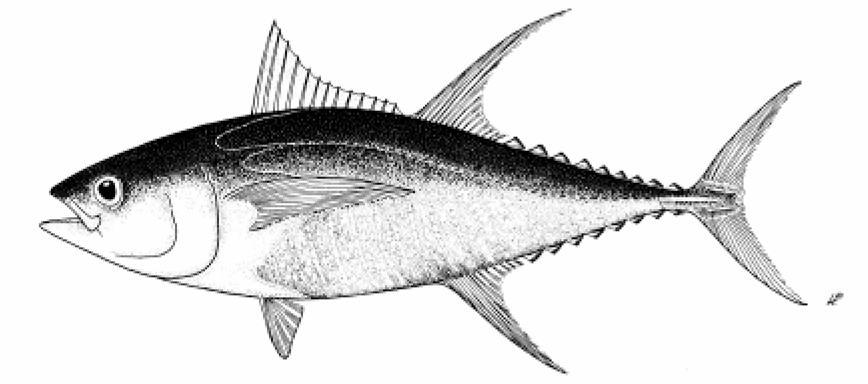
WCPFC–SC1 **BI WP–4**

Western and Central Pacific Fisheries Commission

1st Meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission
WCPFC–SC1
Noumea, New Caledonia
8–19 August 2005

The use of FADs to monitor the behavior and movements of tuna, billfish and pelagic sharks



D.G. Itano, L. Dagorn & K.N. Holland

Pelagic Fisheries Research Programme, Honolulu, Hawaii.

August 2005

The use of Fish Aggregation Devices to monitor the behaviour and movements of tuna, billfish and pelagic sharks

David G. Itano, Laurent Dagorn, Kim Holland and Dean Grubbs

1. Introduction

The tendency of pelagic fishes to aggregate around natural drift objects lead to the utilization of man-made rafts to enhance fisheries, or fish aggregation devices (FADs). Early anchored FAD systems appear to have been developed in the Philippines utilizing bamboo rafts suspending coconut fronds (De Jesus 1982; Barut 1999). Eventually, anchored FADs have been adopted as a fishery enhancement tool by almost every WCPO island country and territory (Preston 1990; Itano 1995).

The use of anchored FADs have been used to enhanced pole-and-line and purse seine production for decades, with sizable FAD networks supporting industrial fisheries in Fiji, Indonesia, the Philippines, the Solomon Islands, Papua New Guinea and to a lesser extent in other Pacific Island countries. Fukofuka et al. (2004) provides a review of the development, design and use of FADs by large scale WCPO fisheries. In recent years, thousands of anchored FADs have been set in the northern PNG zone in support of purse seine operations (Kumoru 2002; 2003). Purse seine fleets worldwide have widely adopted the use of drifting FADs monitored with sophisticated electronics for positioning and remote assessment (Morón, et al. 2001); Itano 2002).

The significance of FADs to worldwide fisheries has lead to major international symposia on the ecology and fisheries for tuna and associated pelagics found in association with floating objects[1],[2] (Scott et al., 1999; Le Gall et al., 2000). Currently, a European Union funded project Fish Aggregation Devices as Instrumented Observatories of pelagic ecosystems (FADIO[3]) is investigating the use of FADs by EU purse seiners in the Indian Ocean, and the Inter-American Tropical Tuna Commission is in the fourth year of a major archival tagging initiative to investigate the role FADs play in the vulnerability of bigeye tuna in the Eastern Pacific Ocean.

2. Importance of FAD studies

There is no question that FADs have become a cost-effective mechanism to enhance pelagic fisheries on a large scale. Currently, over fifty percent of the annual harvest of the primary tropical tuna species is harvested in association with FADs or floating objects. However, FADs also pose an ecological concern due to their tendency to aggregate juvenile tuna, pelagic sharks, billfish and a wide variety of finfish, e.g. wahoo and dolphinfish.

Despite their importance to world fisheries, the mechanisms of aggregation and species-specific behaviors around FADs are poorly understood. A review of several popular theories on tuna aggregation to FADs and drifting objects is given in Fréon and Dagorn (2000). However, active tracking studies and archival tags have been used successfully to demonstrate that FADs can significantly influence the horizontal and vertical behavior of yellowfin and bigeye tuna (Holland et al., 1990; Klimley and Holloway 1999; Dagorn et al., 2000) The observation that FADs can influence bigeye and skipjack tuna to frequent much shallower depths than normal is highly significant in terms of vulnerability of stocks (Schaefer and Fuller, 2002; Musyl, et al, 2003; Schaefer and Fuller 2005).

---

[1] International Workshop on the Ecology and Fisheries for Tunas Associated with Floating Objects, February 11 – 13, 1992. Inter-American Tropical Tuna Commission. La Jolla, California, USA.

[2] Tuna Fishing and Fish Aggregating Devices, Caraibe-Martinique; Trois-Ilets, 15.19 October 1999. IFREMER, IRD, ENSAR.

[3] http://www.fadio.ird.fr/

Ecological research has also suggested that FADs may represent a trophic disadvantage to pelagic resources, limiting their foraging ability and in the case of drifting FADs, advect them toward less productive waters (Marsac, et al., 2000; Ménard, et al., 2000). This “ecological trap” hypothesis is yet to be proved or refuted, and the trophic significance of FADs requires greater attention. Currently, work has been almost completed on the trophic dynamics of FAD associated yellowfin and bigeye tuna on Hawaiian FADs (Grubbs, et al.2002)

Given the extent of FAD utilization by large-scale WCPO fisheries, it is critical to gain a better understanding of the influence of FADs on the behavior of tropical tunas. This is particularly urgent for bigeye tuna stocks that have been significantly impacted by FAD and drifting object oriented fishing by regional purse seine fleets. Some form of management of drifting object sets is one of the input controls being suggested to reduce juvenile bigeye fishing mortality within the Commission area. However, many of these technical measures will depend on gaining a meaningful understanding of the horizontal and vertical behavior of tuna with both drifting and anchored FADs on a sub-regional basis. Data of this type and detail do not currently exist.

In Hawaii, research is currently underway aimed at gaining size and species-specific information on the influence of anchored FADs on tuna, billfish and pelagic sharks. This paper will briefly describe the concept and methodology involved.

3. Methods

3.1 Introduction to the study area

Conventional dart tags have been used successfully in Hawaii to monitor general residence times and local movement patterns of yellowfin and bigeye tuna (Adam, et al. 2003, Itano and Holland 2000). Data logging archival and popup archival tags (PAT) have also been successfully utilized to investigate the vertical and larger-scale horizontal movements of tuna, billfish and sharks. However, neither tag type can be used to gain precise data on FAD associated resources. Despite advances in archival and PAT tag geolocation estimates, the current technology will only provide location estimates in the order of 40 – 60 nautical miles. This is not sufficiently accurate to define FAD associated dynamics when the animals may be constantly moving away from and returning to the same or other nearby FADs with movements in the order of a few kilometers.

For our studies, we have adopted the use of ultrasonic transmitting tags reporting to fixed receivers. The primary study site should be considered the entire Hawaiian Islands chain, characterized as a remote, mid-oceanic mixture of high islands in the main Hawaiian Island group (MHI) and a series of banks and atolls in the Northwest Hawaiian Island group (NWHI) <**Figure 1**>. The main Hawaiian Islands are surrounded by a network of close to 52 anchored FADs, maintained and monitored by the University of Hawaii in collaboration with the State of Hawaii for the benefit of Hawaii-based fisheries (Holland et al. 2000) <**Figure 2**>.

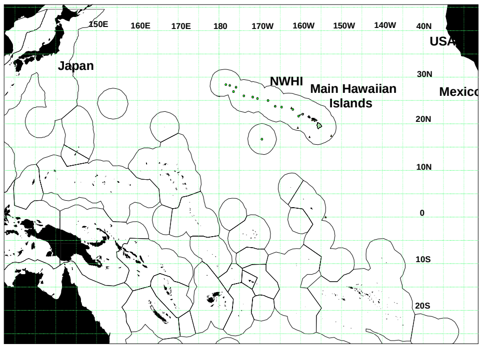


Figure 1. The northwest and main Hawaiian Islands (NWHI, MHI).

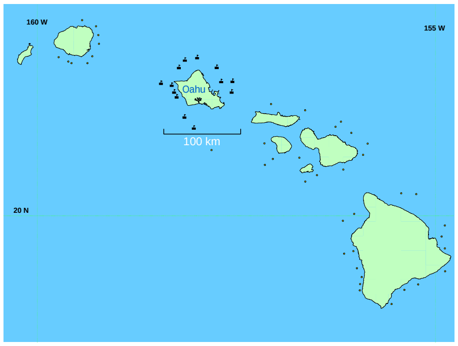


Figure 2. The Hawaii State anchored FAD system.

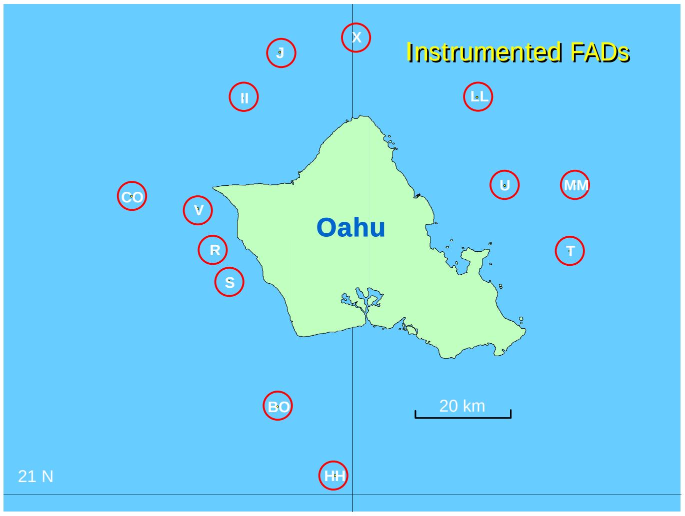


Figure 3. Oahu FADs equipped with sonic receivers.

3.2 Sonic receivers

Thirteen of these anchored FADs surrounding the island of Oahu have been equipped with sonic receivers since August 2002, with data retrieval and battery changes occurring at regular intervals (**Figure 3**). Receivers are mounted beneath the FAD mooring chain at a depth of 18.3 m and serviced by SCUBA equipped divers as reported in Itano, et al. (2004). The receivers will receive and store coded sonic data transmitted by sonic tags that we have surgically implanted in various finfish species. However, this technology has been used on a variety of species, from marine turtles, marine mammals and cephalopods. The receivers can detect coded tags, and hence tagged fish within about a one km circumference surrounding the FAD for the tag models currently used, turning our local FADs into passive listening stations for pelagic species.

3.2 Sonic tags

We are using VEMCO[4] *VR2 Automated Identification Fish Monitoring Receivers*[5] and sonic tags. The vendor offers a wide range of sonic tag types and sizes for a variety of applications. Coded sonic tags have been used throughout our studies that provide specific ID codes allowing the recording of precise size and species-specific data (e.g. fish specific). Fish are landed and surgically implanted with sonic tags within their peritoneal cavity as described in Itano et al. (2004). Fish marked with sonic tags are also externally marked with dart tags which facilitates the reconciliation of sonic data with absences from the receiver data. Also, recovered sonic tags have been re-used up to the time when their battery life expires.

Coded sonic tags of various sizes have been used depending on the size of fish targeted by the study. During 2005, we began to use small V8 and V9P size sonic tags to investigate the FAD associated behavior of small yellowfin and bigeye tuna in conjunction with larger fish of the same species. **Figure 4** shows the larger V16 tags typically used on tuna greater than 55 cm FL and **Figure 5** shows the smaller V8 tags used on tuna less than ~40 cm FL.

---

[4] The use of VEMCO gear does not imply specific recommendations or endorsements. Other manufacturers of electronic tagging equipment offer comparable systems.

[5] http://www.vemco.com/receivers.htm

Figure 4. VEMCO V16 sonic tag.

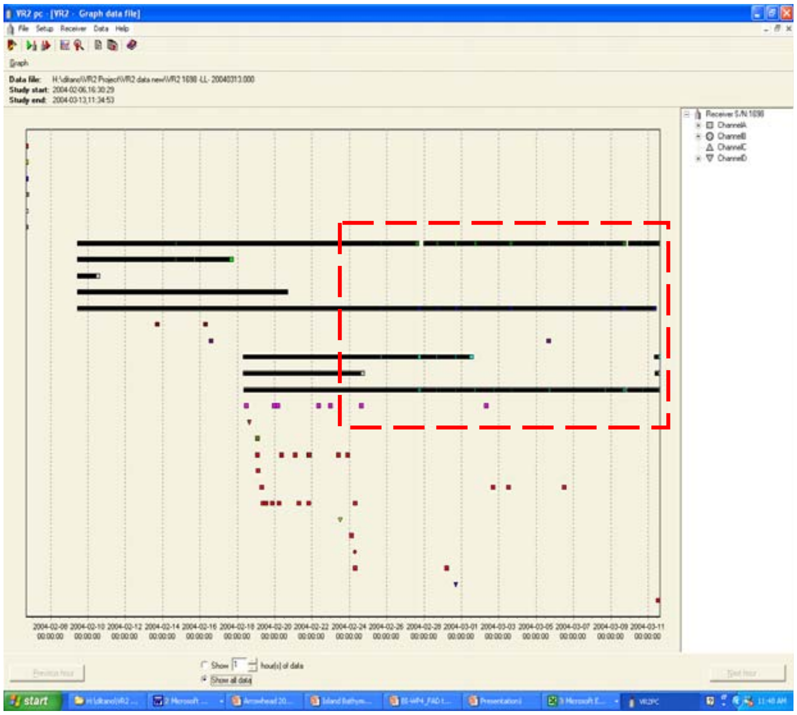
Figure 5. VEMCO V8 sonic tag.

VEMCO sonic tags can also be configured to provide depth and or temperature. The data can be transmitted to and received by the same sonic receivers, thus allowing a fishery independent means to collect fine scale vertical behavior of tuna and other pelagic species. For this aspect of our work, we implanted small V9P tags in small yellowfin tuna (#40 cm) and larger yellowfin (>60 cm) on the same FAD aggregations during the same fishing episode.

4. Example data and application of methodology

4.1 Coded sonic tag data

Coded sonic tags transmit a specific numeric code and provide simple "presence/absence" data specific to that tag. We have deployed this type of tag internally in skipjack, yellowfin, bigeye, striped marlin and pelagic white tip shark (*Carcharhinus longimanus*).

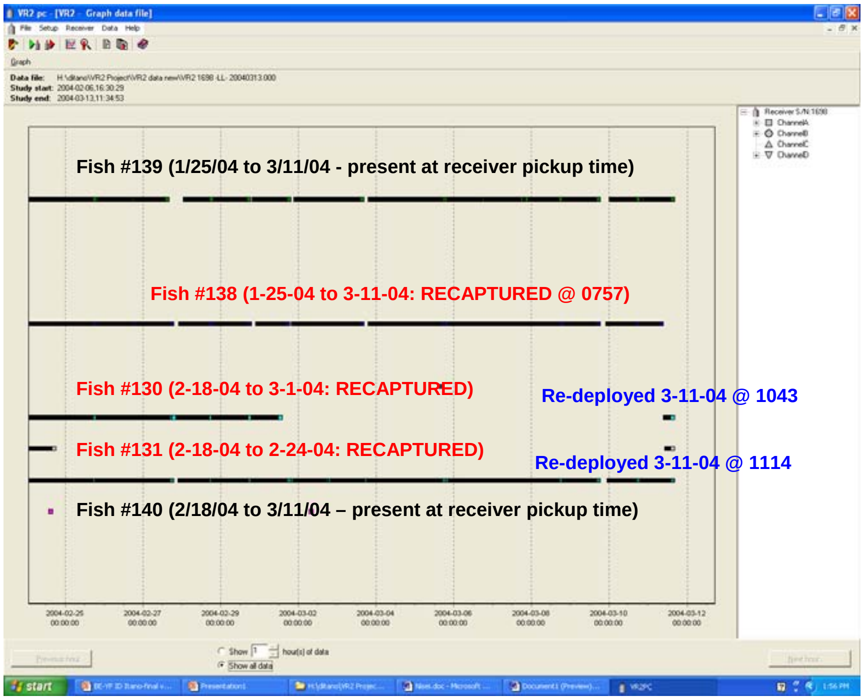


Data file: H:\ditano\VR2 Project\VR2 data new\VR2 1098 -LL- 20040313.000
Study start: 2004-02-06,16:30:29
Study end: 2004-03-13,11:34:53

○ Show 1 hour(s) of data
● Show all data

Figure 6. VEMCO VR2 output in graphical format showing individual tag receptions over time.

Figure 6 is a typical output file in graphical format showing the sonic tag data recorded by areceiver # 1698 from 9 February – 12 March 2004 when it was mounted directly to the FAD LL mooring chain (-18.3 m). The unit was initialized to receive data on 6 February and the data was downloaded on 13 March 2004. The horizontal bars represent the presence of particular tags that had been inplanted previously in yellowfin tuna that were within the detection range of the unit (approximately 1 km). The tags were set to transit data at random intervals at least every 10 – 35 seconds. The near continuous bars indicate that most of the tagged yellowfin remained in almost continuous association with the FAD until they either departed the FAD or were recaptured by other fishermen[6]



Data file: H:\dItano\VR2 Project\VR2 data new\VR2 1698 -LL- 20040313.000
Study start: 2004-02-06,16:30:29
Study end: 2004-03-13,11:34:53

○ Show 1 hour(s) of data
● Show all data

Figure 7. Sonic tag data from five yellowfin tuna on LL FAD.

The data represented in **Figure 6** within the dashed rectangle is represented in greater detail in **Figure 7**. The following is a summary of the fate of these tagged yellowfin releases.

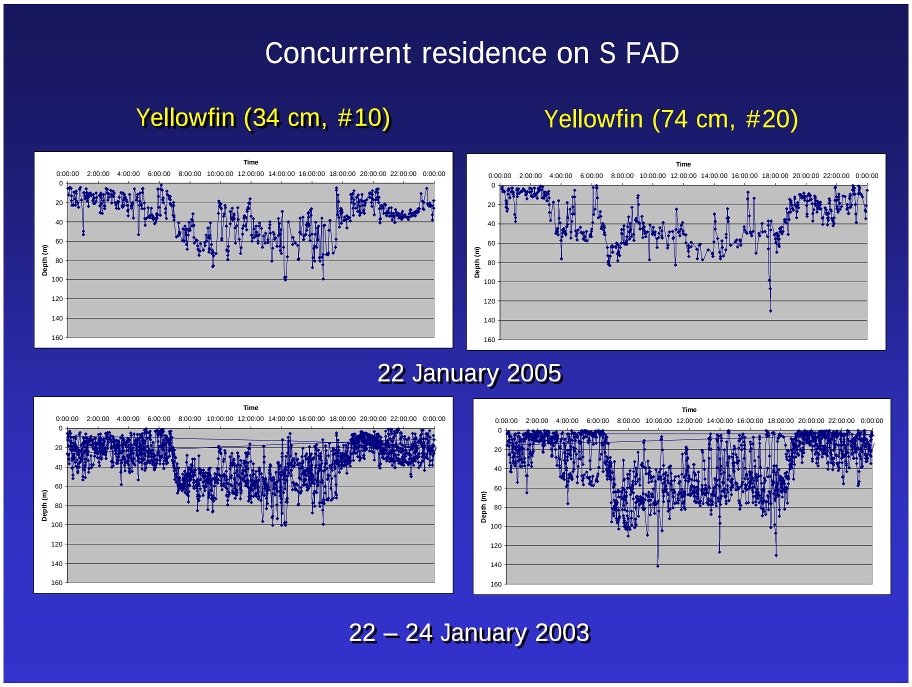
> Tag 139: A 69 cm yellowfin tuna tagged and released at LL FAD on 1/25/04. The fish remained in almost continuous association with the buoy during the entire time that receiver 1689 was on station.
>
> Tag 140: Another 69 cm yellowfin tuna tagged and relased on LL FAD 2/18/05. The fish remained in almost continuous association with the buoy during the entire time that receiver 1689 was on station.
>
> Tag 138: Yellowfin 65.7 cm was tagged and released on LL FAD on 1/25/04. This fish was recaptured by a pole and line vessel after 46 days at liberty on 3/11/04 at 0757. During this period, the fish grew to 71.1 cm. The recapture occurred the just hours before we changed out the receiver on 3/11/04.
>
> Tag 130: Yellowfin 68 cm was tagged and released on LL FAD on 2/18/04. This fish was recaptured by a local handline vessel after 12 days at liberty on 3/1/04 at 1253. This tag was re-used on a different fish on 3/11/04.
>
> Tag 131: Yellowfin 63 cm was tagged and released on LL FAD on 2/18/04. This fish was recaptured by a local handline vessel after 6 days at liberty on 2/24/04 at 1706. This tag was re-used on a different fish on 3/11/04.

---

[6] The third possibility of absence data could be tag or receiver failure.

4.2 Depth sensor sonic tag data

During 2005, we surgically implanted yellowfin tuna with V9P, pressure sensing (= depth recording) VEMCO sonic tags. The strength of this portion of our study was that two distinct size classes of the same species of tuna were marked with identical tags on the same FADs. Typically, both size classes of tuna were released during the same tagging episode, thus releasing both tag cohorts to freely mix or segregate on the same FAD at the same time. These tags remotely collect time stamped data on the vertical behavior of fish that is essentially identical to that obtained from more expensive archival tags, and it is not necessary to recapture the tag.



Concurrent residence on S FAD

Yellowfin (34 cm, #10)

Yellowfin (74 cm, #20)

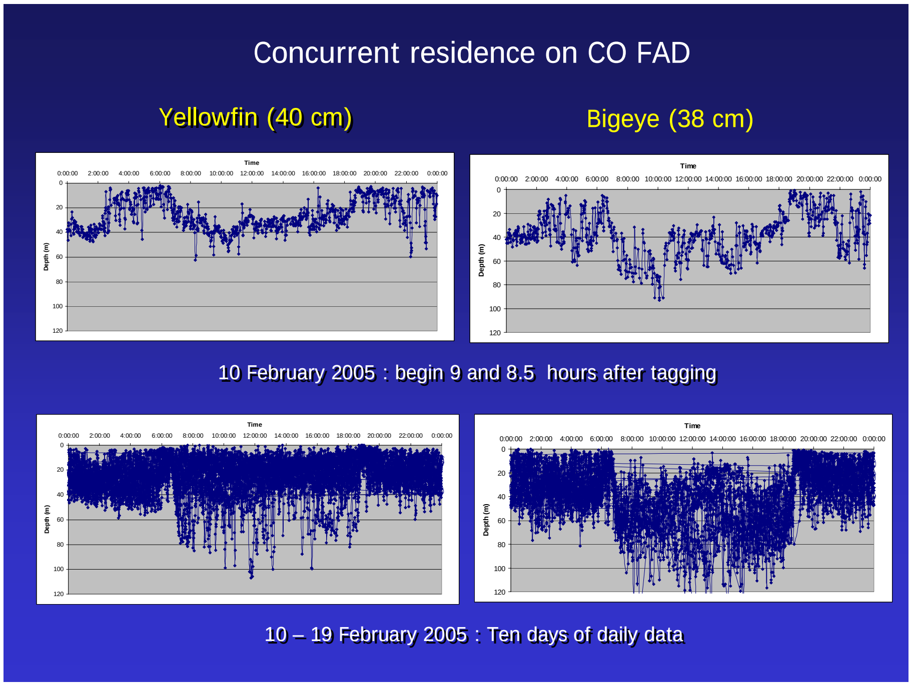
22 January 2005

22 – 24 January 2003

Figure 8. Simultaneous vertical behavior of a small (34 cm) and medium sized (74 cm) in association with the same anchored FAD.

This study initially examined the depth distribution of different size tuna on FADs throughout the 24 hour day/night cycle. An example of the sort of data that results is given in **Figure 8** for yellowfin tuna 34 and 74 cm in fork length, showing their simultaneous behavior on the same anchored FAD. It is noteworthy that their vertical behavior does not appear to be that different. However, the three day plots show that the 34 cm yellowfin dove to depths of around 60 meters during the daytime while the larger yellowfin went to 80+ m with deeper spike dives. However, these figures should not be viewed as in any way representative but are shown for demonstration purposes only.

Another aspect of this study will examine recorded vertical behavior of tunas with trophic selectivity, integrated with the larger scale trophic studies already conducted or completed by our group (described in Grubbs, et al. 2002). To this end, yellowfin tuna captured during tag release trips from both size classes were sacrificed and their stomachs preserved for detailed gut analysis.



Concurrent residence on CO FAD

Yellowfin (40 cm)

Bigeye (38 cm)

10 February 2005 : begin 9 and 8.5 hours after tagging

10 – 19 February 2005 : Ten days of daily data

Figure 9. Comparison of similar sized, small yellowfin and bigeye tuna in simultaneous aggregation to the same anchored FAD.

One bigeye tuna (38 cm) was opportunistically tagged with a V9P depth sensing unit (**Figure 9**). The simultaneous vertical behavior of this relatively small fish was surprisingly different from a yellowfin tuna of similar size (40 cm). It has been thought that small yellowfin and bigeye tuna (<~50 cm) were similar after which their habits began to differentiate. Although this is only one example, it offers intriguing support that the vertical behaviors of bigeye and yellowfin tuna may begin to diverge at very small sizes.

4.3 Sonic tagging of billfish

Tuna are just one component of the FAD based community. Hawaii based trollers and charterboats regularly target billfish on or near anchored FADs. In order to start approaching broader ecosystem questions, we sonic tagged some shortbill spearfish (*Tetrapterus angustirostris*) and striped marlin (*T. audax*) using external tethers darted into the dorsal musculature (**Figure 10**)..

Figure 10. Shortbill spearfish and striped marlin marked with external sonic tags.

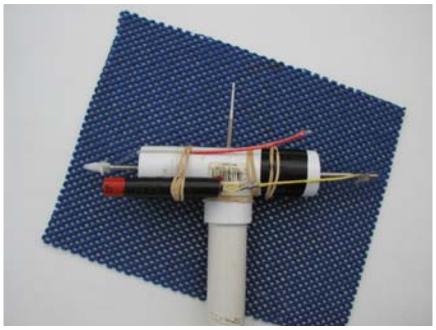


Figure 11. PVC tagging head for external tagging of billfish.

Tags were driven into the upper musculature to a depth of 5 cm using a hammering action with a purpose built double headed applicator constructed of 1.5 inch diameter PVC pipe (**Figure 11**).

V16 Vemco sonic tags were used with the tethers attached to loops reinforced with stainless steel loops held in place with epoxy adhesive (**Figure 12**). Tethers were either vinyl billfish style tags or stainless steel wire. A combination of anchor types were tried, including stainless steel "toggle" type anchors and nylon double barb inter-muscular anchors. Sonic tags were anchored into the muscle below the anterior section of the dorsal fin and a second identifying dart tag was applied nearby.

Results were unsatisfactory. Very few sonic detections were recovered using this method and was suspected that the heavy tags were either pulling free from the animals or dropping off their tethers. Tag retention has always plagued external mounting of electronic tags and continues to be a significant problem for externally mounted PAT tags.

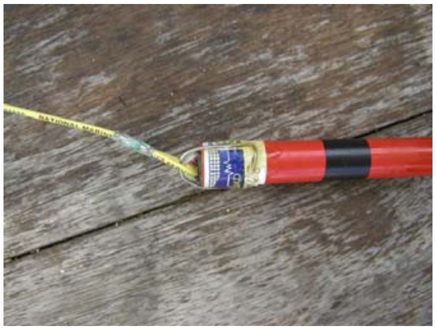


Figure 12. Detail of tag teher.

Figure 13. Out of water internal tagging of marlin.

In order to avoid potential problems with external tag placement and shedding, we have developed tagging methodology for 'out of water' internal implantation of electronic tags in billfish. The system consists of a gunwale mounted tagging cradle where the stern end can be lowered into the water. Billfish and large tuna can be leadered into the cradle which is then raised to level. The entire cradle is padded and hinged, allowing the fish to be gently squeezed to reduce struggling. The fish were irrigated with a saltwater hose in the mouth while a damp cloth material was placed over the eyes to reduce struggling. Following a small scalpel incision, sonic tags[7] were pushed into the peritoneal cavity with a gloved finger and the wound closed with two sutures (**Figure 13**).

Striped marlin were double tagged with an external popup satellite archival tag, thus double tagging the fish with sonic and PAT style tags[8]. Survival, as determined by the sonic and PAT tag data has been very good but these procedures should be considered preliminary and still under development.

4.4 Sonic tagging of pelagic sharks

Pelagic white tip sharks also visit Hawaii FADs and are thought to remain near a particular FAD for extended periods. Due to the uncertain stock status of this generally solitary top predator and the lack of any real data on their relationship with FADs, we have initiated trials to implant sonic tags in the peritoneal cavity of large pelagic sharks. The methodology is similar as has been used in Hawaii for several years to implant large sonic tags inside tiger sharks around the island of Oahu (Holland, pers. comm.).

Basically, the sharks are hooked near the buoy on handlines or heavy rod and reel gear, leadered to the boat where a restraining rope is secured to the tail. We have only attempted this on one pelagic white tip to date, but the large specimen pictured in **Figure 14** (75 cm FL) went immobile when rolled on its back in a similar manner that has been well documented for tiger sharks. A small incision was made in the belly wall, the tag pushed in with a gloved finger and the wound closed with two sutures. Before release, the shark was accurately measured and double tagged with an external, nylon head billfish style tag. The sonic receivers in the area of release have not been retrieved at the time of this report so indications of survival or FAD residence time can not be reported. However, the procedure was relatively simple and straightforward and further tagging will continue in 2005.

Figure 14. Large pelagic white tip shark (Carch*arhinus longimanus*) implanted with sonic tag.

---

[7] V16 sonic tags provided the the Western Pacific Regional Fishery Management Council
[8] PAT tags provided by Pfleger Institute of Environmental Science

5. Summary

Conventional dart tags provide basic evidence of release and recapture locations, while data logging archival and popup satellite archival tags (PATs) can provide rough estimates of general location useful for identifying medium and large-scale movements. In contrast, sonic tags can provide fine-scale residence and life history data making them particularly suited to the study of FAD aggregation dynamics.

Archival tags can be costly and require the recapture and return of tags to the researcher in a functional condition for data retrieval. Considering recapture rates only be in the neighborhood of 10 – 20 %, the overall costs involved in archival tagging grow considerably. More costly PAT tags theoretically report all their data which is conveniently transmitted to the researcher via satellite networks. However, bandwidth in these systems is very limited and expensive requiring data to be pooled or truncated for transmission. Even thought he unit may have been capable of recording highly detailed life history information, the researcher will only receive a portion of this data. The more significant problem with archival and PAT tags has been their reliability under extreme or unanticipated conditions affecting thei ability to store and transfer data after lengthy deployments.

Sonic tags and receivers are relatively inexpensive allowing greater numbers of tag releases per study, which is the researcher's greatest safeguard against random hardware and software malfunctions. The most desirable feature of sonic tags is that data retrieval is independent of the need for recaptures, thus providing essentially "wild" and natural behavior of pelagic fishes over lengthy time periods.

The use of temperature and depth sensing and transmitting tags now provides the ability to receive data comparable to more expensive archival tags from the entire tag release cohort – not just those fish that become vulnerable to recapture. Further developments in sonic tag types that will be designed to provide a greater variety of parameters, e.g. feeding and spawning behaviour, swimming speed, schooling dynamics, etc. will no doubt take place and add to the utility of both sonic and archival tags.

Finally, ongoing efforts toward greater miniaturization and extended battery life will allow complex data collection from a variety of species utilizing the same tags for both large and small animals, thereby standardizing results between species and sizes.

It is anticipated that a careful selection of tag types and technologies will go a long way toward addressing many important questions regarding the dynamics of floating object, mixed-species aggregations. This knowledge will be essential to allow informed management of pelagic fisheries at the ecosystem level.

References

Adam, M.S., J. Sibert, D. Itano, and K. Holland. 2003. Dynamics of bigeye (*Thunnus obesus*) and yellowfin (*T. albacares*) tuna in Hawaii's pelagic fisheries: analysis of tagging data with a bulk transfer model incorporating size-specific attrition. Fish. Bull. 101:215-228.

Barut, N. 1999. The payao fisheries in the Philippines and some observation on the behavior of tunas around payao. International Workshop on the Ecology and Fisheries for Tunas Associated with Floating Objects, February 11 – 13, 1992. Inter-American Tropical Tuna Commission. La Jolla, California, USA.. Background document M. 9 pp.

Dagorn, L., E. Josse, and P. Bach. 2000. Individual differences in horizontal movements of yellowfin tuna (*Thunnus albacares*) in nearshore areas in French Polynesia, determined using ultrasonic telemetry. Aquat. Living Resour. 13: 193-202.

De Jesus, A.S. 1982. Tuna fishing gears of the Philippines. IPTP/82/WP/2. 47 pp.

Fukofuka, S., D. Brogan & D. Itano. 2004. **The development, design and current status of anchored and drifting FADs in the WCPO. 17th Standing Committee on Tuna and Billfish. Majuro, Republic of the Marshall Islands – 11-18 August 2004. INF-FTWG-3**

Fréon, P., L. Dagorn. 2000. Associative behavior of pelagic fish: facts and hypotheses. Le Gall J-Y, P Cayré, M. Taquet (*Eds*.). Pêche thonière et dispositifs de concentration de poisons (*Tuna fishing and Fish Aggregating Devices (FADs*). Actes Colloq. Ifremer, 28: 483-491.

Grubbs, R.D., K. Holland, and D. Itano. 2002. Comparative trophic ecology of yellowfin and bigeye tuna associated with natural and man-made aggregation sites in Hawaiian waters. 15th Meeting of the Standing Committee on Tuna and Billfish. Mooloolaba, Queensland, Australia. 22-27 July 2002. Working Paper YFT-6.

Holland, K., R. Brill, R Chang. 1990. Horizontal and vertical movements of yellowfin and bigeye tuna associated with fish aggregating devices. Fish. Bull. 88: 493-507

Holland, K.N., A. Jaffe, and W. Cortez. 2000. The Fish Aggregating Device (FAD) system of Hawaii. *In* Peche thoniere et dispositifs de concentration de poissons, colloque Caraibe-Martinique; Trois-Ilets, 15.19 Octobre 1999 (J.-Y. Le Gall, P. Cayre, and M. Taquet, *eds*.), p. 537.552. Actes Colloq. Ifremer, 28: 55-62.

Holland, K., D. Grubbs, B. Graham, D. Itano and L. Dagorn 2003. **The biology of FAD-associated tuna: Temporal dynamics of associated and feeding ecology.** 16th Meeting of the Standing Committee on Tuna and Billfish. Mooloolaba, Queensland, Australia. 9th–16th July 2003. Working Paper YFT-7.

Itano, D. 1995. Small boat pelagic fisheries: A review of FAD utilization in the Pacific Islands region. *In* Achieving Goals for Sustainable Living in the Aquatic Continent: Toward a Pacific Island-based tuna industry. D.G. Malcom, Jr., J. Skog, and D. Zachary [*eds*]. Maui Pacific Center. p. 155-182.

Itano, D.G. Super Superseiner. 2002. 15th Meeting of the Standing Committee on Tuna and Billfish. Mooloolaba, Queensland, Australia. 22-27 July 2002. Working Paper FTWG – 10.

Itano, D.G. and K.N. Holland. 2000. Movement and vulnerability of bigeye (Thunnus obesus) and yellowfin tuna (Thunnus albacares) in relation to FADs and natural aggregation points. Aquat. Living Resour. 13(2000) 213-223.

Itano, D.G., K. Holland, L. Dagorn, D. Grubbs, Y. Papastamatiou. 2004. Monitoring movement patterns, residence times and feeding ecology of tuna, billfish and oceanic sharks within a network of anchored FADs. **17th Standing Committee on Tuna and Billfish. Majuro, Republic of the Marshall Islands – 11-18 August 2004. Working Paper BIO-2.**

Klimley, A.P., and C.F. Holloway, 1999. School fidelity and homing synchronicity of yellowfin tuna, *Thunnus albacares*. *Marine Biology*, 133: 307-317.

Kumoru, L. **Status of fish aggregating devices in Papua New Guinea**. 2002. 15th Meeting of the Standing Committee on Tuna and Billfish. Mooloolaba, Queensland, Australia. 22-27 July 2002. Working Paper FTWG – 12.

Kumoru, L. **Notes on the use of FADs in the PNG purse seine fishery**. 2003. 16th Meeting of the Standing Committee on Tuna and Billfish. Mooloolaba, Queensland, Australia. 9th–16th July 2003. Working Paper FTWG – 4.

Le Gall, J-Y., P. Cayré, M.. Taquet (*eds*.). 2000. Pêche thonière et dispositifs de concentration de poisons (*Tuna fishing and Fish Aggregating Devices (FADs*). Caraibe-Martinique; Trois-Ilets, 15.19 Octobre 1999. Actes Colloq. Ifremer, 28.684 pp.

Marsac, F., A. Fonteneau, and F. Ménard. 2000. Drifting FADs used in tuna fisheries: an ecological trap? *In* Peche thoniere et dispositifs de concentration de poissons, colloque Caraibe-Martinique; Trois-Ilets, 15.19 Octobre 1999 (J.-Y. Le Gall, P. Cayre, and M. Taquet, *eds*.), p. 537.552. Actes Colloq. Ifremer, 28: 537-552.

Ménard, F., B.. Stéquert, A.. Rubin, M.. Herrera, and E. Marchal. 2000. Food consumption of tuna in the equatorial Atlantic Ocean: FAD-associated versus unassociated schools. Aquat. Living Res. 13(4):233.240.

Morón,, J., J. Areso, and P. Pallarés. 2001. **Statistics and Technical Information about the Spanish Purse-Seine Fleet in the Pacific**. **14th** Meeting of the Standing Committee on Tuna and Billfish, 9-16 August 2001, Nouméa, New Caledonia. Working Paper FTWG-11.

Musyl, M.K., R.W. Brill, C.H. Boggs, D.S. Curran, T.K. Kazama, and M.P. Seki. 2003. Vertical movements of bigeye tuna (*Thunnus obesus*) associated with islands, buoys, and seamounts near the main Hawaiian Islands from archival tagging data. *Fisheries Oceanography*, 12 (3): 152-169.

Preston, G.L. 1990. Fish aggregation devices in the Pacific Islands Region. Information Paper 4, Twenty-second Regional Technical Meeting on Fisheries (6 - 10 August 1990). South Pacific Commission, Noumea, New Caledonia. (paper originally prepared for the IPFC Symposium on fish aggregation devices and artificial reefs, Colombo, Sri Lanka, May 1990).

Schaefer, K.M., and D.W. Fuller. 2002. Movements, behavior, and habitat selection of bigeye tuna (*Thunnus obesus*) in the eastern equatorial Pacific, ascertained through archival tags. Fish. Bull. 100:765-788.

Schaefer, K.M., and D.W. Fuller. 2005. Behavior of bigeye (*Thunnus obesus*) and skipjack (*Katsuwonus pelamis*) tunas within aggregations associated with floating objects in the equatorial eastern Pacific. Mar, Biol., 146 (4): 781-792.

Scott, M.D., W.H. Bayliff, C.E. Lennert-Cody, K.M. Schaefer. 1999. Proceedings of the International Workshop on the Ecology and Fisheries for Tunas Associated with Floating Objects. Inter-Amer. Trop. Tuna Comm., Spec. Rep. 11. 480 pp.