



**Trial setting of deep longline techniques
to reduce bycatch
and increase targeting
of deep-swimming tunas**



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Introduction

This paper is in response to task **4b** to the Fishing Technology Working Group (FTWG) as developed following discussions of the Preparatory Meeting to the FTWG and the plenary session on the Sixteenth Meeting of the Standing Committee on Tuna and Billfish (SCTB16), held in Mooloolaba, Queensland, Australia, from 9—16 July 2003.

4. Application of gear technology to bycatch reduction

b. Report on current initiatives to mitigate purse seine and longline bycatch and improve targeting through the application of new technology (All FTWG)

This report consists of two case studies where initiatives have been made within the WCPO to develop pelagic longline techniques that increase effective targeting of deep-swimming market species while reducing the likelihood of taking shallow water bycatch.

Problem statement

In general, longline fisheries for pelagic species within the WCPO deploy either “shallow” or “deep” set gear. So called “regular” longline gear was estimated to hang at a depth of 50 to 120 m while deep longline gear covered a wider range from 50 to 300 m — deploying 4—6 hooks between floats (per basket) for shallow sets and an average of 13 hooks per basket for deep sets (Suzuki and Warashina 1977). Deep longlining was introduced to the WCPO in the 1970s and is widely practiced by the major fleets to target deep-swimming bigeye and albacore tuna (Sakagawa et al. 1987). Modern tuna longline vessels may deploy more than 30 hooks per basket and utilize a “line shooter” to set additional mainline between floats to sink the line even deeper. In contrast, typical swordfish style longline sets are very shallow with only four or five hooks per basket and no use of a line shooter. For a detailed description of pelagic longline gear see Beverly et al. (2003) and Swenarton and Beverly (2004).

One problem with shallow-set longline gear is that it places the hooks within the upper mixed layer of the ocean, bringing the gear into conflict and potential interaction with surface fisheries; i.e. subsistence, recreational and small-scale handline and troll fisheries, as well as large-scale purse seine fisheries. Shallow-set gear also produces significantly higher interaction rates with protected or ecologically sensitive bycatch species that are easily overharvested, such as marine turtles, seabirds, marine mammals, oceanic sharks, manta rays and whale sharks. Shallow-set gear also competes with important sport and recreational species prized by surface fisheries such as the marlins, spearfish, sailfish, wahoo, and dolphinfish.

In response, deep-set longline gear has been actively promoted as one means to improve targeting while decreasing the likelihood of interactions with protected species. The importance of reducing interaction rates with protected species cannot be overemphasized. In recent years, longline fisheries have been significantly curtailed and even closed in attempts to mitigate interaction rates with marine turtles and marine mammals.

Possible solution to reducing bycatch and improving targeting

What is now considered conventional deep-set bigeye tuna longline gear utilizes a line shooter setting around 25 to 30 or more hooks per basket on mainlines stretching over 30 to 50 or more nautical miles (nm) of open ocean. However, hooks are still placed from floatline to floatline within each basket, producing a wide range of actual hook depths within a set. Interaction rates with bycatch species of the upper mixed layer still occur. Also, current speed and shear often shallow a set considerably, raising deep longline gear to shallow-set depths.

This paper reports on two independently developed longline systems that attempt to increase targeting of deep swimming species while minimizing the potential for interaction with surface oriented bycatch species.

Background

The Hawaii-based pelagic longline fleet operates within a limited framework allowing for 164 transferable vessel permits for vessels less than 101 feet in overall length. Vessels are monitored by VMS systems and a federal logbook reporting system. Hawaii-based longline vessels targeting bigeye tuna set 20—40 hooks per basket on floatlines set approximately 0.8 km (1/2 mile) apart, achieving hook depths of around 91—366 m (300—1200 feet) (NMFS 2001). The majority of protected species interactions occur with swordfish targeting gear, setting only 4—5 hooks per basket, but interactions still occur with the deep-set gears.

However, pelagic longline gear of less than one nm (1.85 km) in length is permitted under federal regulations to be deployed by any Hawaii commercial fishing vessels outside the permitting and regulatory framework monitoring the main longline fishery. This section reports on the development of a small-scale longline system that targets either bigeye tuna (*Thunnus obesus*) or the lustrous pomfret (*Eumegistus illustris*). While this system may have limited value for large scale fisheries, the concept may be applied to larger scales or find a direct application in WCPO small-scale or artisanal longline fisheries.

Fishing grounds

This system was developed to target bigeye tuna and pomfrets that are concentrated in dense aggregations over the summit of the Cross Seamount, located approximately 290 km south of Honolulu, Hawaii. This particular seamount is unique among the many Hawaiian seamounts, rising sharply from 4,000 to 330 meters, apparently just the right depth for both species. The seamount summit aggregates commercial concentrations of bigeye and yellowfin tuna forming the base for a local handline fishery and is a primary tag release location for Hawaii-based tuna tagging experiments (Itano and Holland, 2000). Handline vessels targeting bigeye tuna over the seamount normally take small to medium sized bigeye around seven to 20 kgs in weight. However, larger fish are available over or near the seamount that have been targeted by Hawaii-based longline vessels.

Development of the fishing method

Hawaiian longline vessels have fished the area of the Cross Seamount for several decades, targeting large bigeye tuna on the outer slopes of the seamount. The offshore handline fishery developed afterwards, peaking in the late 1980 and early 1990 period (Itano, 1998). During the 1990s, some conventional longline vessels began to set gear directly over the seamount summit, causing gear interactions and heated conflicts with the handline fleet. A commonly seen strategy was for a longline vessel to set gear in an “S” pattern, upcurrent of the seamount and haul the gear after it had passed over the area. Although these boats caught some bigeye of a similar small size as the handline vessels, they also took larger fish apparently unavailable to the handline boats.

In response to these observations, some handline boats began to experiment with vertical longline gear to deploy baited hooks all the way down to the seamount summit. These gears were very similar to those described by Preston et al. (1998), consisting of a single vertical line, buoyed at the top and weighted at the bottom, with branchlines snapped on from top to bottom. Catch rates of larger bigeye tuna of 30—60 kgs encouraged further experimentation that continues to the present. The use of vertical longline gear gave way to the use of short sets of deep-set horizontal gear as described below.

Deep-set fishing gear

An informal observer trip was conducted by one of the authors to the Cross Seamount from July 7—14, 2004 to observe the fishing method. Fishing took place on the seamount for six consecutive days. The primary gear type were horizontal longline sets of less than one nm in length. It was explained that this

gear can be quickly adjusted and set in any number of configurations and depths, but is generally set to target either bigeye tuna or pomfret. The bigeye gear is set at mid depth over the seamount summit while the pomfret gear is set deeper, just above the seamount itself. It should be noted that there are currently at least two vessels deploying this style of gear on the seamount. It is believed that both vessels use very similar gear but the descriptions here apply directly to only one of the vessels.

Bigeye longline set

The gear is very simple, consisting of a small, hydraulically driven longline reel with fairlead mechanism, 3.6 mm monofilament mainline, flag buoys, hard plastic floats, five kilogram weights, with stainless steel longline snaps rigged with two meter 2.0 mm diameter monofilament leaders ending in tuna circle or Japan style longline tuna hooks. Exact details of setting times and depth will not be given as requested by the fisherman.

Setting takes place before dawn to take advantage of what is considered the peak biting time for bigeye in this area. The set consists of approximately 100 leaders snapped on the mainline using one or two floats. **Figure 1** shows a tuna set with one set of floats, producing two baskets of 50 hooks each. The setting procedure for this configuration would be as follows:

1. Position vessel upcurrent of target area.
2. Deploy flag buoy #1 and pay out mainline to desired target depth.
3. Attach weight of approximately five kilograms.
4. Snap baited branchlines, closely spaced, approximately 8—10 meters apart.
5. Attach hard buoy float.
6. Snap more baited branchlines.
7. Attach weight of approximately five kilograms.
8. Pay out additional mainline.
9. Attach and deploy flag buoy #2.

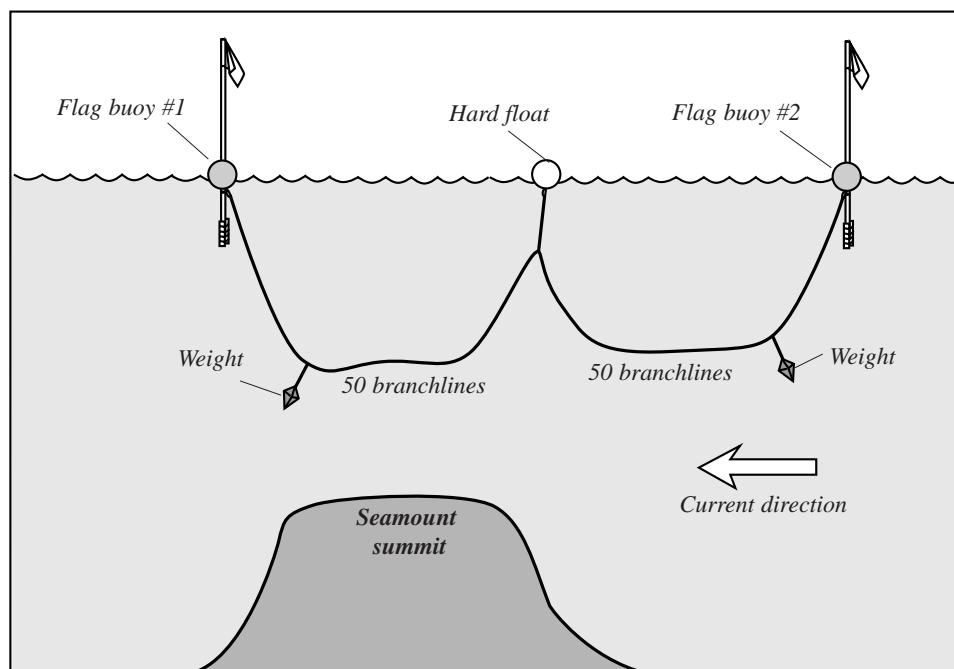


Figure 1: Bigeye targeting set upcurrent of seamount.

This procedure, depending on how many floats are used will produce what are essentially two or three large “baskets” of gear held down by a lead weight. The use of an additional floatline can add additional depth to the set but is not normally used on the seamount due to the possibility of hooking the

seamount summit. The line is normally retrieved after a short soak of two hours or so or when the distance between floats indicates the lines are loading up with catch.

Pomfret longline set

There are several species of pomfrets (BRAMIDAE) that are taken as incidental catch in the Hawaii-based longline fishery, known locally by the generic term “Monchong”. The most common species taken in open water is the bigscale pomfret (*Taractichthys steindachneri*). The larger lustrous pomfret (*Eumegistus illustris*) appears to be a seamount and deep-slope associated species and is more sought-after by the fish buyers due to higher meat yield ratios. After developing the deep-set longline technique to target large bigeye tuna, it became apparent that large quantities of *E. illustris* were also available over the seamount summit. By modifying the gear slightly, it was found that the gear could effectively target this species of monchong while also taking medium and large bigeye as a retained bycatch.

The gear is essentially the same as described for bigeye tuna fishing. However, two or sub-surface floats are used instead of surface hard floats. These sub-surface floats are only slightly positive in buoyancy; their purpose is to keep the deeper set gear from fouling the seamount summit while maintaining the gear at depth. Another important modification to the monchong gear is the addition of more branchlines spaced very closely and the use of smaller circle hooks. Normally, a monchong targeting set will deploy 200 hooks in the same length of mainline. **Figure 2** shows a typical monchong set of 200 hooks on less than one nm of mainline.

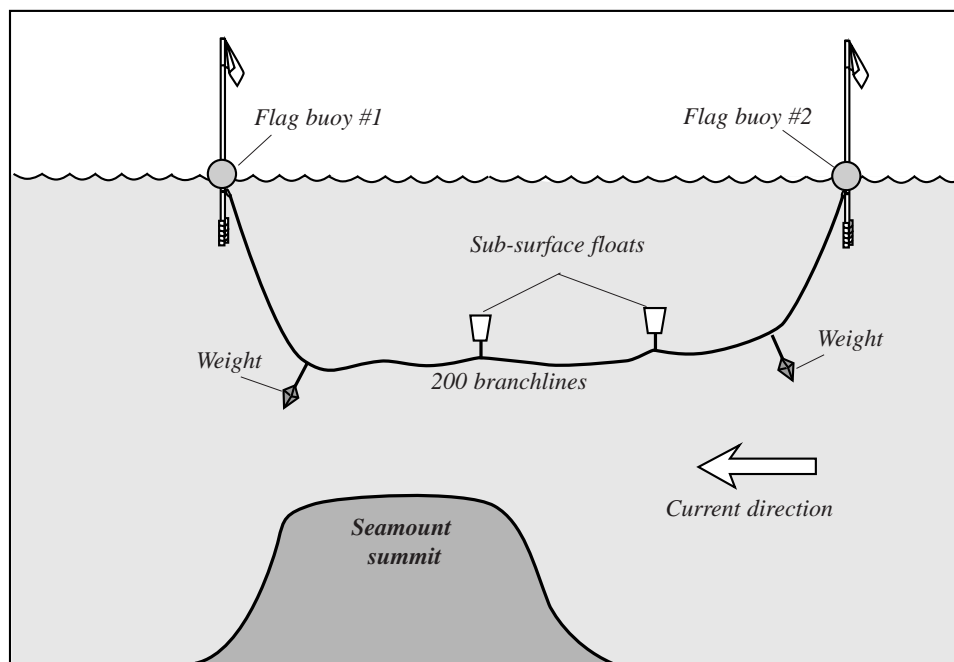


Figure 2: Monchong targeting set upcurrent of seamount.

Catch and effort data

Catch records for the first seven months of 2004 were examined for 12 tuna targeted trips and compared to what was considered a typical monchong targeted trip from January 2003. All fishing took place on the Cross Seamount with anywhere from 2—7 days of fishing per trip. Normally, four or five sets were made per day with an average of 95 hooks per set. Table 1 lists the number and CPUE of bigeye, yellowfin and monchong caught per trip. Mean catch for all 12 trips was 9.1 bigeye, 1.9 yellowfin and 1.4 monchong retained per 100 hooks set. The monchong targeting trip differed considerably for bigeye and monchong, with 2.2 bigeye, 2.0 yellowfin and 8.2 monchong taken per 100 hooks set.

Table 1: Catch and effort data from tuna and monchong targeting longline trips.

Target	End date	#Days	# Sets	Hooks/set	Hooks set	Bigeye pcs	Bigeye CPUE (#/100 hks)	Yellowfin pcs	Yellowfin CPUE (#/100 hks)	Tuna CPUE (#/100 hks)	Monchong pcs	Monchong CPUE (#/100 hks)
tuna	01/14/04	6	24	95	2280	176	7.7	107	4.7	12.4	91	4.0
tuna	01/23/04	4	22	95	2090	225	10.8	82	3.9	14.7	42	2.0
tuna	02/05/04	5	20	95	1900	196	10.3	33	1.7	12.1	12	0.6
tuna	02/15/04	5	20	95	1900	236	12.4	66	3.5	15.9	14	0.7
tuna	04/08/04	5	20	95	1900	135	7.1	18	0.9	8.1	35	1.8
tuna	04/19/04	5	20	95	1900	262	13.8	6	0.3	14.1	1	0.1
tuna	05/06/04	2	8	95	760	77	10.1	9	1.2	11.3	4	0.5
tuna	05/21/04	6	24	95	2280	224	9.8	1	0.0	99	59	2.6
tuna	05/28/04	2	8	95	760	42	5.5	0	0.0	55	24	3.2
tuna	06/15/04	7	28	95	2660	285	10.7	8	0.3	11.0	31	1.2
tuna	07/01/04	7	28	95	2660	197	7.4	68	2.6	10.0	5	0.2
tuna	07/22/04	6	24	95	2280	78	3.4	46	2.0	5.4	1	0.0
Tuna total	60	246	95	23370	2133	9.1	444	1.9	11.0	319	1.4	
monchong	01/15/03	7	28	100	2800	62	2.2	55	2.0	4.2	229	8.2

These figures appear very productive, but it should be noted that the average size of the tuna are considerably smaller than those taken by the federally regulated longline fishery. The mean size of bigeye and yellowfin in this example was 26.9 lbs (12.2 kgs) and 18.1 lbs (8.2 kgs) respectively (Table 2). However, on some trips, yellowfin of a good size contributed significantly to catches, ie the last two trips landed 68 and 46 yellowfin per trip with average weights of 34.2 (15.5 kgs) and 35.6 lbs (16.2 kgs) respectively.

The monchong targeting trip indicates a CPUE of 8.2 fish per 100 hooks with an average size of 11.8 lbs. This size appears to be quite average or a bit low compared to the 12 trip average weight of 12.4 pounds taken on the tuna targeting trips. Reports by the fisherman indicate that some monchong targeting sets have very high catch rates of more than 80 fish per 100 hooks.

Table 2. Catch by number and weight from tuna and monchong targeting longline trips.

Target	End date	Hooks set	Bigeye			Yellowfin		Monchong		
			pcs	wt(lbs)	mean wt (lbs)	pcs	mean wt (lbs)	pcs	wt (lbs)	mean wt (lbs)
tuna	01/14/04	2280	176	3112	17.7	107	11.2	91	1067	11.7
tuna	01/23/04	2090	225	3840	17.1	82	10.6	42	501	11.9
tuna	02/05/04	1900	196	4691	23.9	33	10.9	12	164	13.7
tuna	02/15/04	1900	236	4102	17.4	66	10.5	14	193	13.8
tuna	04/08/04	1900	135	3397	25.2	18	15.7	35	455	13.0
tuna	04/19/04	1900	262	7440	28.4	6	15.3	1	12	12.0
tuna	05/06/04	760	77	2344	30.4	9	14.8	4	59	14.8
tuna	05/21/04	2280	224	7728	34.5	1	59.0	59	743	12.6
tuna	05/28/04	760	42	1504	35.8	0	NA	24	312	13.0
tuna	06/15/04	2660	285	9363	32.9	8	50.5	31	367	11.8
tuna	07/01/04	2660	197	7707	39.1	68	34.2	5	68	13.6
tuna	07/22/04	2280	78	2248	28.8	46	35.6	1	10	10.0
Tuna total		23370	2133	57476	26.9	444	18.1	319	3951	12.4
monchong	01/15/03	2800	62	2352	37.9	55	18.1	229	2701	11.8

Discussion of Hawaiian example

The development of this style of gear is an example of a specialized case of targeting aggregated, structure associated tuna and seamount associated species. However, the system demonstrates a simple method to concentrate hooks within a narrow depth range with greater accuracy than is possible with conventional deep-set longline gear. The key components of the system are heavy weights after the surface floats and the use of slightly buoyant sub-surface floats interspersed with hooks within the “basket”.

A key element to the system aside from the close targeting of concentrated schools is the timing of the set. By setting before dawn, the gear takes advantage of the shallow night-time behavior of bigeye tuna

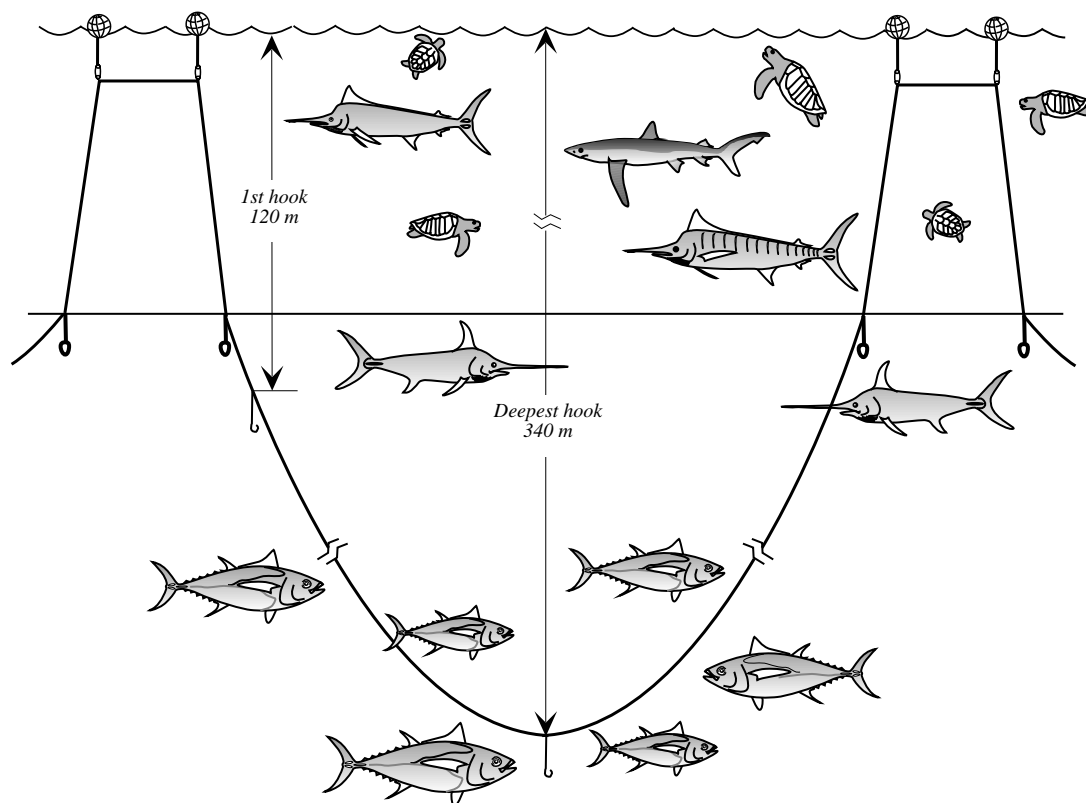
and the higher biting response that is presumed to take place during the early morning hours. In this manner, the gear not only targets concentrated schools, but does so at the optimal time for highest CPUE. The direct application of this methodology to fishing around FADs, both anchored and drifting may be an interesting area to explore.

While the figures for average size of tuna do not appear overly impressive, the fishermen report very favorable marketing results from their deep-set short longline gear. Average prices achieved by this method are considerably higher than those received from handline and troll landings. The handline fishery also catches medium and large size bigeye on the seamount, but they seldom achieve a decent price for these fish. There is an ingrained prejudice against handline caught bigeye in Hawaii due to perceived quality issues resulting in short shelf life of the product and the possibility of the “burnt tuna syndrome” caused by overheating of the muscle mass. Landings of tuna using the deep-set gear described here are reported to achieve much higher prices at the Honolulu United Fishing Agency auction and are considered on a par with the landings of the larger longline vessels. This is a very important consideration locally as the system operates on a daily auction basis, and longline vessel catch is auctioned first, followed by troll and handline landings. Even if the handline boats have good quality fish, their latter position in the auction almost guarantees them lower prices.

Finally, the system is very interesting to the WCPO as it demonstrates the exploitation of a formerly unutilized resource with a stable market demand. Pomfrets are found throughout the world’s oceans and may represent an alternative market species for developing areas.

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1. Introduction and background

A typical pelagic tuna longline catches deep as well as shallow dwelling fish. Unfortunately, many unwanted species are often caught on the shallowest hooks of a longline, even if the longline is targeting deeper species. Attempts have been made in the past to adjust the depth of set to capitalise on the knowledge that the most sought after species are caught in deeper water. Attempts have also been made to avoid the unwanted species that dwell in shallower waters. This has been accomplished in some areas by banning shallow setting. Unfortunately, most attempts to target only deep dwelling species also have a high percentage of their gear in shallow waters, or have technical problems that make them unsuitable and unlikely to be adopted by longline fishermen. This report outlines a new deep setting technique that lands all of the hooks in a longline below a critical depth, out of range of most bycatch species, and down where the most sought after target species are usually captured. The method is simple enough to be adopted by almost any longline operation. Indications during fishing trials were that target species catch rates can be enhanced using this new deep setting technique.

1.1 Pelagic longlining and the bycatch of marine turtles

Pelagic longlining targets tuna and billfish species but also catches other species that may or may not be marketable (Beverly, et al. 2003). Target species include bigeye tuna (*Thunnus obesus*), yellowfin tuna (*T. albacares*), albacore tuna (*T. alulunga*), broadbill swordfish (*Xiphias gladius*), and striped marlin (*Tetrapterus audax*). There are two groups of non-target species caught by longliners: byproduct and bycatch (see Appendix A for a list of non-target species associated with Australia's Eastern Tuna and Billfish Fishery). Byproduct species include those that are not targeted but are retained because they have commercial value. These include species such as mahi mahi, or dolphin fish (*Coryphaena hippurus*), wahoo (*Acanthocybium solandri*), opah, or moonfish (*Lampris guttatus*), and some billfish and shark species among many others.

Bycatch species are those non-target species that are discarded because they either have no commercial value or because they are endangered and are protected by law. Discarded bycatch species that have no commercial value include species such as lancetfish (*Alepisaurus spp*), snake mackerel (*Gempylus serpens*), pelagic rays (*Dasyatis violacea*), some sharks, and undersized tunas and billfish, among many others. Discarded bycatch species that are endangered and are protected by law include sea turtles*, sea birds, marine mammals, some shark species, and, in some areas, billfish.

The bycatch of sea turtles by commercial fisheries, including longlining, is of particular concern. Despite them being caught rarely, some species are considered vulnerable to local and even global extinction because of declining numbers (Robins et al., 2002). Sea turtles can be lightly or deeply hooked in the mouth, entangled in the line, or externally hooked on the neck or flipper. Hard-shelled turtles are commonly hooked in the mouth as a result of biting the bait, while leatherbacks are mostly reported as being entangled in the fishing line or externally hooked in the shoulder or flipper.

The turtle bycatch issue in longline fisheries has recently been examined from a global perspective and some extraordinary global assessments have been made (Lewison, et al. 2004). In their report that quantifies the impact of pelagic longlining on loggerhead and leatherback turtles, Lewison, et al., claim that their analyses from data from 40 nations and 13 observer programs show that, despite infrequent encounters, more than 200,000 loggerheads and 50,000 leatherbacks were most likely taken as pelagic longline bycatch in 2000; and that thousands of these turtles die each year from longline gear in the Pacific Ocean alone.

* There are seven species of sea turtle worldwide: the loggerhead sea turtle (*Caretta caretta*), the green sea turtle (*Chelonia mydas*), the hawksbill turtle (*Eretmochelys imbricata*), the olive ridley turtle (*Lepidochelys olivacea*), the flatback turtle (*Natator depressus*), the leatherback turtle (*Dermochelys coriacea*) and the Kemp's ridley turtle (*Lepidochelys kempii*), which only occurs in the Gulf of Mexico and northwest Atlantic (Robins et al., 2002).

1.2 Hawaii: a case study

Hawaii is a good case study for the bycatch issue in the longline fishery, especially concerning sea turtles. In Hawaii the fishery for tuna and tuna-like species falls under the management regime of the Pelagics Fishery Management Plan that was implemented in 1986 by the Western Pacific Fishery Management Council (Dalzell 2000). Hawaii has a limited entry program with a cap of 164 longline vessels. The majority of the vessels range from 17 to 22 m, and most fish with monofilament longline systems. Because of protected species interactions by vessels fishing close to the Northwestern Hawaiian Islands (NWHI) the Council imposed closures during the 1990s extending for 50 nautical miles (nm) around the NWHI. Longliners, particularly those targeting swordfish, would on occasion catch animals protected under the Undangered Species Act, namely the Hawaiian monk seal (*Monachus schauinslandi*) and the green sea turtle. A similar closure was imposed around the main Hawaiian Islands in response to complaints from small commercial and recreational fishermen that longliners were fishing too close to shore. A vessel monitoring system (VMS) was implemented as a result of the area closures so that vessels' positions could be known at all times.

The displacement from shore solved the problem of interactions between longliners and monk seals, green sea turtles, and small boat fishermen but, longliners continued to interact with other turtle species — loggerheads, leatherbacks, and olive ridleys; and they continued catching and killing albatross (Dalzell 2000). In the USA all species of marine turtles are protected by the Endangered Species Act (ESA), and all migratory birds are protected under the Migratory Bird Treaty Act. National Marine Fisheries Service (NMFS) has operated a sea turtle observer program in the Hawaii longline fishery since 1994 with about 5 per cent coverage (SPC 2000). Based on logbook data from 1994 to 1997, it has been estimated that between 150 and 558 turtles were captured annually in the longline fishery, with mortality ranging from 23 to 103 individuals (Kleiber 1998).

In February 1999 in spite of ongoing efforts to solve the problem, Earthjustice, an environmental group, filed a law suit on behalf of the Center for Marine Conservation and Turtle Island Restoration Network against NMFS accusing them of negligence in their duty to protect endangered sea turtles. The judge in the case (US District Judge David Ezra) agreed that NMFS and the Hawaii-based longline fleet had made no attempts to reduce interactions with and mortalities of turtles caught by longliners. By court order, significant areas were closed to the fishery and a host of lawsuits and counter-suits were begun. The entire Hawaii-based longline fishery was closed from 15 to 30 March 2001 (Anon 2001e). Later the judge modified his injunction and banned swordfishing from the equator to the North Pole and closed 1.9 million square miles of mostly international waters south of Hawaii during April and May to Hawaii longline vessels targeting tuna. Some of the Hawaii-based longliners moved to the US west coast during the closures in Hawaii. Recently NMFS issued new rules prohibiting shallow longline sets targeting swordfish on the high seas in the Pacific Ocean east of 150°W longitude between the west coast and Hawaii (Anon 2004b). This ruling affects longliners based on the US west coast. In April 2004, however, the area closure for longline fishing in the area south of Hawaii was eliminated and the swordfish component of the Hawaii longline fishery was re-opened subject to restrictions on the types of hooks and bait (Anon 2004c). In addition, there were annual fleet-wide limits put on fishery interactions with leatherback and loggerhead turtles, an annual limit on fishing effort, and other mitigation measures.

1.3 Working toward solutions

As a result of the events that took place in Hawaii and elsewhere, attention to the sea turtle bycatch issue in the longline fishery has grown significantly. For example, NMFS has convened a Working Group on Reducing Turtle Bycatch in the Hawaii Longline Fishery (Anon 2001d). The group meets periodically to discuss turtle bycatch issues including fishing gear developments. The turtle bycatch issue has been a regular topic for discussion at the annual meetings of the Standing Committee on Tuna and Billfish (SCTB) since SCTB13 in July 2000 (SPC 2000). International fora have also been held to address the issue. The first International Fishers Forum was held in Auckland, New Zealand in November 2000 and focused on exchanging information and developing measures to minimize the

incidental capture of seabirds in longline fishing operations. The second International Fishers Forum (IFF2) was held in Honolulu, Hawaii in November 2002 (Anon 2002) and addressed the bycatch of sea turtles as well as seabirds by longline fishing gear. The objectives of IFF2, among other things, were: *“to promote the development and use of practical and effective seabird and sea turtle management and mitigation measures by longline fishermen; to foster and exchange...information among fishermen, scientists, resource managers, and other interested parties on the use of mitigation measures and the development of coordinated approaches to testing new measures, and to promote the development and implementation of collaborative mitigation research studies...”*.

Participants from nineteen countries and four inter-governmental organisations (including SPC) participated in the International Technical Expert Workshop on Marine Turtle Bycatch in Longline Fisheries that was held in Seattle, Washington USA in February 2003 (Anon 2003a). Among other things the objectives of the workshop were: *“to exchange information on experimentation with longline gear relative to turtles and target species; and to identify and consider solutions to reduce turtle bycatch in the longline fisheries.”* The workshop identified six strategies to address sea turtle bycatch in longline fisheries including Strategy 4: Modifications to gear and fishing tactics. One of the high priority actions under this strategy was to direct research on effects of circle hooks, bait type, weighted leaders, repellents, different materials, attractiveness of gear, and deep sets.

Laurs, et al. (2001) reported on a variety of proposed research projects planned by NMFS Honolulu Laboratory to solve the turtle bycatch problem in longline fisheries. Among these were the use of blue dyed baits, moving branchlines at least 40 fathoms (73 m) away from floatlines, the use of stealth fishing gear (camouflaged by dyeing it blue-grey), assessment of deep daytime fishing for swordfish, and testing different hook designs. Laurs et al. (2002) report that fishing trials for most of the planned projects were greatly reduced because of restrictions on the research permit granted under the Endangered Species Act. Preliminary results showed that the stealth fishing gear was not as economically viable as normal gear but still had some promise, and large circle hooks (18/0) showed increased catch rates for bigeye but decreased rates for swordfish.

By contrast, an ongoing study carried out in the Atlantic Ocean’s swordfish fishery (Bolten, et al 2001) has shown great promise with the use of large size 18/0 stainless steel circle hooks in reducing turtle bycatch. Commenting on the research, a *US Department of Commerce News* press release (Anon 2004a) stated that encounters with leatherback and loggerhead turtles can be reduced by 65 to 90 per cent by switching the type of hook and bait from the traditional J-hook with squid to a large circle hook with mackerel. The final report on the project was waiting for peer review before publication.

Research activities carried out in Japan by the National Research Institute of Far Sea Fisheries to find management solutions to the incidental bycatch of turtles by longline fishing include studies on the use of circle hooks, modification of fishing bait and gear depth (and) studies on offshore ecology of sea turtles to ascertain the horizontal and vertical distribution of foraging sea turtles (Kiyota, et al 2003).

SPC’s Oceanic Fisheries Programme reviewed turtle bycatch in the western and central Pacific Ocean (WCPO west of 150°W) tuna fisheries for the South Pacific Regional Environmental Programme’s (SPREP) Regional Marine Turtle Conservation Programme (SPC 2001). The WCPO currently supports the largest tuna fishery in the world — about 1.5 million mt of tuna are landed annually by the 200 purse seine vessels operating in equatorial waters of the WCPO and the fleet of several thousand longliners operating throughout the WCPO from 45°N to 45°S. Incidental catch in the longline fishery occurs when turtles encounter baited hooks or when they get entangled in mainlines or floatlines. When mortality occurs it is typically due to drowning. If turtles are hauled just after getting hooked or entangled they usually survive. Observer reports show that tropical areas have more turtle encounters and that depth of set appears to be the most important factor. Analysis of data suggests that bait and time of set do not have as much of an affect as depth of set. Estimates from the observer data show that turtle encounters on shallow sets are an order of magnitude higher than on deep sets, and that when there are turtle encounters on deep sets they are almost always on the shallowest hooks in the set. *“This*

suggests that there is probably a critical depth range of hooks where most marine turtle encounters would be expected to occur in the western tropical Pacific longline fishery”.

A study conducted in Hawaii on turtle dive-depth distribution (Polovina, et al 2002, 2003) revealed that loggerheads spend most of their time shallower than 100 m, and that, even though olive ridleys dove deeper than loggerheads, only about 10 per cent of their time was spent deeper than 100 m. The report concluded that incidental catches (of turtles) should be substantially reduced with the elimination of shallow longline sets. However, when deep sets are being set or hauled, or when current shears prevent the gear from sinking to its expected depth, hooks will occupy relatively shallow depths and this could result in incidental turtle catches. Observer data from Italian longliners operating in the Mediterranean where hooks are set down to 20 m showed most turtles were caught in the top five metres of the water column (Laurent et al., 2001).

Other bycatch species are also associated with hook depth. Yokawa, et al (2003) found that blue marlins were hooked between 40 and 173 metres and that CPUE of blue marlin decreased with increasing depth layer. The use of deep sets to fish deeper than 75 m was identified as a fishing practice that might increase commercial tuna catch rates while reducing black marlin mortality (Campbell, et al 1997). Hoey (1995) reported on experiments undertaken by U.S. fishermen in the mid-to-late 1970s off the east coast of Florida. To fish deeper, floatlines greater than 15 m and branchlines from 25 to 40 m were used which proved to be more effective at catching swordfish and bigeye tuna. An additional benefit was found to be that because of the reduced number of hooks set in shallower depths there were fewer non-target species captured. Boggs (1992) suggested that eliminating shallow hooks from a longline set could substantially reduce the bycatch of spearfish (*Tetrapturus angustirostris*), striped marlin, and other recreationally important billfish without reducing fishing efficiency for bigeye tuna.

1.4 Australia: longlining and bycatch issues

Two major bycatch policies have been developed in Australia — the Commonwealth Policy on Fisheries Bycatch and the National Policy on Fisheries Bycatch (www.affa.gov.au). The Commonwealth policy commits the Australian Fisheries Management Authority (AFMA) to developing bycatch action plans (BAP), which are actually living documents subject to review every two years. AFMA has produced a BAP for Australia’s tuna and billfish fisheries (Anon 2001b). The aims of Australia’s tuna and billfish fisheries BAP are to quantify and reduce impacts of fishing on bycatch species by reducing capture and mortality, and by developing mechanisms to convert bycatch to byproduct; and to increase awareness and support for activities taken to address bycatch issues. The main species groups covered in the BAP are seabirds, turtles, sharks, and billfish.

Permit holders in the Commonwealth tuna and billfish fisheries in Australia are subject to bycatch arrangements set out in the Fisheries Management Regulations 1998 administered by AFMA under the Fisheries Management Act 1991 (Anon 2001a). They are also subject to the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). All Commonwealth operators are prohibited from landing blue marlin (*Makaira mazara*) and black marlin (*M. indica*), and operators in Western Australia are prohibited from landing striped marlin (*Tetrapturus audax*). In addition, the Commonwealth government introduced a ban on shark finning in tuna fisheries from October 2000. The EPBC Act protects a number of listed species (www.deh.gov.au). Listed fauna range from extinct, critically endangered, endangered, vulnerable, or conservation dependent. Operators in Australia’s tuna and billfish fisheries are legally required to avoid all interactions with listed species. When an interaction does occur operators are required to report the incident. Great white sharks (*Carcharodon carcharias*) and grey nurse (*C. taurus*) sharks (*western populations*) are listed as vulnerable under the EPBC Act. Grey nurse sharks (Eastern population) are listed as critically endangered. Loggerhead and olive ridley turtles are listed as endangered, while leatherback, green, hawksbill, and flatback turtles are listed as vulnerable.

In Australia it has been recognised that turtle bycatch in the longline fishery has become a significant issue affecting fisheries management (Robins, et al. 2002). Even though turtles are rarely caught, some

species are considered vulnerable to extinction. Capture of individual turtles may have negative impacts on the fishing industry, and, although turtle populations face other threats that outweigh mortality resulting from fishing operations where turtles are a bycatch, the reduction of mortality from all sources is important. It is estimated that the Australian pelagic longline fishery may incidentally catch around 400 sea turtles annually. One concern is that US trade regulations may require enactment of national laws to protect sea turtles if states want to export to the US.

There are two fisheries in the Australian Fishing Zone (AFZ) that use longlines to target tuna and swordfish, the Eastern Tuna and Billfish Fishery (ETBF) and the Southern and Western Tuna and Billfish Fishery (SWTBF). Both fisheries are managed by AFMA, which is advised by Tuna Management Advisory Committees, or TunaMACs. ETBF is advised by the Eastern Tuna and Billfish Management Advisory Committee (Eastern TunaMAC). Among other things, AFMA runs an observer program, collects daily catch and effort logbook data, and prepares annual data summaries. According to AFMA's data summary for the Eastern Tuna and Billfish Fishery for 2002—03 (Lynch 2003) a total of only 38 turtle interactions were recorded for the season. This included two green turtles, two hawksbills, 14 leatherbacks, two loggerheads, and 18 unspecified turtles. All were reported alive except for one leatherback. Fishing effort for the 2002—03 season was 13,535 sets totalling 12,691,921 hooks. The number of vessels operating in the fishery during the 2002—03 season averaged between 112 and 121. Similar numbers of turtle interactions occurred in previous seasons.

The ETBF incorporates the eastern part of Australia's Exclusive Economic Zone (EEZ) extending from the tip of Cape York in Queensland to the Victorian/South Australian border (Anon, 2003b). Major ports of the ETBF include Cairns, Mooloolaba (the base port for this project), Coffs Harbour, Forster/Tuncurry, Sydney, Ulladulla and Bermagui. The ETBF incorporates the fishing methods of pelagic longline, pole and minor line with pelagic longlining comprising by far the largest part of the effort and catch. Species targeted by fishers of the ETBF include yellowfin tuna, bigeye tuna, broadbill swordfish, striped marlin and albacore tuna (Jusseit & Robinson, 2003). Longliners of the ETBF generally set the gear at maximum depths of 20 and 100 m depending on what they are targeting, with gear occasionally set to depths greater than 150 m (Robins et al., 2002).

Longline vessels of the ETBF are between 15 and 30 m long and set between 200 and 2000 hooks per set (Anon, 2003b) with many vessels deploying 1000 hooks per set. Some vessels operate on the continental shelf (variable distance from shore depending on location) while others travel up to 800 nautical miles from the Australian mainland. Trips are generally three to nine days, although trips up to 20 days have become more common with the advent of larger capacity longliners targeting swordfish and bigeye in offshore grounds. The use of live bait is common among vessels targeting tuna, particularly in the more southern latitudes (eg. 30°—40°S (Bromhead & Findlay, 2003).

1.5 Pelagic longlining: shallow versus deep sets — targeting bigeye tuna

Modern pelagic longline fishing uses several hundred branchlines with single baited hooks hanging from a long nylon monofilament mainline. The line is suspended in the water by floats (buoys, bubbles) on floatlines (buoy droppers, bubble droppers), including floats with flagpoles, lights, or radio beacons. Longlines are usually set and hauled once daily and are allowed to drift freely, or soak, for several hours while fishing. Longlines are set as the boat steams away from the line and are hauled mechanically while the boat steams toward the line. A longline is made up of units or sections of line that are called baskets. They are called baskets because, on the early Japanese vessels, longline sections were stored on the deck in baskets. A basket of longline gear is the amount of mainline and branchlines in between two floats. A basket may contain as few as four or five branchlines or as many as thirty or forty. A branchline is a single line with a snap, or clip, at one end and a hook at the other. The entire longline might contain anywhere from 20 to 200 baskets, and consist of a mainline several nautical miles (nm) long. A typical longline set from a medium-scale longliner would be about 30 to 40 nm long and have about 1200 to 2500 hooks. A typical longline trip on a medium-scale longliner would last about one to three weeks and the line would be set about 6 to 12 times — once each fishing day (Beverly, et al 2003). Pelagic longlines can be set to fish at a variety of depths from the surface layer down to the

thermocline, depending on target species. Even deep-set lines, however, have a high percentage of their hooks — the ones nearest the floats — fishing in shallow water. With traditional Japanese gear, sag was put in the line by hand-throwing coils as the boat steamed (Beverly, et al 2003) so there was some variation in depth of set even when all other parameters remained the same. Since the 1970s longline fishing has evolved — a lot more has been learned about vertical distribution of main target species, relationships of catches to temperature and dissolved oxygen, thermocline depth, and other environmental factors (Hanamoto 1976, 1987, Boggs 1992, Campbell, et al. 1997, Uozumi, et al. 1997, Hampton, et al 1998, Bertrand, et al. 2002, Gunn and Hampton — in press), and actual depths and shapes of longline sets (Mizuno, et al., 1999, Anon 2001c). The introduction of time/depth recorders or temperature depth recorders (TDRs) and hook timers has given more detailed information about the actual depths achieved by longlines. The introduction of monofilament longline systems using mechanised line setters, or shooters, has allowed fishermen to increase and to control the depth of set by throwing line out at a controlled rate faster than the speed of the vessel. Formulas and tables have been written to provide fishermen guides to adjusting depth of set (Beverly, et al. 2003, Anon 1998, Anon 2001c), but basically, without the use of TDRs, it is difficult to know for sure the actual depth achieved because of environmental factors (Boggs 1992, Mizuno, et al. 1999). One thing has not changed, however. The basic shape of the longline has always been a catenary type curve — the shape taken on by a chain or cable suspended between two points and acted upon by gravity; and even with deep sets a substantial portion of the branchlines in the catenary curve remain at shallow depths.

Generally, longline gear fishing deeper in the water column is more effective in targeting bigeye tuna, probably due to the preference of bigeye tuna for 10–15°C water (Hampton, et al. 1998, Hanamoto 1987). Boggs (1992) reported that during tests conducted in Hawaii in 1990 most bigeye were captured at depths greater than 200 m. Prior to 1974, however, virtually all longliners operating in the Pacific set their hooks shallow. Deep setting was introduced around the latter part of 1974 and was quickly adopted by most vessels targeting bigeye tuna in equatorial Pacific waters (Suzuki and Warashina 1977). Suzuki and Warashina compared logsheet data from 265 vessels reporting on 9,945 fishing operations during 1974 and 1975. Typical Japanese longline gear consisted of a mainline (made from tarred polyester rope), branchlines, floatlines, and floats. Basket size was normally from four to six branchlines. With the adoption of deep setting, basket size increased to up to 15 branchlines. Vessels reported fishing about 2000 hooks per operation. Most gear components, aside from basket size, were more or less uniform. Floatlines were 30 m, branchlines were 20 m, and distance between branchlines was 50 m. It was inferred that the gear with more branchlines per basket fished deeper — gear with more than ten branchlines per basket was considered to be deep gear. Hook depths were not measured directly but by assuming a catenary curve shape of the line. A basket with six branchlines was assumed to fish at 170 m while a basket with 13 branchlines was assumed to fish at 300 m (Figure 1). It was also assumed that currents would shorten assumed depths by 30 to 50 m. Bigeye catch rates were better on the deep sets and catch rates for all other species (tuna as well as billfish) decreased with deep sets (Table 1 compares deep sets to regular sets). The table shows the ratios of catch rates of deep longline over regular longline. The smaller the ratio, the more surface dwelling a species is. The chart indicates that bigeye catch is almost doubled by setting deep and that some byproduct and bycatch species catch rates are halved.

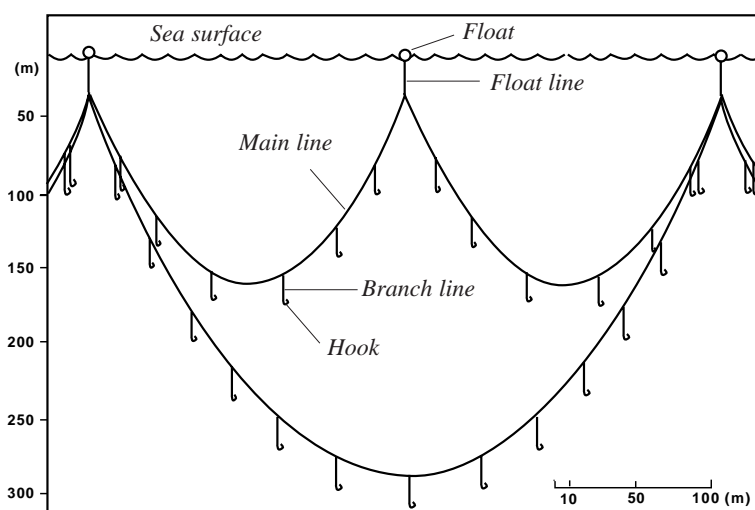


Figure 1: Catenary curves of regular longlines with 6 branchlines and with 13 branchlines per basket (Suzuki and Warashina 1977).

Table 1: Ratio of average catch rate by deep longline over average catch rate by regular longline for various species of tunas and billfish taken by longline gear (from Suzuki and Warashina 1977).

Species	Deep/regular
Sailfish	0.07
Striped marlin	0.28
Black marlin	0.34
Blue marlin	0.56
Yellowfin tuna	0.73
Broadbill swordfish	0.79
Albacore	0.82
Bigeye tuna	1.79

Since the advent of deep setting, some fleets have reverted back to shallow setting. There is a distinction between the Chinese and Taiwanese fleets that fish shallow sets mostly around Micronesia, and the Japanese fleet that fishes deep around Solomon Islands in the WCTO (SPC 2001). The Chinese and Taiwanese fleets fish during a two-week period, one week on either side of the full moon, generally setting at night and targeting bigeye tuna. Longliners targeting broadbill swordfish use roughly the same strategy — shallow night sets using squid bait and lightsticks and fishing around the full moon. The Japanese fleet targeting bigeye tends to set their gear deep and let it soak during the day. The longline fleet operating in the Eastern Tuna and Billfish Fishery in Australia has, for the most part, adopted the strategies of the Taiwanese fleet and the swordfish fleets from Hawaii and elsewhere. A typical pelagic longline in the Australian fishery may be set at varying depths ranging from 50 to 150 m and have from six to eight hooks between floats (Anon 2001a). Archival tag data have shown that bigeye tuna spend the highest proportion of time at 11—15°C and 350—500 m during the day and at 24—28°C and at depths in the upper 100 m during the night (Gunn and Hampton — in press). The Taiwanese, Chinese, and Australian fleets take advantage of the night time behaviour of bigeye tuna, especially during full moon periods, while most other fleets seem to fish during the day at greater depths with no regard for moon phase.

In normal setting practices, whether deep or shallow, theoretical depth of the deepest hook in a basket can be calculated (Beverly, et al. 2003) and the depth of set can be controlled. The best way to regulate the depth of the set and to achieve a deep set is to use a line setter. A line setter throws out the mainline at a greater speed than the boat is travelling. That way there will be a curve, or sag, in the line between the floats. The branchlines will not be at a uniform depth but most will be at a depth greater than the length of the floatlines. The curve, or sag, of the longline is a function of the speed of the boat, the number of branchlines per basket, and the rate at which the line setter deploys the line. The length of the floatlines and the length of the branchlines also determine depth of the hooks but these dimensions do not change so can be added on after calculating the theoretical depth of the catenary curve. However, the true depth will be less than the calculated depth because of currents pushing the floats together, pulling them apart, or pushing up or sideways on the mainline (Boggs 1992, Mizuno, et al. 1999).

To calculate the theoretical depth of the mainline, you need to know the speed of the boat and the speed of the line being ejected by the line setter. The ratio of these two speeds is called the sagging ratio, or SR, and is a dimensionless number (a number without length, weight or time). SR can also be expressed as the ratio of the distance the boat travels to the length of line ejected by the line setter during the same period. For example, if the speed of the boat is 8.3 knots and the speed of the line being ejected by the line setter is 10 knots, then the SR is $8.3 \text{ kn} \div 10 \text{ kn} = 0.83$. The same ratio could be derived by comparing the distance that the boat travels between two floats (1000 m for example) to the length of line between the two floats (1200 m for example). $1000 \text{ m} \div 1200 \text{ m} = 0.83$. Once the SR has been calculated, the depth of the deepest hook on the line can be determined.

There is more than one way to determine the speed of the line being ejected by the line setter. There are line-setting timers that give line speed readout in nautical miles per hour (kn)

(www.linemaster.com.au). Alternately, a hand held tachometer can be used to determine the speed, in revolutions per minute (RPM), of the large drive wheel of the line setter. As the line passes directly over the drive wheel, the amount of line ejected in one minute is equal to the circumference of the drive wheel in metres times the RPM. To find the speed of the line in kn you need to divide this number by 31 (there are 1852 m/nm, $1852 \div 60 = 31$, or 31m/min). For example, if the line setter drive wheel speed is 400 RPM and the drive wheel circumference is 0.785 m – multiply $0.785 \text{ m} \times 400 = 314 \text{ m}$. The line setter would eject 314 m of line each minute. Dividing this number by 31 gives a line speed of 10 kn.

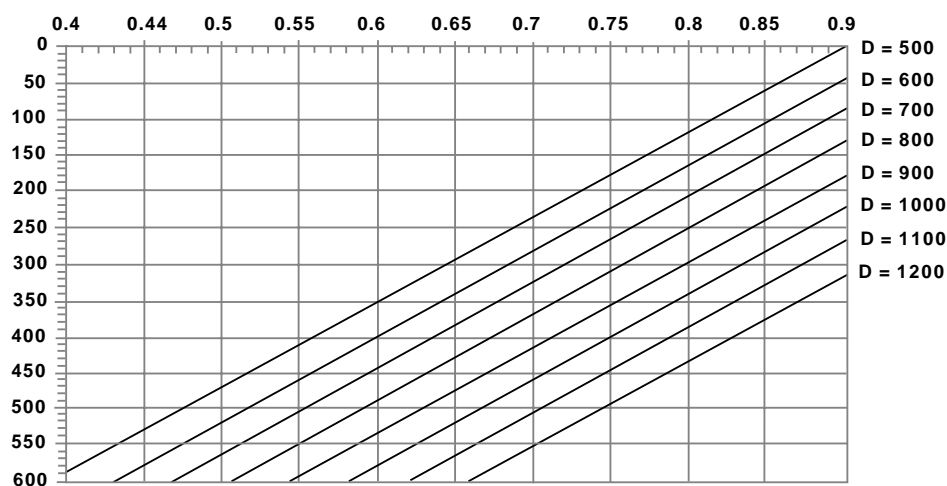
The ratio between the boat speed and the line speed in the example above is $8.3 \text{ kn} \div 10 \text{ kn}$, or 0.83, which can be rounded off to 0.8. This is the SR. The depth of the curve can be found on a table of pre-calculated depths based on numerous SRs and numbers of hooks in a basket. Table 2 gives theoretical depths for six SRs against five different basket sizes. These depths were calculated on the assumption that the distance between branchlines — and branchlines and floats — is always 50 m. Note: the calculated depths in Table 2 have been reduced by 20 per cent.

Table 2: Theoretical depths of curve of mainline based on different sagging ratios (SR) and basket sizes (Beverly et al. 2003).

Basket size	SR 0.4	SR 0.5	SR 0.6	SR 0.7	SR 0.8	SR 0.9
10	200	190	175	155	130	95
15	290	275	255	230	190	140
20	385	365	335	300	250	185
25	475	450	415	370	310	230
30	570	535	495	445	370	270

In the 1990s the French Polynesia government promoted a program to support the growing longline fishery there, which had boomed from eight vessels in 1991 to 60 vessels by 1997 (Anon 1998, Anon 2001c). One of the goals of the program — called — ECOTAP, was to develop a method that would allow fishermen to set their longlines at specific depths to enhance target CPUEs. The project refined work done earlier by Suzuki and Warasinia (1977) and others by using TDRs to measure actual depth of set. Results from experiments showed that distance between floats and sagging rate were the key factors in determining depth of set. The ECOTAP team produced a table (Table 3) that shows different depths for different distances between floats and different sagging rates. Results from the field tests using the method showed that deepest branchlines were reaching depths of 440 to 660 m and yielding nominal CPUEs of 57 kg/100 hooks. Yields for albacore tuna were similar to those of the commercial fleet but bigeye tuna yields were 20 times greater than those of the other longliners in the fleet. Note, however, that even with deep sets targeting 400 m, 10 per cent of the branchlines in the ECOTAP study were shallower than 100 m and only about 50 per cent of the branchlines in a basket were at depths of over 300 m. Conclusions were that the method for determining depth of set was effective and could be useful to fishermen for targeting appropriate depths to increase CPUEs and to decrease bycatch.

**Table 3:
Determining
depth of set.
Right-hand
side is distance
between floats,
top is SR, left-
hand side gives
depths. From
ECOTAP
(Anon 2001c).**



Attempts have been made in the past to target bigeye using other methods besides adjusting the sag in the line — such as using longer floatlines, using lead weights attached to middle of each basket, or by attaching branchlines only on the deepest portion of each basket — with mixed results. One fisherman operating out of Pohnpei, FSM, tried using 100 m long monofilament floatlines (pers. comm. from Mark Tickell). He had to install hydraulic leader carts on the boat just for winding in the floatlines. Eventually the idea was abandoned as it was deemed to be unmanageable. The long floatlines would

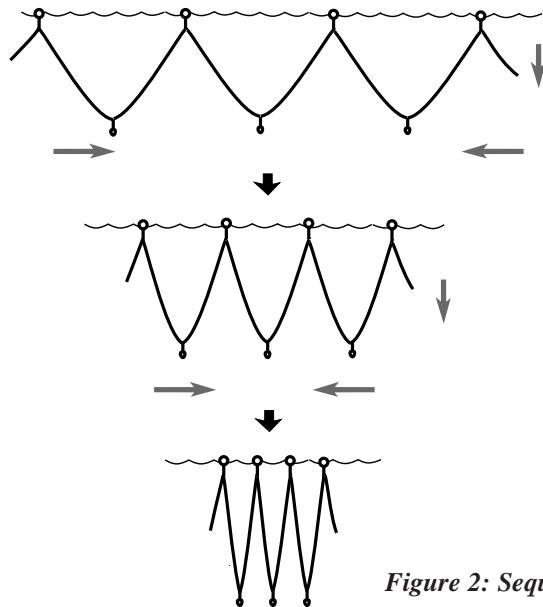


Figure 2: Sequence showing collapse of weighted longline.

tangle with the mainline during hauling and, even when they weren't tangled up with the mainline, they were difficult to haul when trailing 100 m behind a moving boat. A technique has been tried using lead weights in the middle of each basket (pers. exper. of author). Attaching a three kilogram lead weight in the middle of 30 hook baskets proved to be successful in Hawaii in increasing bigeye catches in the early 1990s. However, there was one basic problem encountered in the technique. The weights would continue to sink all during the soak, pulling the floats together and causing the line to collapse (floats come together) resulting in huge tangles (Figure 2). Even without line collapse, many of the hooks in the basket would still be fishing shallow.

Some Indonesian longline fishermen targeting bigeye tuna altered their fishing techniques by attaching branchlines only to the deepest part of the catenary curve (Whitelaw 2000). TDR data showed that there was still a lot of hook movement through the water column. The Indonesians fished during the day with this technique.

Some fishermen operating out of Hawaii and fishing mostly on seamounts have adopted a technique of weighting a very short longline down to the tops of the seamounts, effectively fishing for bigeye tuna with a horizontal bottom longline (pers. comm. from David Itano). The technique is actually similar to the technique described in this report but on a smaller scale. Reportedly, the fishermen have been very successful in not only capturing bigeye tuna but also commercial quantities of the lustrous pomfret (*Eumegistus ilustris*).

None of the above techniques were designed to mitigate bycatch encounters. All were designed to enhance target species CPUEs and most had a certain degree of success. Increasing the sag to get the line deeper works to increase target species CPUE but does not eliminate shallow water bycatch encounters. Using lead weights in the middle of the basket also works but causes problems with line collapse, and still leaves many hooks in shallow water. Using very long floatlines eliminates some bycatch while enhancing target species CPUEs, but it is not a feasible technique due to technical problems. Eliminating the hooks nearest the floats works to enhance target species CPUE but there is little control over actual depth of set. Modifying a pelagic longline to resemble a horizontal bottom longline seems to have the most promise.

2. New deep setting technique

After the events that led to the restrictions and closures placed on longline fishing in Hawaii, it was clear that scientists, fisheries managers, and fishermen needed to find solutions, probably through gear development, to find out if a sustainable tuna and swordfish longline fishery could survive while not jeopardizing the survival of other marine species. To this end, in 2003 a new technique for setting longlines to mitigate bycatch and enhance target species CPUEs was proposed (Beverly 2003). The

proposed technique uses lead weights suspended by paired floats at depths below where most bycatch encounters occur. Portions of the mainline are effectively used as very long floatlines, suspending the entire fishing portion of each basket at depth. No additional long floatlines are needed and there is little danger of line collapse, as each lead weight is suspended by a float directly above it. Additionally, since the line is weighted, there is more certainty of the actual depth of the fishing portion of the longline, and less hook movement in the water column.

A project to trial this technique was carried out by SPC with help from SeaNet and the commercial longline fleet operating out of the east coast port of Mooloolaba, Queensland, Australia. The project was funded by AFMA, with in kind contributions from SPC and the vessel owners. Fishing trials took place during April and May 2004.

2.1 Objectives

The objectives of the project were:

- To demonstrate that tuna and swordfish longlines can be set and hauled effectively at prescribed depths below the deepest depth of the mixed layer in the fishing area and down to the top of the thermocline. In other words, to demonstrate that this setting technique can land all baited hooks in a zone below where most unwanted bycatch species such as sea turtles, certain billfish and gamefish species, and sharks are normally hooked;
- To demonstrate that this setting technique will enhance the CPUE of bigeye tuna and day swimming broadbill swordfish;
- To perfect the parameters of the setting technique so that the technique can be easily duplicated by other vessels in the longline fleet; and
- To conduct the trials side-by-side with usual fishing practices, either from the same vessel or from another vessel, and to compare project results with historical results from the same fishery.

2.2 Methodology

In order to set the entire line deep without using very long floatlines, normal floats and floatlines were used in pairs separated by a blank section of mainline with no baited branchlines for a distance of 50 m. The section of mainline that holds the baited branchlines was suspended directly under these floats and was weighted down at each end by a three kilogram lead weight attached to the mainline by a standard snap. The distance between the normal floats and floatlines and the lead weights was the target depth for the shallowest hooks in the basket — 100 m for example. Therefore, portions of the mainline acted as long supplementary floatlines. These portions of the mainline being used as supplementary floatlines were hauled the same as the mainline. All parameters, such as target depth of shallowest hooks, were simple to change and the only new gear needed was lead weights (two for each basket) with lines and snaps, additional floats and floatlines (double the usual number), and additional mainline (increased by 25 per cent). All other fishing gear remained the same as the boats normally used.

The new deep setting technique eliminated the problems encountered with previously tried techniques. There were no cumbersome 100 m long floatlines to haul and store; and the mainline did not collapse as with the technique that used lead weights suspended in the middle of each basket. It was still possible, however, that the mainline could collapse due to currents pushing the two ends of the line together — as this happens occasionally even with unweighted longlines — but line collapse did not occur during the project.

The experimental longline was set as follows: First, line setter speed and boat speed were determined based on SR for the basket size and depth being used, and the boat was put on course. After the first

radio buoy was deployed, a float with normal floatline was attached to the mainline and thrown. The mainline was being paid out at a rate slightly faster than the speed of the boat. After 50 m of line was paid out, a second float was deployed. Then 100 m, or more, of mainline was paid out in the same manner, depending on target depth of shallowest hook. This section of mainline acted as supplementary floatline. The lengths of these sections were metered using the line-setting timer. Some line setting timers can be set to give a beep at linear intervals of, say, 50 m. This is the easiest approach. Otherwise, if a time interval is used, the length of line ejected in that time has to be calculated. For simplicity, in either case, an interval of 50 m is best. Therefore, one beep of the line setting timer equaled 50 m, so there was one beep between floats and two beeps between the second float and the first lead weight (if 100 m was the target depth). After the first weight was deployed, baited branchlines were attached to the mainline in the normal fashion. After 12 to 20 branchlines (one basket) had been deployed, a second lead weight was attached to the mainline. The second lead weight was attached at the beep normally used to signify a float, ie, the end of that basket. A float was attached after two more beeps and a second float on the next beep and the whole process was then repeated.

TDRs were used on the experimental baskets to determine actual depth of the line. TDRs were purchased from an Iceland company, Star-Oddi (www.star-oddi.com). The data loggers came with a hard silicon protective housing. Before using the TDRs they had to be rigged with wire leaders and swivel snaps, and with a snap to retain the data logger in the housing. The Star-Oddi TDRs have a temperature range of -1 to 35°C , a depth range of 0.5 to 600 m, and are capable of recording 43,582 measurements. Battery life is five years and the clock operates in real time.

Sagging rate — or the ratio between the distance the boat travelled for one basket and the length of line paid out for one basket — needed to be calculated. Sagging rate was calculated the same way sagging rate is calculated for a normal longline set except that the expected shape of the line from float to float was rectangular rather than a simple curve. Sagging rate was based on target depth of shallowest hook, distance between hooks, distance between the paired floats, and basket size. Sagging rate was easy to calculate but would be different for each target depth of shallowest hook and for different basket sizes. Total distance travelled by the boat for each basket was equal to total length of line paid out minus twice the depth. Total line paid out for each basket was equal to the length of line in the basket (the portion with branchlines attached) plus twice the depth plus the distance between the two floats at the end of the basket. The ratio of these two numbers — length of line paid out and distance travelled by the boat — gave the sagging rate. For example, if the target depth of shallowest hook was 100 m and there were 20 hooks in a basket with 50 m intervals, then the boat travelled $1050\text{ m} + 50\text{ m} = 1100\text{ m}$. The length of line paid out was $1100\text{ m} + 2 \times \text{depth}$, or 1300 m . Therefore, the sagging rate was $1100\text{ m}/1300\text{ m}$, or 0.85 (Figure 3).

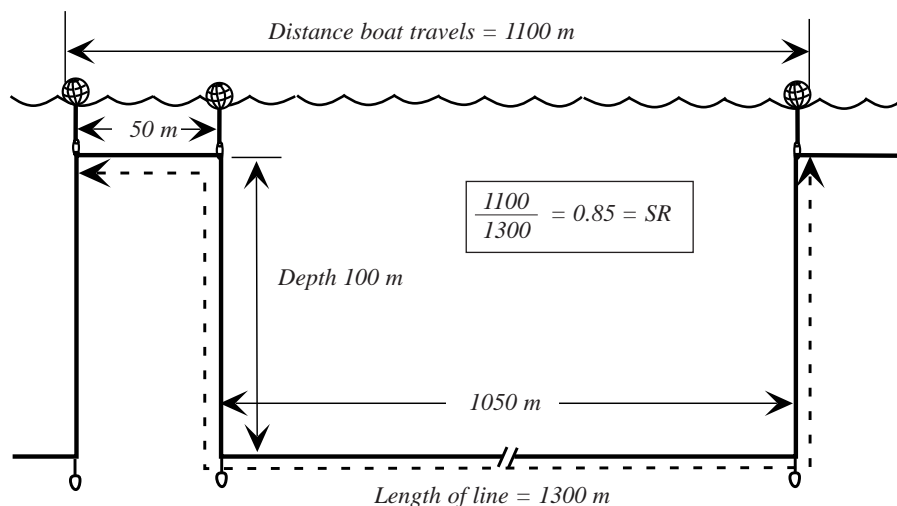


Figure 3: Calculating sagging rate for one basket using the deep setting technique

Once sagging rate had been calculated, boat speed and line setter speeds were adjusted. In the above example, if line setter speed was 10 kn then boat speed was set at 8.5 kn — in order to achieve a sagging rate of 0.85 and to eject ample line to get the line to settle as planned. Theoretically, if all parameters were followed then there shouldn't have been much sag in the fishing part of the line

between the two lead weights. The basket of line should have taken on a roughly rectangular shape with the fishing portion of the line lying parallel to the surface. In reality, however, during trials it was found that considerable sag still occurred between the lead weights. Therefore, the line actually fished at a variety of depths, but all below the target depth of shallowest hook*. If necessary, more sag could have been put into the fishing portion of the line by decreasing boat speed or by increasing the number of hooks in a basket, as with normal setting.

It was assumed that as the line settled and the lead weights sank, that the paired floats would be stretched apart and the fishing portion of the basket would be stretched as well, both a result of the pendulum action of the sinking lead weights (Figure 4). As the long floatline portions of the mainline supporting the lead weights became more and more vertical, the entire line would become more and more taught, finally arriving at the shape depicted in the last section of Figure 4.

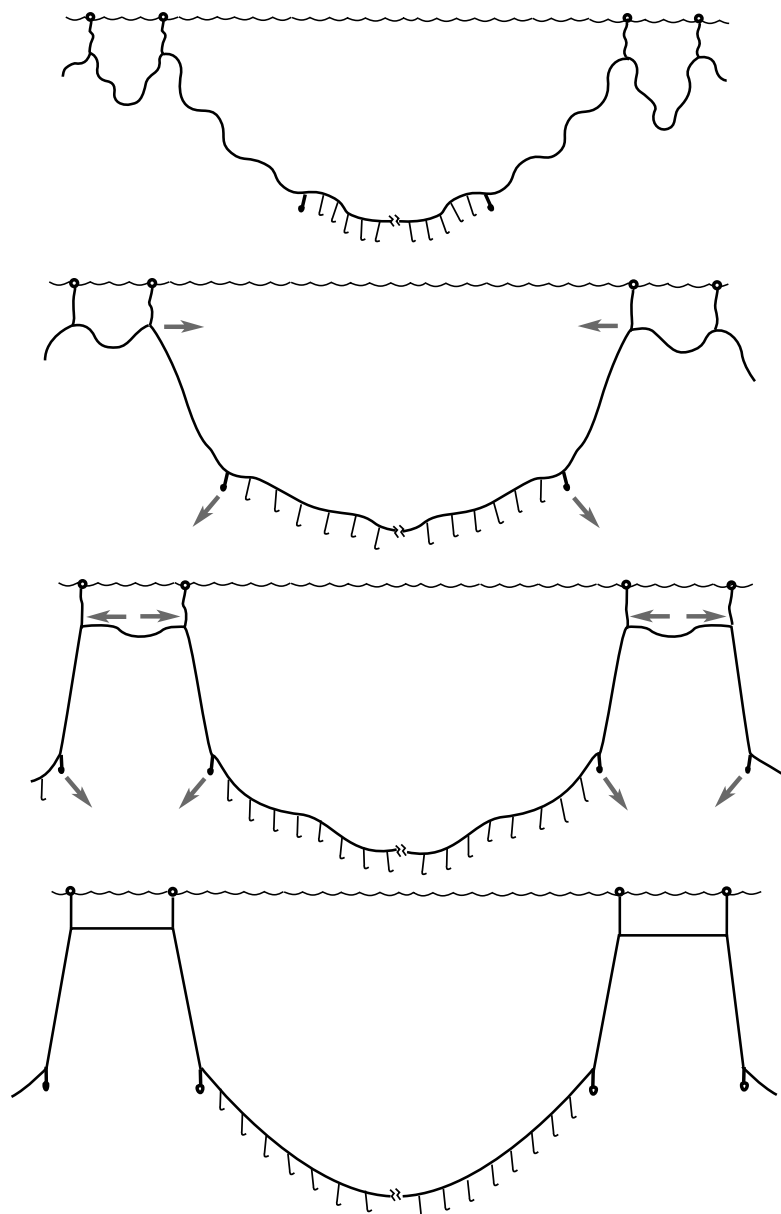


Figure 4: Settling sequence of weighted longline.

* Actual depth of the shallowest hook will be target depth plus the length of the floatline suspending the mainline, plus the length of the branchline — if the branchline sinks vertically — plus the sag between the lead weight and the first branchline. Thus, for a target depth for the shallowest hook of 100 m using 10 m floatlines, the line will actually reach 110 m. If the branchlines are 24 m long and they sink vertically, then the shallowest hook would be at 134 m or more, depending on sag. To eliminate complications in describing the new deep setting technique, target depth of shallowest hook in this report refers to the distance between the attachment point of the floats and the attachment point of the lead weights as in Figure 3 above.

2.3 Fishing trials

2.3.1 Results: F/V Blue Moves

Between 30 March and 06 April a total of seven sets were made in coastal waters along the continental shelf around 29°S and 154°E. Each set consisted of 1000 hooks baited with *Illex* spp. squid with a light stick on every other branchline. Sets were made generally just on or after sunset and hauls were made the following day starting in the morning. Fishing was generally terrible. A total of 7000 hooks yielded only 51 saleable fish (not counting numerous *Escolar* spp. that were retained but are of low value). The catch consisted of 14 yellowfin tuna, two bigeye tuna, 27 mahi mahi, three swordfish, and five albacore weighing approximately 1.5 mt. This would have been a good catch for one or two sets, but for seven sets was a disaster.

Unfortunately, poor catches like this had been typical for the Mooloolaba fleet for the previous six months. The fishery was in a near state of collapse. Low catch rates combined with weak market demand in Japan, high value of the Australian dollar, increased operating costs (bait, fuel), and increased licensing costs were causing peril to the fishery. Banks had already repossessed five longliners and were hovering over several others (Clark 2004). Many boats were tied up, inactive until conditions improved. In hindsight, this was probably not a good time to be conducting a longline project where favours were needed from boat owners and captains.

On a more positive note, the deep setting technique worked fine. Project baskets were set on three of the seven sets, two using the line setter and one without using the line setter. The boats normal technique was to set without the line setter, doing a typical swordfish type set (shallow night set around the full moon using squid and lightsticks). Baskets had twelve hooks each. Branchlines were long at 24 metres while floatlines were relatively short at 10 metres. Floatlines were all polypropylene. No leaded swivels were used on the branchlines, which consisted of two sections of 1.8 mm monofilament, 18 m and 6 m, separated by a Futaba swivel. Hooks varied from 3.6 stainless steel Japan tuna hooks to 16/0 tuna circle hooks. Most of the boats viewed by the Principle Investigator fishing out of Mooloolaba had similar gear, including F/V *Diamax*.

During the project sets, basket size was kept at 12 hooks but the setting sequence was changed for the weighted baskets. Each beep of the line setter beeper indicated 50 m of line had been paid out. This had been determined by measuring the speed of the line setter using a hand-held tachometer and then calculating line speed. The line setter ran at 400 RPM and had a drive wheel circumference of 0.785 m. Therefore, line was ejected at 10 kn ($400 \text{ RPM} \times 0.785 \text{ m} = 314 \text{ m/min}$ and $314 \text{ m}/31 \text{ m/min} = 10 \text{ kn}$). With a line speed of 10 kn it was determined that a beeper interval of 10 seconds would be equivalent to approximately 50 m of line. Floats were attached one beep apart (50 m), weights were attached after two beeps (to achieve a depth of 100 m), twelve hooks were then attached at 50 m intervals, another weight, two beeps, and two more floats, etc. To achieve the needed sag in the line, boat speed was set at 7.5 kn. This gave an SR of 0.75, which would allow 850 m of line to be ejected for every 650 m the boat travelled. TDRs were attached at both ends and at the middle of each weighted basket to monitor depth of set. The TDRs were set to record every ten minutes. TDRs were also put on some normal baskets for comparison (Figure 5).

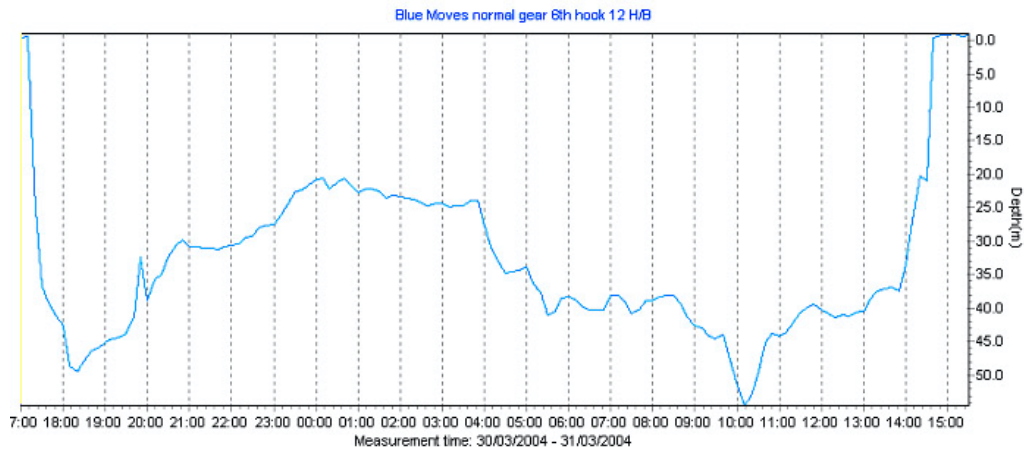


Figure 5: Depth graph showing 6th hook position in a normal 12 hook basket without using the line setter. Average depth of hook was about 40 metres (depth changes were thought to correspond to tidal currents, which are on five to six hour cycles along the east coast of Australia).

Results from the weighted gear were generally good. Actual depths corresponded to target depths for the shallowest hooks of 100 m on the sets using the line setter (Figure 6). The gear was a little cumbersome to set at first but hauling went without difficulty. In fact, the line came up very easily as it was made taught by the weights. The middle hook position sank deeper than the end hook position (Figure 7).

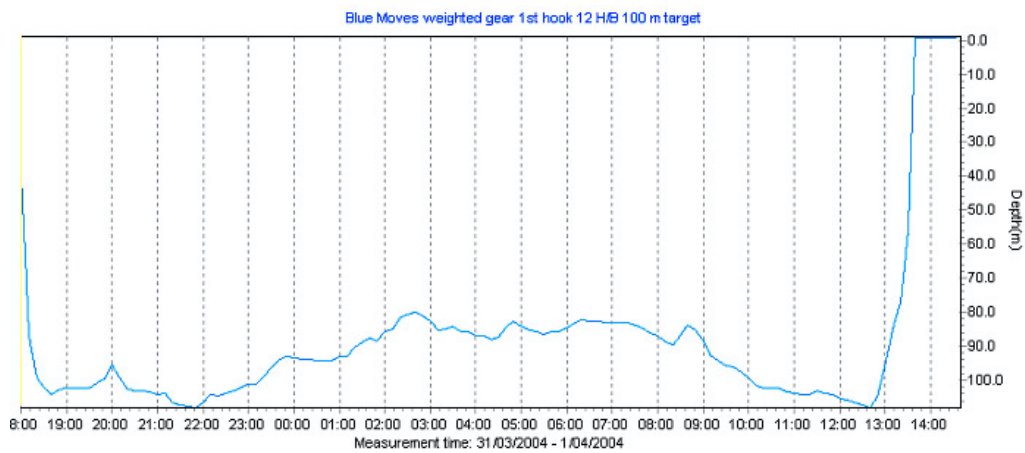


Figure 6: TDR graph for 1st hook in a 12 hook basket using lead weights with a target depth for the shallowest hook of 100 m using the line setter. SR was 0.75. Average depth of hook was about 95 metres

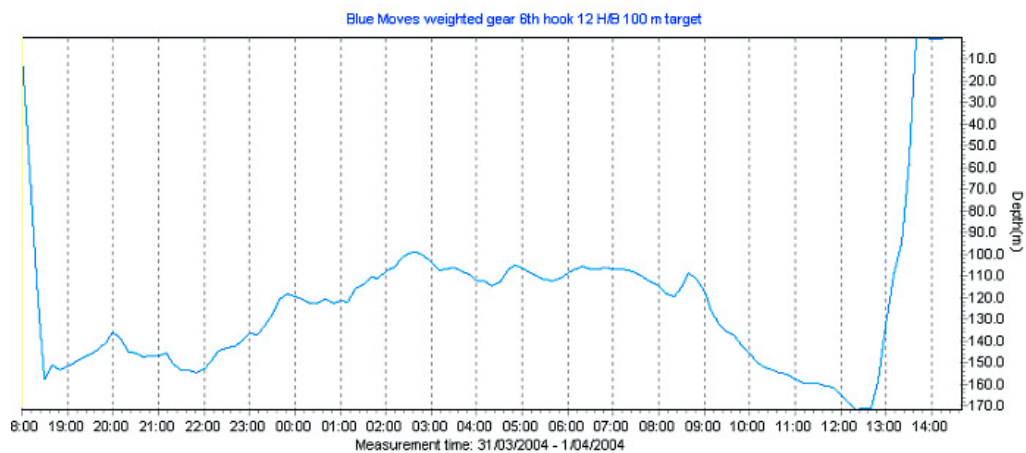


Figure 7: TDR graph for 6th hook in a 12 hook basket using lead weights with a target depth for the shallowest hook of 100 m using the line setter. SR was 0.75. Average depth of hook was about 140 metres.

Results from the set using lead weights but without using the line setter showed that weights have almost no effect on sinking the mainline if there is no sag put into the line (SR is 1.0). The line initially sank to 45 m but came back up to 25 m with the stretch and spring back of the line (Figure 8). Therefore, the deep setting technique did not work without using a line setter.

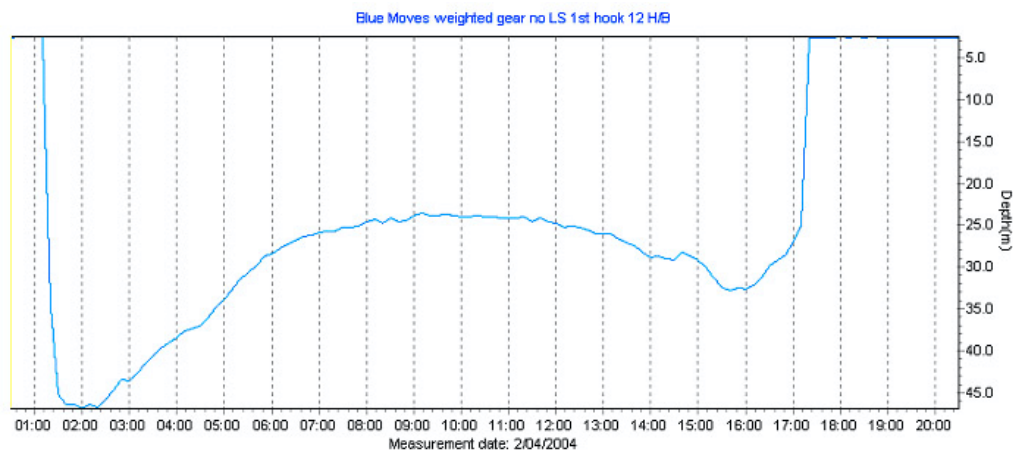


Figure 8: Depth graph for 1st hook in a 12 hook basket using lead weights with a target depth of shallowest hook of 100 m but without using the line setter.

The trip on F/V *Blue Moves* was considered to be a shakedown cruise to work out any bugs in the deep setting technique. Some modifications were made to the gear after the first set. The lines on the lead weights were shortened to one-half metre and the lines on the TDRs were shortened as well. This made the setting sequence much easier on the third set. It was determined that 50 m between floats was sufficient to avoid tangles with the portions of mainline acting as floatline. Also, the technique of using the line setting timer to regulate depth was initiated.

2.3.2 Results: F/V Diamax

21/04 — F/V *Diamax* got underway at 1050, heading northwest. After three days of travel two sets were made around 18°S and 155°E without much luck. The first set was 800 hooks with 20 hooks per basket but without using the deep setting technique. This was a training session for the crew. The bait was *Illex* spp. squid with no lightsticks. TDRs showed a range of depths for the gear. On the first basket with TDRs the line was at 25 m on the ends and about 200 m in the middle of the basket.

Lead weights were attached on the second set on 23 baskets with 20 hooks per basket. The target depth for the shallowest hooks on the weighted gear was 150 m. The remainder of the line was also set with 20 hooks per basket but in the normal fashion. A total of 1000 hooks were set. TDRs showed the normal gear to be at 40 m on the ends and 200 m in the middle of the basket (Figures 9 and 10).

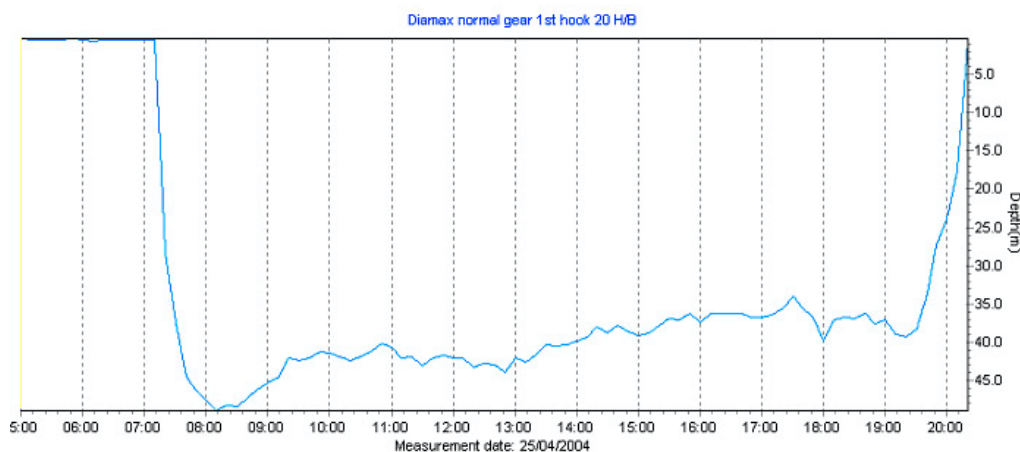


Figure 9: Depth graph for 1st hook in normal basket with 20 hooks. Average depth of hook was about 40 metres.

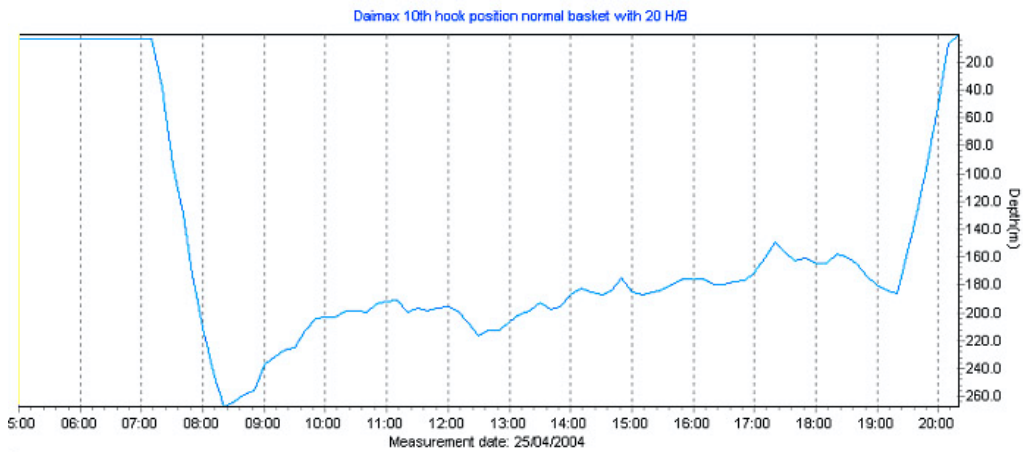


Figure 10: Depth graph for 10th hook in normal basket with 20 hooks. Average depth of hook was about 200 metres.

The weighted gear sank to 160 m on the ends and 300 to 350 m in the middle of the basket (Figures 11 and 12).

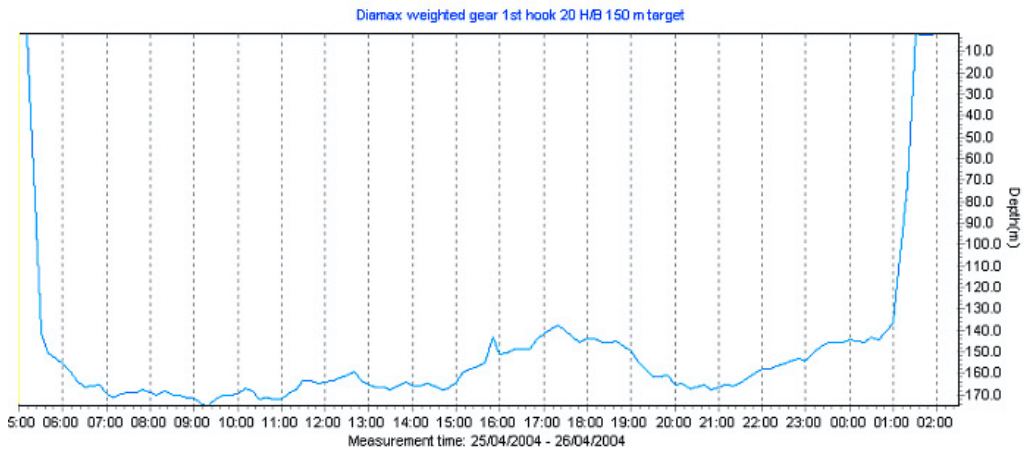


Figure 11: Depth graph for 1st hook in weighted basket with 20 hooks and target depth of shallowest hook of 150 m. Average depth of hook was about 160 metres.

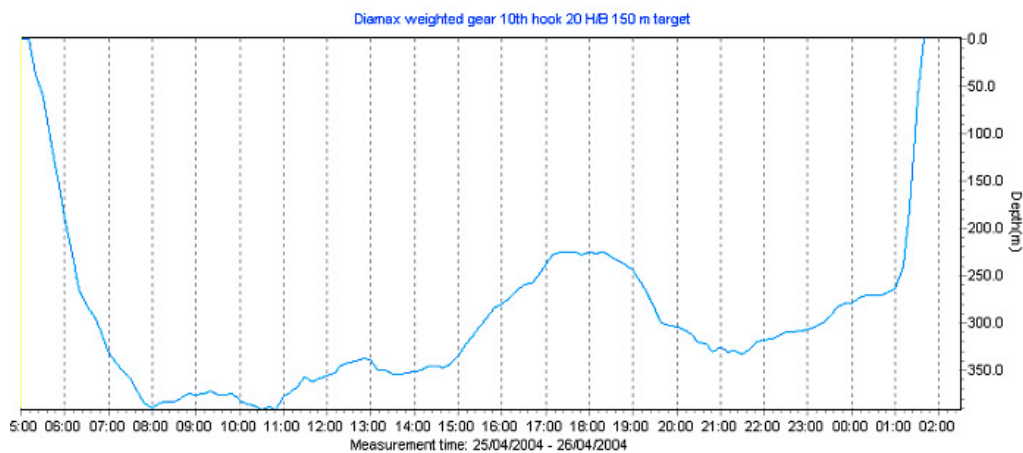


Figure 12: Depth graph for 10th hook in weighted basket with 20 hooks and target depth of shallowest hook of 150 m. Average depth of hook was about 325 metres. Note that there was more vertical movement than on the 1st hook position.

A decision was made to head south after the poor fishing in the north. A temperature break was identified using the on-board real-time altimetric charts from MaxSea (www.maxsea.com). The remaining five sets were carried out around 23°S and 156°E fishing between the 24 to 25°C surface

isotherms. Fishing improved a great deal so no further movements were made other than slight adjustments. On each set, 400 hooks in 20 hook baskets were set using lead weights while 600 hooks were set using normal gear configurations in 10 or 20 hook baskets. The setting sequence was altered each day so that weighted baskets were set first, last, alternately, or in the middle of normal baskets. TDRs were put on both types of baskets. A decision was made to keep the target depth of the shallowest hook at 100 m, knowing that the sag would get the middle of the baskets deeper. Figures 13 and 14 show the first hook and middle hook depths for a weighted basket with 20 hooks per basket and a target depth for the shallowest hook of 100 m. Sagging rate for the set was 0.85. Figure 15 is a schematic diagram of the theoretical shape of that basket.

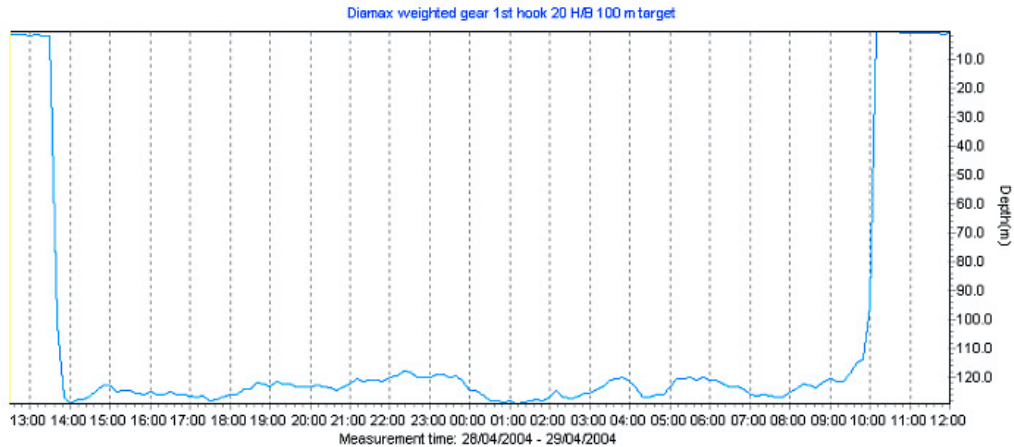


Figure 13: Depth graph for 1st hook in weighted basket with 20 hooks and target depth for shallowest hook of 100 m. SR was 0.85. Average depth of hook was about 120 metres.

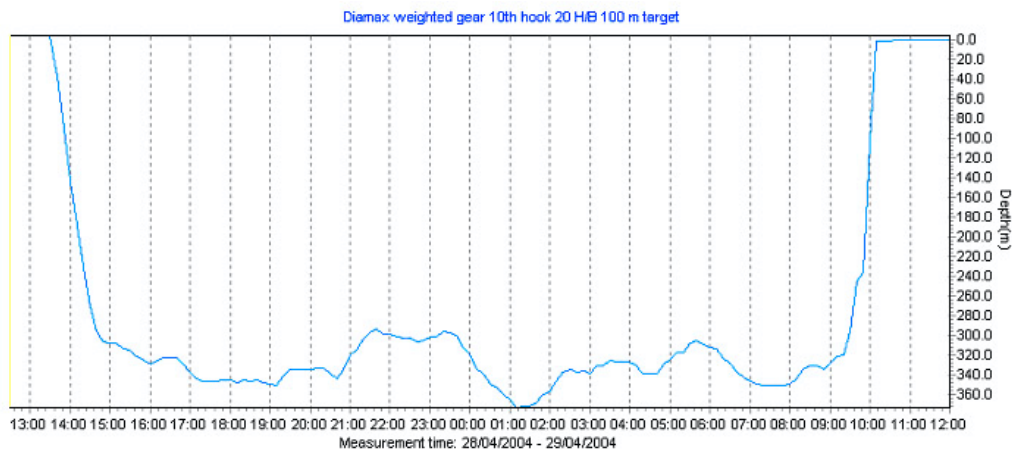


Figure 14: Depth graph for 10th hook in weighted basket with 20 hooks and target depth for shallowest hook of 100 m. SR was 0.85. Average depth of hook was about 340 metres..

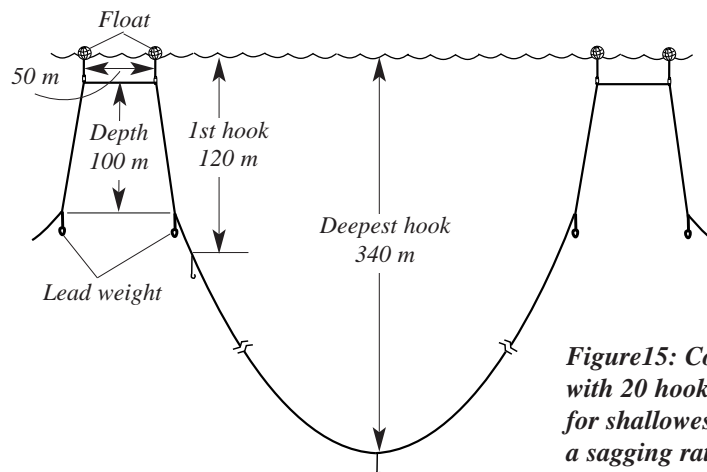


Figure 15: Configuration of weighted gear with 20 hooks per basket and target depth for shallowest hook of 100 m using a sagging rate of 0.85.

A large swordfish (188 kg H&G) was caught on the same set depicted in the TDR graphs above. Fortunately, there was a TDR attached adjacent to the branchline that was taken by the swordfish. Figure 16 shows depth (130 m) and bite time (1715) for a daytime swordfish bite.

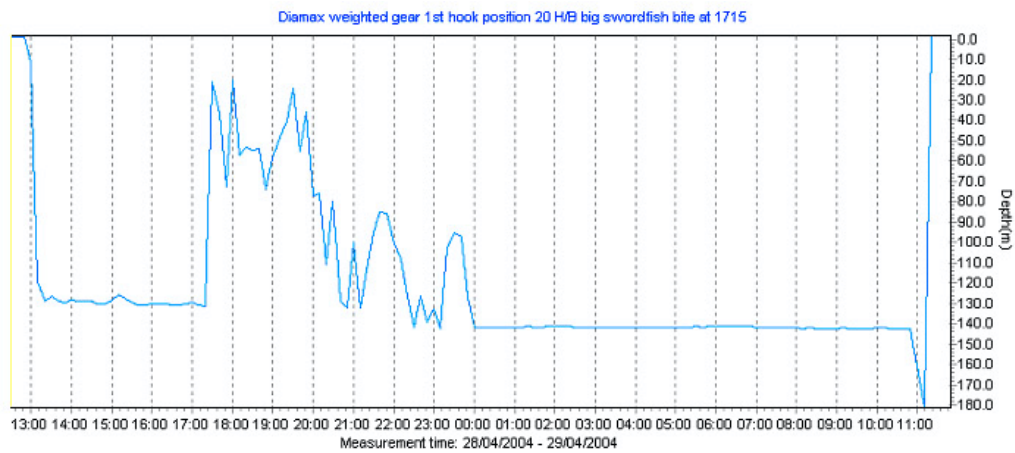


Figure 16: Depth graph for 1st hook in a weighted basket with 20 hooks and target depth for shallowest hook of 100 m. The spike at 1715 and 130 m indicates a swordfish bite. Presumably the fish died at midnight.

Several bigeye tuna were caught on the weighted gear. Often TDR data showed spikes indicating depth and time of bite. For example, Figure 17 shows time, depth, and temperature for a bigeye bite.

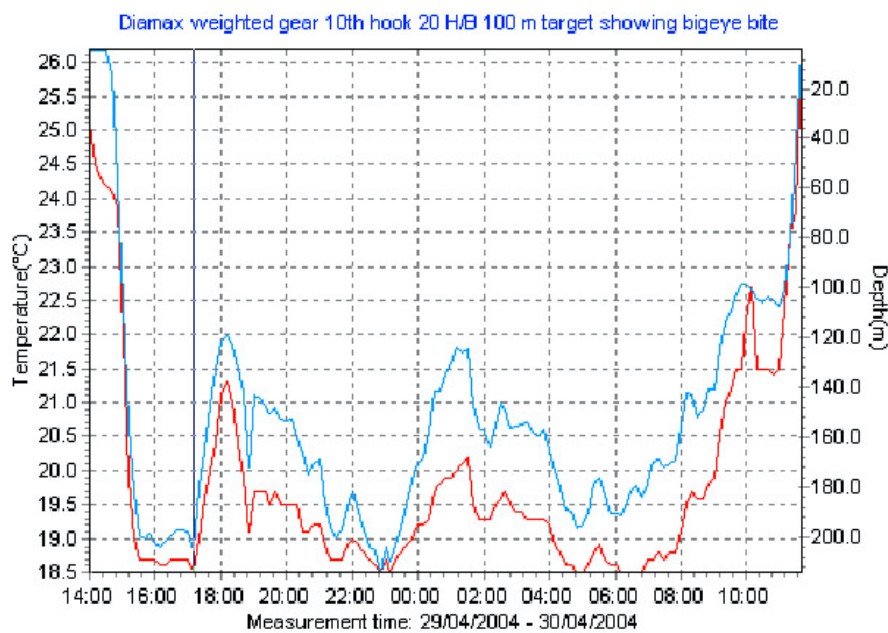


Figure 17: Temperature/depth graph for 10th hook in a weighted basket of 20 hooks and a target depth for shallowest hook of 100 m. The spike at 1715 indicates a bigeye tuna bite. Depth was 200 m and temperature was 18.5°C. Blue line (upper) is depth, red line (lower) is temperature.

As hook depth was the main concern during this project, temperature lines have been omitted from most of the TDR graphs above. As an aside, the relationship between temperature and depth in Australian waters along the east coast seems to be almost linear (Campbell, et al. 1997). In other words, there isn't much of a thermocline and temperature drops relatively evenly with depth. This is indicated in figure 18, where the temperature line follows the depth line on the TDR graph very closely.

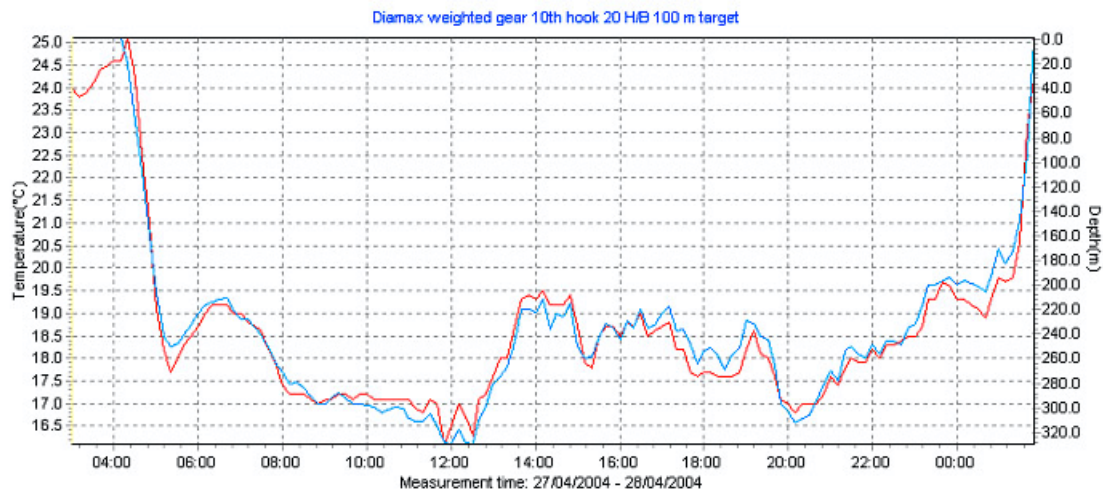


Figure 18: Temperature/depth graph for 10th hook in a weighted basket of 20 hooks and a target depth for shallowest hook of 100 m. Blue line is depth, red line is temperature.

The setting sequence for the project gear was very easy to control. F/V *Diamax* was equipped with a line setter readout connected to a Linemaster setting timer (www.linemaster.com.au). The timer gave a read-out in kn for the line setter speed and could be set so the beeps occurred at 50 m intervals. A separate beep came up to indicate that it was time to throw a float (or a radio buoy, which had a different sounding beep). For a 20 hook basket the line setter was adjusted to run at 9 kn while the setting timer was set to beep at 50 m intervals and number of beeps per basket was set at 26. Boat speed was set slightly less than line setter speed at about 7.7 kn to give a sagging rate of 0.85.

The setting sequence went like this: at the end of a basket a lead weight was thrown at the beep normally used for a float – then after two beeps a float was thrown — after another beep another float was thrown — after two more beeps another lead weight was thrown — then 20 branchlines were attached at 50 m intervals on the beep — then another lead. The second lead was thrown on the beep usually used to indicate that it was time to throw a float. The float signal indicated that the basket was finished. Allowing two beeps between lead weights and floats insured that there was exactly 100 m between the lead weights and the floats. Since the normal floatlines were 10 m long the leads would actually settle at about 110 m. Length of the branchlines was not considered because they were not weighted and could have hung vertically or horizontally — TDRs were attached directly to the mainline and not to branchlines for fear of losing them to fish bite.

2.4 Fishing effort and catch

Fishing effort and catch for the trip on F/V *Blue Moves* will not be discussed further. Fishing was too poor to draw any results about either type of gear — normal or weighted. The following refers only to the effort and catch on the trip made on F/V *Diamax*. Seven sets were made in all, but no weighted gear was used on the first set. A total of 6000 hooks were set on the following six sets, 2420 with lead weights and 3580 without lead weights. A total of 86 fish weighing 3.2 mt were caught on these six sets. Nominal CPUEs were therefore 1.43 fish per 100 hooks and 53.3 kg/100 hooks. For comparison, longline CPUEs for all target and non target species for the Eastern Tuna and Billfish Fishery for the years from 1998—99 to 2002—03 averaged about 60 kg/100 hooks (Lynch 2003).

A total of 69 fish of the five main target species were caught on the six sets (bigeye, yellowfin, albacore, swordfish, and striped marlin). The weighted gear caught 31 target species fish weighing 1184 kg on 2420 hooks giving nominal CPUEs of 1.3 fish per 100 hooks and 49 kg/100 hooks. The normal gear caught 38 target species fish weighing 1452 kg on 3520 hooks giving nominal CPUEs of 1.08 fish per 100 hooks and 41 kg/100 hooks. These CPUEs were based on average fish weights. Bigeye tuna, by the way, averaged 37.6 kg G&G. In reality the figures would have been somewhat different if the

Principal Investigator had been able to keep track of each fish*. By observation, fish caught on the deeper weighted gear were generally bigger than fish caught on the shallower gear. This included a 90 kg (G&G) bigeye tuna and a 188 kg (H&G) broadbill swordfish. In any case, the project gear outfished the normal gear by about 17 per cent overall.

Further manipulation of the catch figures shows CPUEs for normal gear for bigeye tuna of 0.56 fish /100 hooks and 21 kg/100 hooks — while CPUEs for weighted gear for bigeye tuna were 0.95 fish /100 hooks and 36 kg/100 hooks. Therefore, weighted gear outfished normal gear for the main target species by 42 per cent. For swordfish the normal gear had CPUEs of 0.3 fish/100 hooks and 17 kg/100 hooks, while the weighted gear CPUEs were 0.25 fish/100 hooks and 14 kg/100 hooks — nearly the same. All of the swordfish caught on the weighted gear were caught at depths greater than 100 m and many were caught during daylight hours.

3. Discussion and conclusions

Most of the original design parameters of the deep setting technique were retained but others were changed, most during the trip on F/V *Blue Moves*, but some on the trip on F/V *Diamax*. It was found that three kilogram lead weights were sufficient to sink the fishing portion of the line down to the target depth of the shallowest hook. Lines to attach the lead weights to the mainline need be only about 0.5 metres long, and one standard longline snap was enough to keep the lead weights in place. Originally the lines were four metres long and had two snaps to keep them from sliding on the mainline. These proved to be too cumbersome, especially during setting. Floatline lengths of ten metres were sufficient and, in any case, had little effect on target depth of shallowest hooks, other than adding to the overall depth achieved by a small amount. Fifty metres was enough for the distance between the two floats at each end of a basket to keep the longer portions of mainline being used as supplemental floatline from tangling. These lines became entangled once only and that was when a large swordfish was hooked on the first hook in a basket and pulled the lines together. Two sizes of hard plastic longline floats were used during the trials — 300 mm floats with 14.5 kg buoyancy, and 360 mm floats with 20 kg buoyancy. The 300 mm floats proved to be sufficient to support the three kilogram lead weights and the longline. The setting timer proved to be very useful in regulating the distance between floats and lead weights, ie, the target depth of the shallowest hook. A setting timer with a linear readout in meters per beep is probably the best choice as fewer calculations need to be carried out. The original expectation of the entire basket of branchlines fishing at or near the same depth was unrealistic and, in fact, was not realised. The fishing portion of the line suspended between the two lead weights hung in a sagging shape, similar to the sag usually encountered in normal longline fishing. This sag probably occurred because of the weight of the branchlines. Each snap weighed 45 grams and each hook weighed 15 grams. This would add a total of 1.2 kilograms to each 20 hook basket. This worked out to be advantageous, however, as a range of depths could be fished, all below the target depth of the shallowest hook. In other words, nothing changed in the way the line fished except that everything was displaced 100 m downwards.

All original project objectives were met. The technique was perfected and proved to work almost flawlessly. Experienced longline fishermen should have little or no trouble adapting to the technique. Target depths were achieved so that all hooks fished below the mixed layer where bycatch encounters normally occur. The technique was simple enough so that it could be duplicated on almost any longline vessel using a monofilament system with a reel and line setter. F/V *Diamax*, for example, had a crew composed of 75 per cent green fishermen who, never the less, were able to grasp the routine of setting following the beeps and the commands given, after two or three sets and no previous experience. The captains of both boats used during the project grasped the concept readily and were very helpful in working out the initial bugs. Finally, target species CPUEs on the trip on F/V *Diamax*, compared to the normal portion of the sets, were enhanced or unchanged, depending on species and, although one short

* The Principal Investigator wasn't able to keep track of individual fish because, as in the case of F/V *Blue Moves*, he was required to work as a deckhand on F/V *Diamax*. His job was to do all gear repairs during hauling or to drive the boat (after a control cable on the outside station broke).

trip was not statistically significant, it may be considered to be indicative — further testing is required.

There were some drawbacks to the technique, however. More gear was needed to do the deep setting technique — additional floats and floatlines, lead weights with line and snaps, and more mainline. For a boat setting 1000 hooks in 20 hook baskets this would cost around AUD\$4000. It could be cheaper if less expensive weights were used. More time was needed to set and haul the weighted gear. For example, if the target depth for the shallowest hooks was 100 m then 50 seconds more setting time was needed for each basket (providing that ten seconds equalled 50 m of line being ejected from the line setter). A similar increase in time was needed for hauling. For a line totalling 1000 hooks with 20 hooks per basket, this would add a total of an hour and forty-five minutes to time spent on deck. Lastly, as was pointed out by the captain of F/V *Diamax*, fewer yellowfin tuna and byproduct species were caught on the deep-set gear. Byproduct species add significantly to a longline vessel's revenue. Byproduct species such as mahi mahi, however, tend to bite during the haul so catch rates for these fish wouldn't be affected.

Australian longline vessels, such as F/V *Blue Moves*, which fish primarily along the continental shelf of eastern Australia where there is little or no thermocline and where there are strong tidal currents, probably would not adopt a technique that involves setting during the day and setting deep. Despite the downturn of 2003—04 in the fishery, they have done well in the past with shallow night sets fishing on the full moon and targeting both bigeye tuna and swordfish. Other vessels in the Australian fleet, such as F/V *Diamax*, that venture further from shore as is required by the conditions of their permits, may be more likely to adopt a new style of fishing, especially if target CPUEs are enhanced. The choice of Australia as a venue for the deep setting project was based on funding considerations and on convenience. The deep setting technique, however, was designed with a wider audience in mind. If further testing shows that bycatch mitigation and target CPUE enhancement can be significant using the deep setting technique then it could be taken up by longline fleets almost anywhere including the Pacific Ocean, Atlantic Ocean, Indian Ocean, and the Mediterranean Sea.

Results from the trip on F/V *Diamax* were encouraging but were only indicative of the deep setting technique's possibilities. No turtles were caught, but this was expected. Turtle encounters in the longline fishery are infrequent. What was shown, however, was that all hooks in a longline can be set in the zone outside of where turtle encounters normally occur. By inference, no turtles would have been caught unless they struck baits as the line was being set or hauled, or if they became entangled in floatlines. The same can be said for other mixed layer bycatch species. The slight increase in nominal target species CPUEs using the deep setting technique as compared with normal setting during the trip on F/V *Diamax* was also only indicative of what might happen in the longer term. More work needs to be done to prove the efficacy of this new technique and to show that it can significantly mitigate encounters with turtles and other mixed layer bycatch species while, at the same time, significantly increase the nominal CPUE of deep water target species, especially bigeye tuna. Work also needs to be done to ascertain if the deep setting technique will prove to be feasible for deep day swordfish sets. The large swordfish caught at 130 m at 5 PM on F/V *Diamax* was astounding to the captain but was also only indicative. If a longer-term project shows that the deep setting technique will significantly reduce bycatch, thought should be given to how to implement the technique. In any event, the fact that AFMA funded the project and the fact that two Australian longline companies offered their vessels as testing platforms, demonstrates the type of proactive co-operation needed to solve the bycatch problem in the longline fishery.

Lastly, the deep setting technique could be used as a research tool to aid investigators looking into bigeye tuna habitat. Archival tag data have shown that bigeye tuna spend the highest proportion of time at 11—15°C and 350—500 m during the day and at 24—28°C at depths in the upper 100 m during the night (Gunn and Hampton, in press). Investigations have shown that bigeye tuna CPUEs can be enhanced by targeting deep depths during the day (Suzuki and Warashina 1977, Boggs 1992, Hampton, et al. 1998). However, most experimental targeting has depended on the traditional catenary curve shape of a longline, leaving a high percentage of the hooks in shallow water. Better results might be

obtained if investigators could land most or all of the hooks in a narrower depth band, corresponding to daytime bigeye tuna habitat as revealed by archival tag data.

4. References

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**Non-target species mentioned in Harris & Ward (1997) in relation
to the Eastern Tuna and Billfish Fishery.**

Common name	Scientific name
Barracuda, Great	<i>Sphryaena barracuda</i>
Bream, longfinned	<i>Taractichthys longipinnis</i>
Bream, Ray's	<i>Brama brama</i>
Bream, Southern ray's	<i>Brama australis</i>
Dolphin, common	<i>Delphinis delphinis</i>
Dolphin, spotted	<i>Stenella sp.</i>
Dolphins	<i>Tursiops spp.</i>
Escolar	<i>Lepidocybium flavobrunneum</i>
Fish, Bony	<i>Teleosts</i>
Fish, Porcupine	<i>Diodon histrix</i>
Flying fish	<i>Exocoetidae</i>
Kingfish, Yellowtail	<i>Seriola lalandi</i>
Lancetfish	<i>Alepisaurus sp.</i>
Langetfish, Longnosed	<i>Alepisaurus ferox</i>
Mackerel, butterfly	<i>Gasterochisma melampus</i>
Mackerel, Snake	<i>Lepidocybium flavobrunneum</i>
Mahi mahi	<i>Coryphaena hippurus</i>
Marlin, Black	<i>Makaira indica</i>
Marlin, Blue	<i>Makaira mazara</i>
Oilfish	<i>Ruvettus pretiosus</i>
Oilfish, Black	<i>Lepidocybium flavobrunneum</i>
Opah	<i>Lampris guttatus</i>
Rainbow runner	<i>Elegatis bipinnulata</i>
Ray, Manta	<i>Manta spp.</i>
Rays	<i>Dasyatidae</i>
Rudderfish	<i>Centrolophus niger</i>
Sailfish	<i>Istiophorus platypterus</i>
Seabird, Albatross	<i>Diomedea sp.</i>
Seabird, Fleshfooted shearwater	<i>Puffinus carneipes</i>
Seabird, Muttonbird	<i>Puffinus tenuirostris</i>
Seabird, Petrel	<i>Procellaria sp.</i>
Seabird, Skuas	<i>Stercorariidae</i>
Seabird, Shearwaters	<i>Puffinus spp.</i>
Seerfish	<i>Scomberomorus spp.</i>
Shark, Blue whaler	<i>Prionace glauca</i>
Shark, Dusky	<i>Carcharhinus obscurus</i>
Shark, Oceanic white tip	<i>Carcharhinus longimanus</i>
Shark, Porbeagle	<i>Lamna nasus</i>
Shark, Shortfinned mako	<i>Isurus oxyrinchus</i>

Shark, Silky	<i>Carcharhinus falciformis</i>
Shark, Thintail thresher	<i>Alopias vulpinus</i>
Shark, Tiger	<i>Galeocerdo cuvier</i>
Sharks	<i>Carcharhinidae (mainly)</i>
Spearfish, Shortbill	<i>Tetrapturus angustirostris</i>
Sunfish	<i>Mola sp.</i>
Swordfish	<i>Xiphias gladius</i>
Toado, Starry	<i>Arothion firmamentatum</i>
Tuna, Dogtooth	<i>Gymnosarda unicolor</i>
Turtle, unidentified	<i>Chelonidae</i>
Wahoo	<i>Acanthocybium solandri</i>

Frequently asked questions — re: the new deep setting technique.

1. *Why set the line deep?* To avoid certain shallow swimming bycatch species and to enhance the catch of certain deep swimming target species.
2. *Don't traditional, or normal, longline sets reach deep into the water column?* Yes, but a high proportion of the hooks are still fishing in the shallow part of the water column.
3. *Can a deep set be achieved by using very long floatlines?* Yes, but there are problems with hauling, untangling, and storing very long floatlines.
4. *Can a deep set be achieved by attaching a lead weight to the middle of a basket of longline gear?* Yes, but the lead weight will continue to sink beyond the target depth, pulling the floats together and causing the line to collapse.
5. *Why not just eliminate all of the hooks on the shallowest portion of each basket?* This can be done but there is still some uncertainty about the depth of the remaining hooks; and a large portion of the mainline will not be fishing.
6. *How is a deep set achieved, using this technique?* A deep set is achieved by attaching paired lead weights directly below paired floats on 100 m long portions of mainline, sinking the entire fishing portion of the line below the target depth of the shallowest hook, eg, 100 m.
7. *Why are two floats necessary?* Two lead weights could be suspended under a single float, but chances are that they would become entangled, especially if they are hanging vertically beneath the float.
8. *How much space is needed between the paired floats to avoid tangles with the weighted portions of the line?* During trials, 50 m was found to be sufficient.
9. *How heavy do the lead weights need to be?* During the trials, three kilograms was found to be sufficient.
10. *Do the lead weights slide on the mainline as it is being hauled?* No, not if good quality swivel snaps are used.
11. *How is the spacing between the floats and the lead weights regulated?* By using the line setting timer, which is set to indicate 50 m of line for each beep. Lead weights are attached two beeps before the first float or two beeps after the second float to achieve a depth of 100 m. The paired floats are separated by one beep.
12. *Are larger floats needed?* No, 300 mm hard plastic floats with 14.5 kg buoyancy (the most common longline floats) were sufficient to suspend the lead weights and hold up the longline.
13. *What additional gear is needed?* Lead weights, more floats and floatlines, and more mainline.
14. *How much will this additional gear cost?* For a longliner fishing 1000 hooks in 20 hook baskets, about AUD\$4000.00.
15. *Are there any disadvantages to the deep setting technique?* Yes, it takes longer to set and haul — about one-and-a-half hours is added to the time on deck for a longliner setting 1000 hooks. Also, fewer byproduct species are caught because they are usually caught in the upper 100 m of the water column.

16. *Were any problems encountered during hauling?* No, in fact the line came up easier than the normal portion of the line, probably because the lead weights kept it taught.
17. *Does sag need to be put into the line?* Yes, the length of line ejected by the line setter needs to be greater than the distance the boat travels for each basket.
18. *Will the deep setting technique work without using a line setter?* No, without sag the line will not sink to the target depth.
19. *Were target depths of shallowest hooks achieved during trials?* Yes, TDRs showed that target depths for shallowest hooks were achieved.
20. *Was the entire basket fishing at the same depth?* No, there was still sag in the fishing portion of the line. In fact, this sag could be adjusted by increasing the sagging rate or by putting more branchlines in a basket, as with normal setting practices.
21. *Were bycatch encounters reduced?* No significance can be placed on project results concerning bycatch mitigation except to say that, by inference, if no hooks landed in the zone where bycatch encounters normally occur, then no bycatch encounters would take place (except during setting and hauling when the line was settling or being recovered).
22. *Were target species CPUEs enhanced?* Overall CPUE was 17 per cent better with weighted gear fishing side-by-side with normal gear; bigeye tuna CPUE was enhanced by 42 per cent; and swordfish CPUE was only reduced a small amount. However, these results are not significant but only indicative.
23. *Were any broadbill swordfish caught during the day at depth?* Yes, several swordfish were caught below 100 m during daylight hours, as was revealed by spikes on TDR graphs.
24. *Is more testing required?* Yes, the fishing trials were only indicative of the potential of this technique — it works — but catch and effort were too small a sample to reveal anything significant.
25. *Was the technique easy for the captains and crew to implement?* Yes, both boats used during the project had largely green deck crews. Captains and crew picked up the setting sequence very easily, after initial bugs were worked out.
26. *What needs to be done now?* More testing is needed, especially in other locales such as Hawaii, where turtle bycatch in the longline fishery has become a major issue. More data is needed so that it can be determined if the deep setting technique significantly (statistically) reduces bycatch encounters (of turtles as well as other bycatch species) and enhances target species CPUEs. Also, the technique could be used as a research technique for fisheries biologists studying bigeye tuna habitat and foraging behaviour.