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BEHAVIOUR OF YELLOWFIN (*Thunnus albacares*) AND BIGEYE (*T. Obesus)*IN A NETWORK OF ANCHORED FISH AGGREGATION

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Behaviour of yellowfin (*Thunnus albacares*) and bigeye tuna (*T. obesus*) in a network of anchored Fish Aggregation Devices

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1. Introduction

The Pelagic Fisheries Research Program (PFRP) of the University of Hawaii[1] has supported a number of investigations relating to the significance of aggregation and spatial heterogeneity of pelagic resources to fisheries exploitation. Studies in Hawaii have included work related to anchored FADs due to the worldwide significance of catches made in association with floating objects[2] with related negative impacts to juvenile tunas and increasing bycatch levels in purse seine fisheries. Although longline gear is considered the main factor contributing to bigeye depletion rates in the WCPO, purse seine floating object sets and the surface fisheries of Indonesia and the Philippines (many of which are FAD related) are believed to have had significant impacts on juvenile bigeye tuna, particularly in the tropical regions (Hampton, et al. 2005a). In contrast, fishery impacts on the WCPO yellowfin stock are driven by surface fisheries with overfishing now predicted to be occurring (Hampton, et al. 2005b).

Consequently, exploring mechanisms to avoid the take of undersize target tuna species, juvenile bigeye in particular, and non-target and dependent species (NTADs i.e. pelagic sharks, billfish, wahoo, dolphinfish, etc.) found in association with floating objects has become a priority research task of the Commission. The design and testing of potentially viable measures to mitigate undesirable consequences of FAD-directed fisheries will require a thorough understanding of the biology and behavior of the species in combination with familiarity with the technical aspects of the fisheries in question.

During the First Regular Session of the Scientific Committee (SC1)[3], the meeting charged the Biology Specialist Working Group (SWG) and the Fishing Technology SWG to investigate:

> *Fish (particularly yellowfin tuna and bigeye tuna) behaviour induced by the presence of FADs and other floating objects (using tagging)[4];*
>
> *identify the impact of FADs on fishing mortality of juvenile target species and all life phases of non-target species[5]; and*
>
> *identify and institute the collection of technical data on fishing gear and methods of special interest – particularly in relation to FADs[5].*

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[1] http://www.soest.hawaii.edu/PFRP/pfrp1.html

[2] For the purposes of this paper, a "floating object" is equivalent to the broad definition of a "FAD" as *any man-made device, or natural floating object, whether moored or not, that is capable of aggregating fish.*

[3] First Regular Session of the Scientific Committee, Noumea, New Caledonia, 8-19 August, 2005

[4] Report of the First Regular Session of the Scientific Committee, page 43, para 7.9

[5] Report of the First Regular Session of the Scientific Committee, page 45, para 7.20

Information of this kind will be needed to allow meaningful evaluation of various management options directed at floating object fisheries. Unfortunately, there is little in the way of documented knowledge and directed research in either area (tuna behavior on FADs or technical issues related to FADs). Initial examination on the behavior of tuna on anchored FADs revealed basic information on depths and diurnal movement patterns of yellowfin to a small number of anchored FADs (Cayre´ 1991; Holland and Brill 1990). Recently, significant advances have been made toward the understanding of tuna behavior on anchored FADs utilizing acoustic or data archiving tags (Klimley and Holloway 1999; Ohta and Kakuma 2005; Schaefer and Fuller 2005). However, these studies examined a small number of FADs or a small subset of FADs within in a larger group. This working paper discusses recent studies on the behavior of yellowfin and bigeye tuna in association with a continuous network of anchored FADs surrounding one island in the Hawaiian archipelago (Figure 1, North Pacific)[6].

2. Experimental design

The experimental design and preliminary findings of the research in question were documented and described during SC1 (Itano et al. 2005). To summarize:

Study region:	Hawaiian Islands, central north Pacific
Study area:	Island of Oahu, central Hawaiian Islands
Specific study sites:	13 anchored FADs surrounding the island of Oahu
FAD type:	147 cm diameter steel sphere moored to bottom (Holland et al. 2000)
FAD site description:	Oceanic waters, ~ 8 – 27 km offshore, most ~ 20 km offshore in depths of 565 – 2470 m (mean depth 1412 m)
Acoustic receivers:	Each FAD equipped with one VEMCO[7] VR2 sonic receiver, mounted 18.3 m below the surface directly to the mooring line.
Acoustic tags:	Internal (peritoneal) implants of coded VEMCO acoustic tags, and coded depths (pressure) transmitting tags
Conventional tags:	Tuna implanted with acoustic tags were also marked with an 11 cm plastic dart tag below the second dorsal fin to promote the reporting of recaptures.
Species tagged:	yellowfin, bigeye, skipjack tuna, striped marlin, oceanicwwhite tip and silky shark

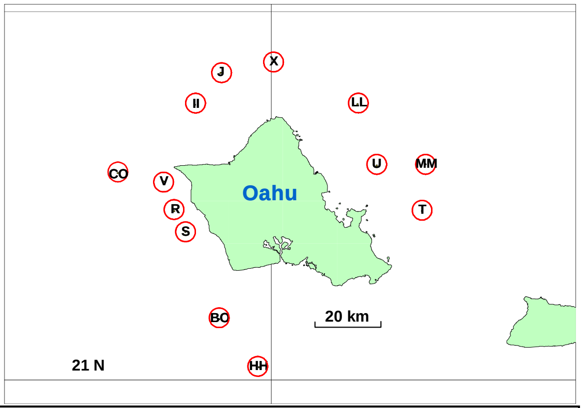

Figure 1. Position of anchored FADs equipped with underwater sonic receivers around the island of Oahu, Hawaiian Islands.

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[6] The precise results of the study are in final publication review; only generalized observations will be discussed here.

[7] http://vemco.com/

3. Observed behaviors

3.1 Dataset examined

A release dataset of 45 yellowfin and 12 bigeye tuna were examined through a 20 month tag release period with receivers monitored for a significant period following the last release after which the tag batteries would have expired. A separate dataset of small (<40 cm) and medium sized (>60 – 83 cm) yellowfin tuna equipped with depth sensing sonic tags will also be discussed. The depth sensing sonic tags transmit the tag (fish) depth at frequent intervals to the sonic receiver, thus providing archival tag quality data without having to recapture the animal and manually download the data as necessary for an archiving tag.

All of the tagged tuna were caught in association with a receiver-equipped FAD and released within 100 meters of the same FAD. All of the fish were detected by the FAD receiver network, generally within ~30 minutes of release. It should be noted that the range of detection of the receivers is approximately 700 meters, which we feel is a reasonable, if not conservative proxy for a FAD association. In other words, if the tagged fish was within this distance of a FAD, it’s individually coded sonic tag would record its presence at intervals close to every minute. In this study we are assuming that when a sonic tagged fish is no longer detected at a FAD, it has left the FAD completely. There is no way to determine where it has gone unless it is subsequently recaptured or it is detected at another FAD equipped with a sonic receiver.

Sonic tag recaptures of bigeye and yellowfin tuna have been examined after times at liberty of 3 to 90 days that exhibited rapid and complete healing of the incision area where the tag was inserted into the peritoneal cavity. Fishermen also reported that sonic tag recaptured tuna (of short times at liberty) took baited lines and behaved normally. These observations suggest that these tuna resumed normal behavior soon after tagging with rapid healing. It should be noted that non-detection of a sonic tag can also be caused by a tag malfunction, receiver malfunction, an unreported recapture or natural mortality. However, we assume a high recapture reporting rate due to close association with the fishing community, low post-tagging mortality and examine this data over a short time period which support the validity of the data.

3.2 Horizontal movements

The majority of sonic tagged yellowfin tuna were only detected at their FAD of capture and release. However, this statistic is partially obscured by the fact that recapture rates were very high with 15 yellowfin being recaptured on their FAD or release. If these fish are not considered in the movement analysis, about one fourth of the sonic tagged yellowfin visited other FADs in the network. All but one of the bigeye were detected only at their FAD of release, but few bigeye were tagged.

Yellowfin tuna were also seen to make excursions away from a FAD at greater than day-length absences and then return to the same FAD. However, the general rule for both species was near-continuous aggregation to a FAD until the fish apparently left the FAD completely, never to return.

Eight yellowfin visited several FADs in the array and in most cases visiting the nearest FAD. When multiple FADs were visited, two different patterns emerged: 1) a tendency to visit FADs different FADs in a continuous direction around the island without missing any, or 2) yellowfin moving between a small cluster of two or three FADs over an extended period of time.

Rapid movements between FADs less than ~20 km apart were noted. The rate of movement between these FAD locations suggested that the tuna were traveling directly or in a near direct path between

FADs as has been observed in active sonic tracking studies (Holland et al. 1990; Marsac and Cayré 1998; Brill et al. 1999; Dagorn et al. 2000). Day-scale up to periods of some weeks between FAD visits were also recorded.

3.3 Schooling synchronicity

Tuna from the same tag release cohort were seldom observed to leave a FAD alone, with most (presumed) departure events involving near-synchronous departures of multiple tagged individuals. Most of the time, not all of the tagged population on a FAD departed on the same day. However, it was common that once a group of tuna began to leave a FAD, the rest followed within a week.

On temporal scales of less than one day, interesting simultaneous departure and arrival data was noted for groups of tagged tuna, particularly at sunset. This data is still being examined and will not be discussed in detail here.

3.4 Time residency

Generally speaking, when fish were tagged and released at a FAD, they remained at that FAD almost continuously until they were recaptured, or left the FAD completely. Mean continuous residence times for both species were about one week in duration although continuous residence times of yellowfin greater than two months were also noted.

A clear pattern emerged with tuna remaining longer at their original FAD of release than compared to subsequently visited FADs. The average total time residency of yellowfin within the entire FAD network was about one month but only one week for bigeye. However, the bigeye dataset is considered limited in number and scope compared to the yellowfin.

3.5 Size-dependent vertical behavior

The next phase of our study utilized pressure sensitive sonic tags capable of transmitting fine-scale time/depth data to the FAD-mounted receivers[8]. This technology produces a long-term diurnal record of diving behavior of the tagged fish that is comparable to data obtained from archival tags. The advantage of this approach to FAD studies is that it provides fine-scale vertical behavior of a known subject at a known location, e.g. an anchored FAD, drifting FAD, seamount, etc.

This aspect of the work was designed to examine the vertical behavior of different sizes of yellowfin tuna commonly found in FAD associations. Identical depth sensing sonic tags were implanted into two size classes of yellowfin tuna (<40 cm vs >60 cm) found in concurrent residence on the SAME FAD. In other words, sonic tagging was not initiated until both size classes were confirmed to be present on a FAD and vulnerable to our fishing gear.

Analyses of these data are ongoing, but a separation of vertical behavior between size classes is apparent, particularly during the day period. Only one small bigeye tuna (38 cm) has been tagged with a depth sensing sonic tag to date. Even at this small size, the bigeye exhibited deeper diving behavior when compared to similarly sized yellowfin tuna. Additional research is clearly required.

Stomach contents of tuna from both size classes were also collected from the same FAD aggregations where depth tags were released in order to examine the possibility of differential feeding strategies.

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[8] Pressure data is converted to depth reported to 0.1 m to a depth of 200 m)

4. Summmary and Discussion

Results of these studies support the use of sonic tagging and passive receivers as an efficient way to gain important behavioral data on aggregated pelagic species. It should be noted that our estimates of time residence at the initial FAD of release likely underestimate their total residence time. Presumably, the fish we caught and tagged had already been in association with the FAD for some unknown time prior to capture. However, we do not believe total time residence estimates are a great deal longer than our estimates as FADs were checked regularly during the study period and surveyed with depth sounder and through fishermen interviews. The network of knowledge within a discrete group of commercial or semi-commercial fishermen that specialize in fishing FADs was found to be highly reliable.

In general, we found that when tuna were "on" a FAD, they remained in nearly continuous aggregation until they were either recaptured or left that FAD entirely. Fishing mortality was surprisingly high if our tagged fish remained on a FAD or within the network of FADs for an extended period of time. The recapture rate of sonic tagged yellowfin was 40%, suggesting a highly efficient hook and line fishery exploits Hawaiian anchored FADs.

When tagged tuna left a FAD, they usually left the FAD array, and possibly the entire island completely, never to return. On only a few occasions, extended absences and returns were recorded (>2 weeks). When they did visit other FADs, they did so in a continuous movement pattern in one direction around the island as if "checking" each FAD in turn. Rarely did they resume a long-term continuous residence at any of these subsequently visited FADs. However, the fish that did remain in the network for long periods of time and visited many FADs seemed to have a true affinity for FAD aggregations compared to other behavior, but exposed themselves to a high risk of recapture.

Both synchronous behavior suggestive of cohesive schools and non-synchronous movement behavior were noted among tag release cohorts. This suggests that the aggregation of tuna at a FAD may consist of multiple schools of the same and different species that mix at the FAD with different motivations and time scales dictating their residence times.

5. Futther work

The longer residence times of tuna at their original FAD of capture and release suggest that some element of the local environment may contribute towards making the FAD more "attractive" than others. Directed research relating fine-scale environmental factors, localized prey environment and trophic relationships need to be designed and developed.

When the tuna left a FAD after a period of continuous residence, they usually did not re-associate to the FADs surrounding the island of Oahu, or did so briefly before disappearing. This may imply that the island-scale conditions were no longer attractive and the fish may have left the island entirely. Indeed, tag recaptures were subsequently reported from other islands in the Hawaiian chain. It should be noted that the geographic scale of this study encompasses all FADs surrounding a single island and thus represents an expansion from previous studies. However, these 13 FADs and one island are part of a network of 55+ anchored FADs spread throughout the six inhabited islands, and Oahu represents only one island among dozens of high islands, atolls, banks and seamounts that make up the Hawaiian Ridge system.

In order to gain a better understanding of where fish go after they leave our FADs, the addition of archival and popup satellite linked archival tags should be considered.. Also, our results must be viewed in relationship to the environment and FAD characteristics that exist in Hawaii. Similar studies should be conducted at larger scales on all species of interest (particularly bigeye) and include NTAD species if ecosystem concerns are to be addressed.

Fortunately, the PFRP has recently funded a sonic tagging study on skipjack, yellowfin and bigeye tuna of the WCPO. This work will form a component of a recently initiated tagging project of the Secretariat of the Pacific Community (SPC) and the National Fisheries Agency (NFA) of Papua New Guinea. The SPC/NFA project will use all tag types in conjunction with biological sampling and trophic studies to assess the tuna resources of the Bismarck and Solomon Seas. Assessing the impact of the large-scale fisheries that exploit anchored FADs in this region and the influence of seamounts to aggregation and vulnerability are primary objectives of this project and will be described in detail during SC2.

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