Research on mitigation of the interaction of sea turtle with pelagic longline fishery in the western North Pacific

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ABSTRACT
We conducted shallow-set longline fishing operations on a research vessel in the western North Pacific, May-July, 2002-2004. We investigated sea turtle interaction with a pelagic longline fishery and preliminarily examined the potential gear modifications (bait and hook types) for reducing sea turtle bycatch or mortality. A total of 54 loggerhead sea turtle *Caretta caretta* were caught in 76 operations (about 74,000 hooks), which were all alive. The mean straight carapace length was 67 cm (range: 52 - 82 cm); this suggested most of loggerhead sea turtles caught in this area were sub-adult. Loggerhead sea turtle catches ranged from 19.1 to 24.5 °C in sea surface temperature, which were concentrated in warm water masses in the Kuroshio extension. The Loggerhead sea turtle catch was more frequently observed on hooks hauled after sunrise. For bait type, the catches by mackerel bait were fewer than those by squid bait. In the circle hook trial in 2003, the deep-hooking rates (proportion of deep-hooking (at esophagus or pharynx) to total in numbers) on squid bait were 0.41 and 0.23 in 3.8 sun conventional tuna hook (n = 22) and 3.8 sun Tankichi type circle hook (which had similar size to 3.8 sun conventional tuna hook) (n = 13), respectively, but the difference was not significant (P > 0.05, extended Fisher's exact test). In 2004 the large 18/0 circle hooks (which had a larger size, compared to 3.8 sun tuna hook) were tested, but its effect was not clarified due to very small catch numbers. Following these researches, we have been conducting sea turtle mitigation studies, with evaluation of their impacts on target and other non-target species catches.

KEYWORDS: bycatch, circle hook, longline fishery, mitigation measure, sea turtle

INTRODUCTION

There has been increasing concern about the impact of longline fisheries on sea turtles. A reduction in sea turtle mortality related to longline fisheries is required as well as other conservation measures under holistic managements (FAO 2004). The FAO has developed the "Guidelines to Reduce Sea Turtle Mortality in Fishing Operations", including longline fisheries (FAO 2005).

Recently, research to develop mitigation measures (e.g., modification of bait type, hook type or fishing depth) has been conducted for reducing incidental catch or mortality of sea turtles in various fishing grounds (e.g., Boggs 2004, Bolten et al. 2004, Gilman et al. 2005, Hall 2005, Watson et al. 2005). In these studies, catch rate or survival of sea turtle has been reported to relate to fishing depth, bait type, and hook shape and size. Sea turtle interaction with longline fishery and its mitigation measures have to be examined for each fishing ground (Gilman et al. 2005), with consideration of species and size composition of sea turtle, fishing style, oceanographic characteristics and so on.

In the western North Pacific off the coast of Japan, the commercial shallow-set longline fishery targeting swordfish (*Xiphias gladius*), or pelagic sharks such as blue shark (*Prionace glauca*) has been managed. The foraging habitat of loggerhead sea turtle (*Caretta caretta*) overlaps with this area (e.g., Nobetsu et al. 2004).

We conducted fishing operations in the western North Pacific, 2002 - 2004 to investigate sea turtle interaction with the pelagic longline fishery. The first objective was to collect the information of interaction status between sea turtle and the longline fishery. We investigated species, size composition and mortality of sea turtle caught. We also examined specification of the oceanographic characteristics in sea turtle catch, and the effect of light and dark periods and soak time on sea turtle catch rate. Secondly, we analyzed the sea turtle catch data and examined potential gear modifications (bait and hook types) for reducing incidental catch or mortality of sea turtle.

MATERIALS AND METHODS

Fishing operations were conducted on a research vessel, the Taikei-maru No. 2 (196 GT) in the western North Pacific off the coast of Japan (31 - 38 °N, 142 - 164 °E), 10 May - 20 June, 2002, 10 May - 9 July, 2003, and 11 May - 30 June, 2004. Fishing operations were carried out 22, 33 and 32 times in 2002, 2003 and 2004, respectively.

Line setting was started in the evening and completed before sunset; this process took about 2 hrs. Hauling began before sunrise and took about 4 - 6 hrs, which is the usual style of commercial fishing vessels operating in the area. Each basket had four hooks and branch lines, and we usually used about 900 hooks in each operation. But on 4 and 2 occasions in 2003 and 2004, respectively, we used about 400-600 hooks due to the severity of the weather. Float lines were made of polyester, and branch lines were made of polyester and polyamide; float lines were 8 m in length, and branch lines had a total length of 15 m. Leaders were 2.5 m stainless steel wire. Four hooks between floats were set at depth of about 40-90 m.

We used mackerel (*Scomber japonicus*) and squid (*Todarodes pacificus*) bait and alternated bait types every 10 baskets except for 5 operations in 2003 due to the lack of mackerel bait.

We used conventional tuna hooks and three types of circle hooks. In a longline set, we divided about 900 hooks into three blocks (block no.1-3). About 300 conventional 3.8 sun tuna hooks usually flanked in both side blocks (i.e., total about 600 hooks) and about 300 circle hooks were installed in the middle block. The types of circle hook used were 3.8 sun Tankichi type (Hisamatsu Ltd.) in 2002 and 2003, and large 18/0 type with 0° and 10° offset (PACIFIC FISHING TACKLE MFG., Co., Ltd) in 2004 (Fig. 1; Yokota et al. 2006). The 3.8 sun Tankichi type had a similar size, and 18/0 type had a larger size, compared to 3.8 sun tuna hook (Fig. 1).

On both sides of 300 tuna hooks, we defined anterior tuna hooks: block no.1 (set finally and hauled firstly) and posterior tuna hooks: block no.3 (set firstly and hauled finally). The soak times of anterior tuna hooks were therefore shorter than those of posterior tuna hooks. Hauling the anterior hooks was begun before sunrise and hauling the posterior hooks was begun after sunrise.

During hauling, the species, number, and condition (live or dead) of individual animals caught were recorded. Lengths and weights of animals retrieved were measured on deck. When sea turtle were caught, the latitude, longitude, and sea surface temperature at the catch point were recorded. Hooking location was recorded as follows; i) hooking at mouth, ii) hooking at body or flipper, iii) deep-hooking (i.e., at esophagus or pharynx), and failing to retrieve.

We compared sea turtle catch rates (catch per 1000 hooks) on anterior tuna hooks to those on posterior hooks for each bait type, using successful operation data in 2003 (24 operations) to examine the effect of soak time and light and dark period on sea turtle catch.

Deep-hooking rates (proportion of deep-hooking in total catch numbers) were defined and calculated for each hook type. We compared differences in hooking location between circle hook (3.8 sun Tankichi type) and conventional tuna hook in 2003

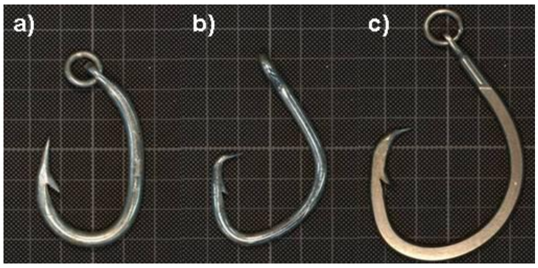

Fig. 1 a) 3.8 sun conventional tuna hook, b) 3.8 sun Tankichi type circle hook, and c) 18/0 type circle hook.

research, applying extended Fisher's exact test.

RESULTS

A total of 54 loggerhead sea turtle (1, 40, and 13 in 2002, 2003, and 2004, respectively) were caught in 76 operations (74038 hooks), which were all alive. No other sea turtle species was caught in either year.

Straight carapace length (SCL) frequency distribution of loggerhead sea turtle caught is shown in Fig. 2. The mean length ± S.D. was 67 ± 5.4 cm.

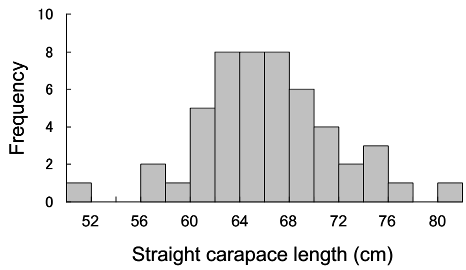

Fig. 2 Frequency distribution of straight carapace lengths of loggerhead sea turtles caught, 2002-2004.

Sea surface temperature distributions of loggerhead sea turtle catches and fishing operations are shown in Fig. 3. While fishing operations ranged form 17.0 to 25.5 °C in sea surface temperature, loggerhead sea turtle catches ranged from 19.1 to 24.5 °C. The fishing operations were conducted around the boundary of warm and cold water masses in Kuroshio extension (Fig. 4). The catches were concentrated in warm water masses.

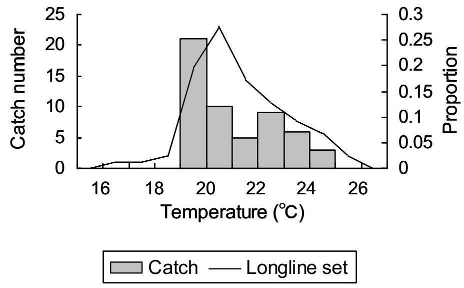

Fig. 3 Sea surface temperature distribution of loggerhead sea turtle catch points, and fishing operations, 2002-2004. The left x-axis is catch number, and the right axis is the proportion of longline sets.

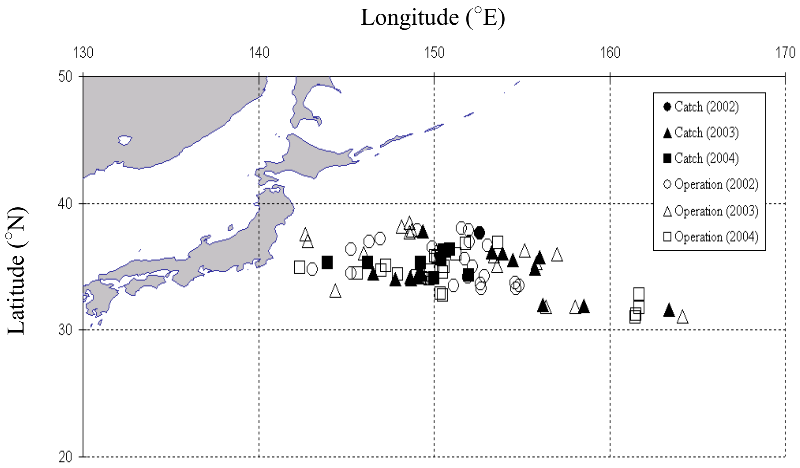

Fig. 4 Locations of loggerhead sea turtle catches and fishing operations in the western North Pacific, 2002-2004.

Fig. 5 shows mean catch rates of loggerhead sea turtle on anterior 150 hooks (block no.1) and posterior 150 hooks (block no.3) of tuna hook and squid bait in 24 operations in 2003. While the mean catch rate was 3.1 in posterior hooks in which hauling was begun after sunrise and had longer soak times, the catch was zero in anterior hooks in which hauling was begun before sunrise and had shorter soak times. With mackerel bait, only one loggerhead sea turtle was caught incidentally in anterior hooks.

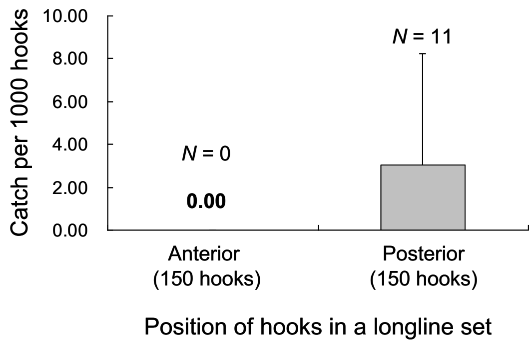

Fig. 5 Mean loggerhead sea turtle catch rates on anterior 150 hooks and posterior 150 hooks of tuna hook and squid bait in 24 operations, 2003. N indicates catch number. Hauling anterior hooks began before sunrise (shorter soak time) and hauling posterior hooks after sunrise (longer soak time).

Table 1 shows the total numbers of hooks and loggerhead sea turtles caught, and mean loggerhead sea turtle catch rate for each hook and bait type. Only one loggerhead sea turtle was caught in 2002, as previously noted. For bait type, the catch rates by mackerel bait were fewer than those by squid bait in both hook types in 2003 and 2004.

There was no substantial difference in catch rates between 3.8 sun tuna hook and circle hooks in either

Table 1. Total numbers of hooks and loggerhead sea turtle catches, and mean loggerhead sea turtle catch rate for each hook and bait type.

year	Hook type	Bait type	Hook no.	Catch no.	Mean catch rate (S.D.)
2002	Tuna hook (3.8 sun)	Squid	7260	1	-
	Circle hook (3.8 sun Tankichi)	Squid	1800	0	-
	Tuna hook (3.8 sun)	Mackerel	7260	0	-
	Circle hook (3.8 sun Tankichi)	Mackerel	1800	0	-
2003	Tuna hook (3.8 sun)	Squid	10498	22	1.89 (2.66)
	Circle hook (3.8 sun Tankichi)	Squid	5400	13	2.29 (4.35)
	Tuna hook (3.8 sun)	Mackerel	7982	3	0.35 (1.03)
	Circle hook (3.8 sun Tankichi)	Mackerel	4200	2	0.46 (1.72)
2004	Tuna hook (3.8 sun)	Squid	6912	7	1.12 (2.54)
	Circle hook (18/0 0°off set)	Squid	3401	0	-
	Circle hook (18/0 10°off set)	Squid	3574	4	1.12 (3.76)
	Tuna hook (3.8 sun)	Mackerel	6976	1	-
	Circle hook (18/0 0°off set)	Mackerel	3401	0	-
	Circle hook (18/0 10°off set)	Mackerel	3574	1	-

year even though we did not perform any quantitative analyses. And in 2004, large 18/0 circle hook with 0°off set had no loggerhead sea turtle catch in either bait type, but catch numbers in either bait and hook combinations were very small.

Proportion of hooking location and failing to retrieve of loggerhead sea turtle for each hook on squid bait in 2003 are shown in Fig. 6. The deep-hooking rates were 0.41 and 0.23 in 3.8 sun conventional tuna hook and 3.8 sun Tankichi type circle hook, respectively, but the differences in hooking location were not statistically significant between hook types ($P > 0.05$, extended Fisher's exact test).

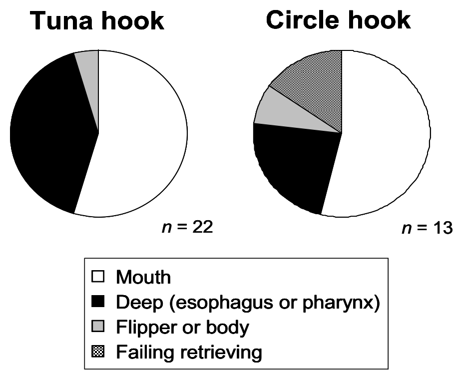

Fig. 6 Proportion of hooking location and failing retrieving of loggerhead sea turtle for 3.8 sun tuna hook and 3.8 sun Tankichi type circle hook on squid bait in 2003.

DISCUSSION

Results indicated that there was an interaction of loggerhead sea turtle with the shallow-set longline fishery in the western North Pacific and hooked sea turtle were all alive. With respect to after-release survival, the satellite tracking and the captive experiments on the survival of hooked loggerhead sea turtles, which were caught in the fishing operations, demonstrated the long-term survivals of loggerhead sea turtles (Minami et al. 2003, Kiyota et al. 2005). In shallow-set longlines, the hooked sea turtles could surface to breathe. The shallow-set longline has a higher risk of catching loggerhead sea turtles, but has a lower risk of mortality than deep-setting longline. Careful handling and release would lead to further improve post-hooking survival or vitality (Yokota 2005).

This study indicated that most of loggerhead sea turtles caught incidentally in the western North Pacific were sub-adults (mean SCL ± S.D.: 67 ± 5.4 cm). Loggerhead sea turtle become mature around 70 cm in SCL (Kamezaki et al. 1995). Loggerhead sea turtles caught in this area had larger body sizes, compared to those caught in the central Pacific around Hawaii (mean SCL ± S.D.: 56.4 ± 0.8 cm; Gilman et al. 2006) or in the western North Atlantic (mean SCL: 56.8 cm, range: 32.4-68.0 cm; Watson et al. 2005). Considering the differences in body size of sea turtle between the areas, which might affect the relationship between sea turtle size, and hook size or feeding behavior; i.e., effectiveness of mitigation measures, we should conduct mitigation studies to reduce incidental catch of sea turtle, and information exchange on the scientific results.

Loggerhead sea turtle catches occurred above about 19 °C in sea surface temperature, and concentrated in warm water masses, that is consistent with the results of satellite tracking (Nobetsu et al. 2004, Minami et al. 2004). Sea turtles have habitat preference for warm water in general. Watson et al. (2003) indicated that fishing water temperatures below 20 °C can significantly reduce loggerhead sea turtle interactions while increasing swordfish catch in the western North Atlantic. Investigation of oceanographic characteristics on habitats of sea turtle and target species would help to reduce incidental catch of sea turtle as well as to control target species catch such as swordfish (e.g., Bigelow et al. 1999).

The comparison between catch rates on hooks hauled after sunrise and hauled before sunrise suggested that shortening daylight soak time of hooks reduced incidental catch of loggerhead sea turtle. Watson et al. (2003) also reported that loggerhead sea turtle catch rate increased significantly with increased daylight hook soak time in the western North Atlantic. Activity pattern and feeding behavior of loggerhead sea turtle may be related to light conditions.

The catch numbers of loggerhead sea turtles on fish bait were substantially fewer than those on squid bait; this was similar to the result in other studies (e.g., Watson et al. 2005). Kiyota et al. (2005) conducted a captive experiment in a water tank about hooking mechanisms and observed loggerheads feeding baited-hooks. In the experiment, loggerheads were likely to swallow the whole squid bait which had flexible and tough muscle texture. In contrast, loggerheads bit and cut fish baits and ingested small pieces of fish muscle. They interpreted that the bait texture was related to the difference in feeding mechanism and hooking rates. The use of fish bait is expected to be one of the most effective methods to reduce incidental catch of loggerhead sea turtle.

In general, it has been considered that hook size affects the hooking rate of sea turtles and hook shape affects hooking position of sea turtles. We could not quantitatively examine the effect of circle hooks on catch rates of loggerhead sea turtle in the research because of the insufficient data numbers. The deep-hooking rate in the circle hook was lower than that in the conventional tuna hook, but our data did not indicate significant differences in hooking locations between the circle hook and the tuna hook. This insignificance might be caused by the small sample size relative to its difference.

Minami et al. (2006) reported that small 4.3 sun circle hooks showed catch rates of loggerhead sea turtle similar to conventional tuna hooks, but large 5.2 sun circle hooks reduced incidental catch of loggerhead sea turtle in the experimental fishing operations in the western North Pacific, 2005. Minami et al. (2006) also suggested that performance of circle hooks appears to be dependent on hook size and morphology. In terms of hook size, it has been reported that the use of large 18/0 circle hooks highly reduced incidental catch of loggerhead sea turtle in the central Pacific or in the western North Atlantic (e.g. Waston et al. 2005). But the differences in body size of loggerhead sea turtles between these areas and our study area may change the hook-size effect on turtle catch rates. Detailed examinations of ideal size and shape of circle hook are needed to make more effective circle hooks to reduce catch rate and deep-hooking rate of loggerhead sea turtle in the western North Pacific (Yokota et al. 2006a).

Based on the information obtained in this research, we have been conducting a series of studies to develop mitigation measures for sea turtle-fishery interactions (e.g., circle hook or de-hooking device), with evaluation of the impacts of the measures on target and other non-target species catches in the western North Pacific (Minami et al. 2006, Yokota 2005, Yokota et al. 2006b).

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