The Fish Aggregating Device (FAD) system of Hawaii

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Abstract

Hawaii was one of the first locations to adapt the Philippine payao concept for use in high energy, deep-water environments. Initial experimental FAD deployments were made by the National Marine Fisheries Service in 1977. In 1980, the State of Hawaii started deploying FADs in a programme that has since expanded to its current status of 52 approved surface FAD sites. Funding is primarily derived from federal US programmes and the FADs are primarily focused on the sport fishing community. FAD sites were selected to expedite access by sport fishermen; specific sites were chosen after consultation with fishermen at public hearings. Since 1997, the FAD system has been managed on a collaborative basis between the State of Hawaii and the University of Hawaii. Hawaiian FADs evolved through two previous designs before the current system of single-sphere spar-buoy was adopted. Today's FADs have an "inverse catenary" mooring system comprised of sections of floating and sinking rope attached to a "tripod" concrete block anchor system. FAD sites range between 3.2 km and 46 km from shore. Mooring depths range between 200 and 3,000 metres. Average on-site longevity is 31 months; there is no correlation between longevity and depth of mooring. Windward locations have significantly shorter lifespans than leeward locations. Ten to twenty FADs are replaced each year. Each FAD costs approximately US$ 7,500 to build and deploy.

Hawaiian FADs are heavily used by private and commercial sport fishermen and by small-scale artisanal and commercial fishermen. Commercial pole-and-line boats occasionally use the FADs to capture skipjack tuna. Hawaiian FADs will continue to be used for various types of pelagic fisheries research.

Geographical context

The Hawaiian archipelago is located in the Central North Pacific. Although the entire archipelago stretches over 2,500 km from the island of Hawaii at 19°N-155°W to Midway and Kure atolls at about 28°N-178°W, the Hawaiian FAD system is deployed only around the eight main Hawaiian islands which stretch from Hawaii to Kauai. These are the permanently inhabited islands of the archipelago. Because the islands are of volcanic origin, water depths increase very rapidly away from shore. In some places, the ocean is over 3,700 m deep within 15 km of shore. Prevailing wind and surface ocean currents are from the North-East. The northeast "tradewinds" typically blow at between 15 and 40 km/h which cause the ocean to have "tradewind seas" of about 1 to 2 m superimposed on any other existing ocean wave activity.

History of FADs in Hawaii

Hawaii was perhaps the first place where the Philippine payao concept was adapted for use in deep, high-energy environments. Modern use of FADs in Hawaii started in 1977 when the National Marine Fisheries Service, Honolulu Laboratory (a federal US agency) deployed a few experimental FADs in nearshore waters (Matsumoto *et al.*, 1981; Shomura & Matsumoto, 1982). Very good catches of skipjack tuna *(Katsuwonus pelamis)* were taken from around these early FADs by pole-and-line baitboats and sport fishing was also reported to be excellent. Based on these results, the State of Hawaii Division of Aquatic Resources sought funding to deploy a network of FADs around the islands. In 1980, 26 FADs were deployed. These were of two types: the "pentasphere" which was a group of 5 small (71 cm diameter) buoys welded together and the foam-filled tire design (Higashi, 1994). However, following analysis of the performance of these FADs and the reasons for FAD losses and mooring failure, the system was changed to the use of a single sphere float. By 1983, all Hawaiian FADs had been converted to the single sphere design.
Higashi (1994) has prepared an exhaustive and detailed account of the evolution of FAD design and deployment in Hawaii and, consequently, the rest of this paper will focus on the current status of the Hawaiian FAD system. We will also discuss the various research projects which have focused on these FADs and projects which are planned for the future.

Rationale and funding for the Hawaiian FAD system

The majority of funding for the modern Hawaiian FAD system is obtained from the Sport Fishing Restoration Act (SFRA). This is a federal US programme designed to provide financial support for the management and improvement of sport fisheries within the United States. The money for this programme is raised through a 10% tax on sport fishing equipment and taxes on pleasure boat fuel and importation tariffs on pleasure boats. These funds are disbursed to individual States and, in Hawaii, some of these funds are used to support the FAD system. The SFRA requires that participating States provide some local funds to match the federal money. From the 1980s until 1997, these matching funds came from the budget of the Hawaii Division of Aquatic Resources (HDAR). However, because of reductions in HDAR budget, the Hawaiian FAD system is now administered on a cooperative basis by HDAR and the University of Hawaii, which provides some matching funds for the programme. Since 1997, the daily operation of the FAD system has been conducted by the University of Hawaii.

Because the large majority of the funding for the Hawaiian FAD system comes from the SFRA, the system is primarily designed for the benefit of sport fishing and is certainly not focused on industrial scale fishing. This emphasis on sport fishing greatly influences the location of the FADs and is the reason why all the FADs are located near the main Hawaiian Islands (that is, not in remote areas). Sport fishermen were consulted when the sites for individual FADs were selected.

Design, deployment and location of FADs

Design

Since 1983, all Hawaiian FADs have been of the single-sphere, spar-type float. The float consists of a steel sphere (147 cm diameter) to which are attached a 1.1 m hollow tubular mast to hold the light system and a 2.1 m counterweight pipe which is welded to the bottom of the float. The FAD weighs 399 kg and has a positive displacement of 1,361 kilogramme. Thirty metres of 13 mm chain are attached to the counterweight pipe by a shackle-and-swivel and another shackle-and-swivel links the chain to the mooring rope system. Zinc anodes are installed on the chain.
The mooring system is comprised of sections of negatively buoyant polyester-polyethylene rope and positively buoyant polypropylene-polyethylene rope which deploys in an inverse catenary system of the type described by Boy & Smith (1984) and Gates *et al.* (1996). FADs anchored in windward locations are moored with 25 mm diameter rope, FADs deployed in leeward locations are anchored with 19 mm diameter rope. The mooring scope ratio is normally 1.3:1 although scopes of 1.53:1 are used in locations with very strong currents. The entire mooring rope (both the sinking and floating sections) is purchased from the manufacturer in one piece. That is, Hawaii personnel perform no splicing of the two rope sections because the sinking and floating sections of the mooring are seamlessly connected by the manufacturer. The mooring rope is anchored by 25 metres of 13 mm chain to each of three 771 kg concrete block anchors deployed in a "tripod" configuration. The light system is a yellow light flashing every 15 seconds and powered by a bank of 6-volt batteries and activated by a light-sensitive switch.

Deployment

Deployment is conducted exclusively by commercial vessels chartered specifically for this task. Over the years, a variety of different companies have been used. Differences in the skill level of the different deployment boat operators have been one of the persistent problems with the operation of the Hawaiian FAD system. In a normal deployment operation, the float is deployed first, the mooring line is payed out on the ocean surface and, finally, the anchors are released from the vessel.
In order to reduce the costs of deployment, missing FADs are replaced in groups, or "batches". In this way, several FADs can be replaced during a single charter of a deployment vessel, which might, for instance,

deploy six replacement FADs in a single trip. Typically, between 10 and 20 FADs are replaced each year. Currently, the average cost for each FAD is approximately US$ 7,500 per FAD (including rope and mooring components, float sphere, fabrication and deployment). Because the rope is the single most expensive component, there is considerable variation in cost among FADs because of the wide range of mooring depths. Batteries are replaced during periodic maintenance and during deployment trips.

FAD locations

As mentioned previously, the principal target group for Hawaiian FAD system is the sport fishing community. Because of this, all FAD locations are within a one day transit distance from at least one of the main Hawaiian Islands (fig. 1). Many of the current FAD sites were selected on the basis of public meetings with fishermen and sport fishing clubs. After initial selection of sites that were preferred from a fishing perspective, some were discarded as unsuitable because of too much surface vessel traffic or because of objections from the US military. The current 52 FAD sites are all approved by the US Coast Guard and the sites are marked on official navigation charts for the area.

Hawaiian FADs are located between 3.2 km and 46 km from the nearest point of land. Depths of deployment range from approximately 200 m to approximately 3 000 m with the majority located in water between 700 m and 1,600 m deep. Thirty-two sites can be considered "windward" locations and 20 are in "leeward" locations (fig. 1).

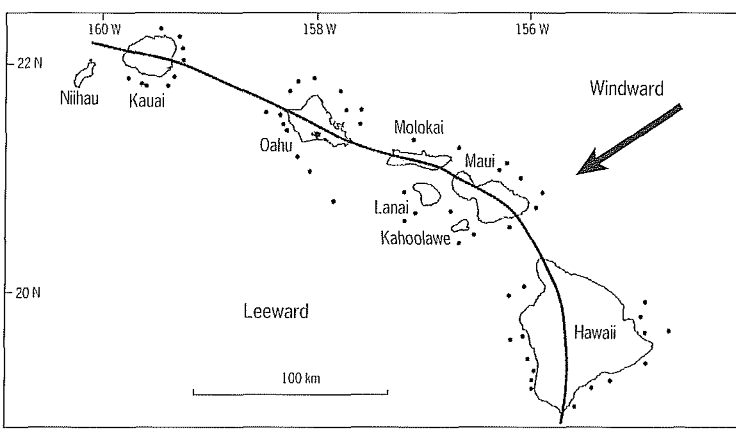


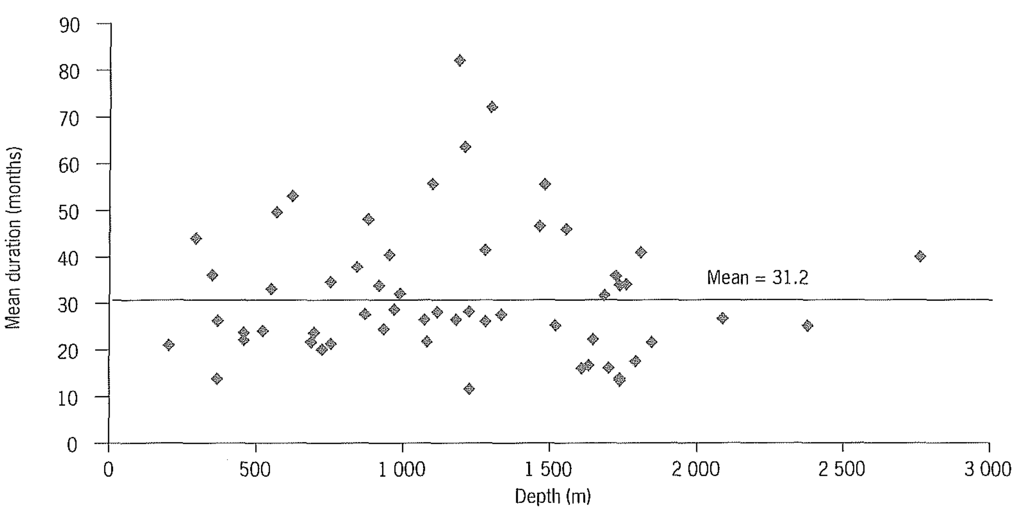
Figure 1
Location of FADs around the main Hawaiian Islands. Persistent northeast tradewinds allow the FADs to be divided into "windward" and "leeward" locations.

Analysis of physical parameters of the current FAD system

In the past year, we have begun to analyse the physical performance of the FAD system so that we can improve longevity, reduce costs per FAD and improve the effectiveness of the system. Although minor changes in construction materials and mooring components have occurred, the current design and deployment strategy have been in place for about 15 years. Analysis of the trends in longevity yielded some interesting results.

Up to February 1999, single-sphere FADs of the modern design and mooring system have been deployed on 275 occasions. Based on the assumption that deployments of FADs that remained on-station for less than one month were due to improper deployment or other equipment failure, durations of less than one month were excluded from analyses of FAD on-site longevity. On-site durations of one month or less comprised 6% of total deployments. Excluding these durations of less than a month, the overall average on-site longevity of Hawaiian single-sphere FADs was 31.2 months (SD = 14.8). There was no correlation between distance from shore and on-site longevity and there was no significant correlation between depth of deployment and longevity ($r = 0.019$, $df = 57$, $p > 0.05$). A plot of on-site duration versus deployment depth illustrates that, at all depths, longevity is quite evenly distributed around the overall mean of 31.2 months (fig. 2). This is somewhat unexpected finding with important ramifications. For instance, it means that FADs could be placed further from shore to service commercial vessels or to service "long-range" sport fishing and have the same longevity expectations as nearshore FADs. Given the fact that there is some evidence that remote FADs aggregate more fish (Kakuma, 2000), this result suggests that the number of "distant" FADs could be increased without too much increase in cost to the programme.

Figure 2
Relationship between ocean depth and FAD longevity. Overall average longevity is 31.2 months.



By contrast, there is significant difference ($p < 0.05$) between FADs moored at "windward" locations and those moored at "leeward" locations even though the windward FADs are moored with thicker rope. Average on-site duration at windward sites is 24.9 months (SD = 8) whereas leeward sites average is 43.4 months (SD = 17). It is usually not possible to confirm the reasons why FADs break from their moorings because the FAD is often not recovered for inspection or is recovered only after it has incurred additional damage after the initial failure. However, the most common confirmed cause of failure in Hawaiian FADs is the

swivel-shackle assembly where the rope meets the chain or where the chain meets the bottom spar on the float. Other quite common causes of loss are parting of the mooring line and being run over by very large vessels such as inter-island cargo barges.
The failure of the swivel-shackle assembly may be one of the reasons why windward FADs have shorter lifespans than leeward FADs. It is possible that the more exposed windward locations have more "tradewind seas" that impart more short-frequency movements and friction damage in components (such as the shackles) that are close to the surface. By contrast, deeper components of the mooring system (such as the rope) are more isolated from these surface conditions which are why there is no correlation between depth of mooring and the longevity of the FAD.
We are considering installing a small diameter "safety cable" that will link the top of the rope and the bottom of the buoy so that, if the swivels fail, the FAD will stay on station until repairs can be made.
Analysis of the longevity of FADs that are still on-site since their last deployment (that is, FADs currently in the water) shows they have been on-site for an average of 37.7 months. That is about 6 months longer than the overall, long-term average (31.2 months) and suggests that the minor modifications we have made in mooring components and attention to initial deployment conditions is paying off in terms of overall longevity.

Recently, we have instituted an automatic telephone system that provides information about the current status of the FAD system and that allows people to report any missing FADs. For the same reason, we have constructed an interactive Web page which gives a history of the Hawaiian FAD system and provides updates about the status of the FAD system: *www.hawaii.edu/himb/fads/*

Usage patterns and economic impact of Hawaiian FADs

There have been no consistent records of the usage patterns of Hawaiian FADs by private individuals or by the various commercial sectors of the fishery. Further, the records of commercial landings of nearshore fisheries in Hawaii are not sufficiently reliable or fine-scaled to give an accurate picture of the impacts of FADs on Hawaiian economy.
Certainly, the FADs are extremely popular with the sport fishing sector in Hawaii. The FADs are utilized by a wide range of sport vessels ranging from large powerboats to small rubber craft and even man-powered canoes. A wide variety of fishing methods are evident, the most common being trolling, vertical jigging and drift fishing of live or dead bait. The FADs are also used extensively for subsistence scale operations, which target small sizes of yellowfin tuna *(Thunnus albacares)*, bigeye tuna *(T. obesus)*, skipjack tuna and, less often, mackerel scad *(Decapterus* sp.*)*. In some parts of the islands, the FADs contribute a significant part of the food supply for families in those areas.

Although the Hawaiian FAD system is intended primarily as an aid to sport fishing and is underwritten by funds derived from the sale of sport fishing equipment, commercial operations derive significant advantage from the FAD system. Probably the biggest beneficiary is the commercial sport fishing sector. Sport fishing charter boats visit the FADs extensively and use the FADs to catch target species such as tuna, marlin and "mahi-mahi" *(Coryphaena hippurus)*. They also use the FADs to catch live bait for marlin fishing. FADs provide charter boats with much improved chances of success, even if the fish are small tuna caught on light tackle. In fact, light tackle sport fishing at the FADs is one of the options promoted by the commercial sport fishing sector. Nearshore handline fishermen that target large tuna for the high-quality sashimi market also fish at the FADs both during the day and night in those seasons when large fish can be found close to shore. The FADs are not the primary location for these fishermen but form one part of their overall fishing strategy.

The FADs are also used occasionally by live-bait pole-and-line boats that primarily target skipjack tuna. Pole-and-line boats use the FADs most often when fishing is bad in the whole region and, under these circumstances, these vessels will also take small yellowfin and bigeye. There are no legal restrictions that limit use of the FADs by commercial operators although the pole-and-line vessels do often cause bad feelings when they fish at the FADs. Because pelagic longline fishing is prohibited within 25 miles (40 km) of the shore of the main Hawaiian Islands, longliners do not utilize the FADs and there are no conflicts between longliners and the other FAD users.

Future prospects

For the foreseeable future, the Hawaiian FAD system will continue in much the same way as it exists at the moment. This, of course, is contingent on continued funding from the SFRA. Certainly, it is improbable that Hawaii could maintain this system in the absence of federal funding. A few new FAD locations are being discussed with fishermen and a few seldom-used sites may be abandoned.

We do intend to continue and expand the research activities associated with Hawaiian FADs. Several fisheries research projects have derived significant benefit from access to the Hawaiian FAD system and, now that the system is administered by the University of Hawaii, it is intended that this tradition of research activities should be expanded. Hawaiian FADs have been used in studies of the movement patterns of tunas (Holland *et al.*, 1990; Klimley & Holloway, 1999) and in a preliminary investigation of the feeding behaviour of tuna at FADs (Brock, 1985). Currently, the FADs are being used as an integral part of a large-scale tag-and-release study to investigate the movement patterns of yellowfin and bigeye tunas in Hawaii (Itano & Holland, 2000; Sibert *et al.*, 2000). These tag-and-release experiments will continue for several years with an emphasis on elucidating the duration of residence and visitation patterns of tunas associated with FADs. Also, there are preliminary plans to deploy a series of oceanographic instruments on the moorings of several FADs and to use the FADs for a comprehensive investigation of the feeding behaviour of aggregations of yellowfin and bigeye tunas. All of these research activities will be particularly timely given the probable immanent implementation of international management of tuna resources in the Pacific. Given the importance of tuna aggregations in general, and the widespread use of FADs in particular, it is anticipated that any international management protocol will place high value on the type of data that we can produce from scientific work conducted around Hawaiian FADs.

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