiura, S.M., 1999. Different residence times of yellowfin tuna, *Thunnus albacares*, and bigeye tuna, *T. obesus*, found in mixed aggregations over a seamount. Fish. Bull. 97, 392–395.
- Itano, D.G., 2000. The reproductive biology of yellowfin tuna (*Thunnus albacares*) in Hawaiian waters and the western tropical Pacific Ocean: Project summary. SOEST Publication 00-01, JIMAR Contr. 00-328.
- June, F.C., 1953. Spawning of yellowfin tuna in Hawaiian waters. U.S. Department of the Interior, Fish and Wildlife Service, Fish. Bull. 77, 47–64.
- Kleiber, P., Hampton, J., 1994. Modeling effects of FADs and islands on movement of skipjack tuna (*Katsuwonus pelamis*): estimating parameters from tagging data. Can. J. Fish. Aquat. Sci. 51, 2642–2653.

- Mizuno, K., White, W.B., 1983. Annual and inter-annual variability in the Kuroshio Current System. *J. Phys. Oceanogr.* 13, 1847–1867.
- Mysak, L.A., Magaard, L., 1983. Rossby wave driven Eulerian mean flows along non-zonal barriers with applications to the Hawaiian Ridge. *J. Phys. Oceanogr.* 13, 1716–1725.
- Patzert, W.C., 1969. Eddies in Hawaiian Waters. University of Hawaii at Manoa. Hawaii Inst. Geophysics, HIG-69-8, 51 p. with figures 1-71.
- Patzert, W.C., Wyrki, K., 1974. Anticyclonic flow around the Hawaiian Islands indicated by current meter data. *Phys. Oceanogr.* 4, 673–676.
- Qiu, B., Koh, D.A., Lumpkin, C., Flament, P., 1997. Existence and formation mechanism of the North Hawaiian Ridge Current. *J. Phys. Oceanogr.* 27, 431–444.
- Rizutto, J., 1983. *Fishing Hawaii Style, Volume 1, A Guide to Saltwater Angling.* Fishing Hawaiian Style, Ltd. Honolulu, Hawaii.
- Smith, M.K., 1993. An ecological perspective on inshore fisheries in the main Hawaiian Islands. *Mar. Fish. Rev.* 55, 34–49.
- White, W., 1983. A narrow boundary current along the eastern side of the Hawaiian Ridge: The north Hawaiian Ridge current. *J. Phys. Oceanogr.* 13, 1726–1731.
- Yuen, H.S.H., 1979. A night handline fishery for tunas in Hawaii. *Mar. Fish. Rev.* 41, 7–14.