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Effects of Hook and Bait Types on Bigeye Tuna Catch Rates in the Tuna Longline Fishery

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ABSTRACT A pelagic tuna longline research cruise in the eastern and central Pacific Ocean from September to October of 2006 was conducted to compare catch rates with the use of different hook type and bait combinations. Traditional tuna hooks (J 4) and three circle hook types (C15, C16, C18), along with five bait types (chub mackerel (CM), jack mackerel (JM), milkfish (MF), sardine (SD), and squid (SQ)) and hook number as a proxy for hook depth were evaluated for their effect on bigeye tuna catch rates (fish per 1,000 hooks) using Generalized Linear Models (GLMs). Results from 28 sets indicated significant differences in bigeye catch rates between individual longline sets and hook number. The GLM explained 33% of the deviance in bigeye catch rates with these two factors. An alternative model formulation included bait type which had a small effect (explaining 2.7% of the deviance) on catch rates. Hook type had a negligible and non-significant effect in the GLMs. These results indicate that all of the hooks and baits tested are equally effective at catching bigeye tuna and that hook number (depth) was the paramount operational factor in explaining bigeye tuna catch rates.

Key words : Tuna hook, circle hook, bait type, catch rate, bigeye tuna, *Thunnus obesus*, Tuna longline

INTRODUCTION

Due to the high commercial value of bigeye tuna (*Thunnus obesus*) in the Japanese and Korean sashimi markets, bigeye tuna is an important species in pelagic longline fisheries. Since 1990, bigeye tuna has accounted for 44% of the total tuna longline catch by weight in the Pacific Ocean (Lawson, 2007).

There is increasing scientific and public concern regarding the responsible management of fisheries resources and there is also a demand for the development of effective mitigation methods when resource problems are identified. In pelagic tuna longline fishing, the reduction of the incidental catch of sea turtles, sharks and seabirds has become a focus of a international fisheries research (SCTB, 2003), In order to ensure rapid assimilation of effective measures by the commercial fishery entities, scientists have been looking for measures which can reduce bycatch while simultaneously maintaining fishing efficiency for target species (e.g., bigeye tuna, swordfish). One promising technology is the use of circle hooks in place of traditional j-style hooks and tuna hooks. Several studies have been conducted on the effect of circle hook types on the catch rate of target species (Watson *et al.*, 2005; Gillman *et al.*, 2006; Kim *et al.*, 2006; Watson and Kerstetter, 2006; Read, 2007).

In contrast to J-style and tuna hooks, circle hooks tend to catch fishes in the corner of the jaw rather than in the throat because the tip of the hook curves inside and the width of the hook is broad (Trumble *et al.*, 2002; Cooke and Suski, 2004). Some vessels targeting tuna have switched voluntarily to circle hooks following studies (Falterman and Graves, 2002; Kerstetter and Graves, 2006) that suggested that they may increase tuna catch rates.

Additional research is being conducted in several Regional Fisheries Management Organizations to compare the effects of hook and bait types on catch rates of pelagic species. The objective of this paper was to present an analysis of bigeye tuna longline catch rates with

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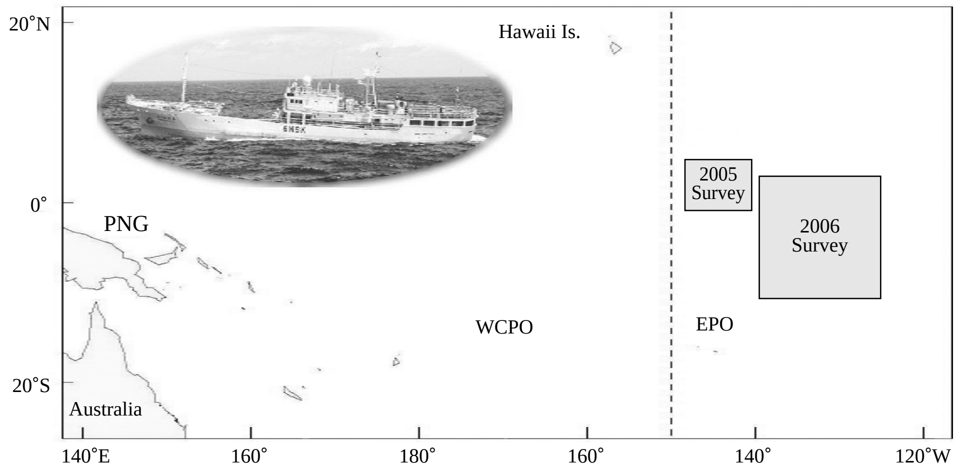

Fig. 1. Longline research area in the eastern and central Pacific Ocean from 20 September to 23 October 2006, also showing the location of a previous study (Kim *et al.*, 2007).

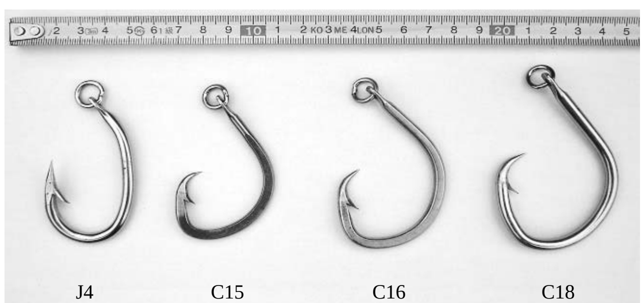

Fig. 2. Four types of longline hooks deployed on the research longline cruise: one size of traditional tuna hook (J4) with a 5° offset and three sizes of circle hooks (C15, C16, C18) with a 10° offset.

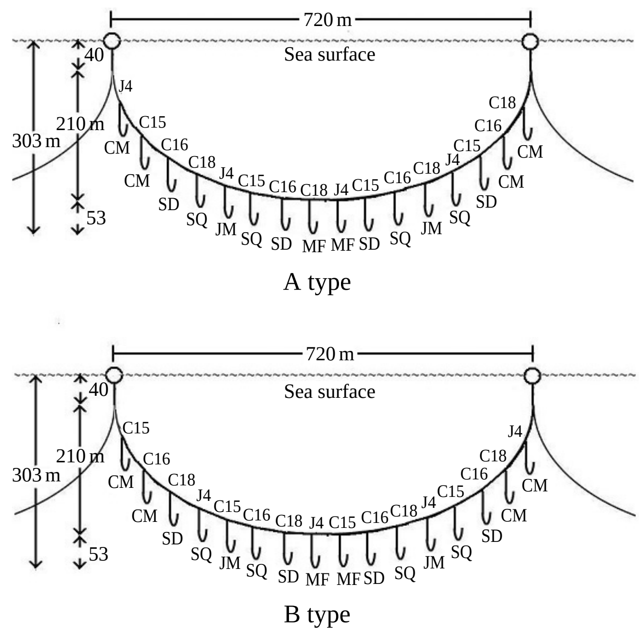

Fig. 3. Sequential order of hooks set during the initial fourteen (A type) and last fourteen (B type) sets on the research longline cruise.

various hook and bait types and by hook number, based on a study conducted in the Pacific Ocean.

MATERIALS AND METHODS

A Korean tuna longline vessel (416 GRT) was chartered from 20 September to 23 October 2006 to conduct longline fishing in the central eastern Pacific Ocean (9° 13′～1° 36′S and 126° 00′～138° 21′W). A total of 28 longline sets (one set per day) were monitored during the 34 days of the cruise (Fig. 1). The fishing vessel targeted bigeye tuna and the main fishing depth ranged from 100 to 300 m. The hooks were of two styles: traditional tuna hooks of size 4.0 (J4) with a 5° offset, and circle hooks of three sizes (C15, C16, C18) with a 10° offset (Fig. 2) making a total of four hook types. The number of hooks deployed in each longline set ranged from 2,080 to 2,352 or 520 to 588 of each hook type. The hooks were sequentially set by type of hook in the order of J4-C15-C16-C18 during the initial fourteen longline sets (set numbers 1～14; A type) and C15-C16-C18-J4 during the last fourteen sets (set numbers 15～28 (B type), Fig. 3).

Longline setting began at around 8:30 am in the morning and finished by 2:00 pm. Longline hauling began after about 3 hours of soaking, and hauling, the longline continued until the following early morning when retrieval was finished by 7:00 am. Hauling started at the end position of the set for 26 sets and hauling started at the start position of the set for two sets. A total of 62,464 hooks (15,616 J4 hooks and 46,848 circle hooks) were set in the experiment,

There were 16 hooks deployed between each of the surface floats in succession and the mean length of main line deployed was 135 km. The baits used were chub mackerel (CM), sardine (CD), squid (SQ), jack mackerel

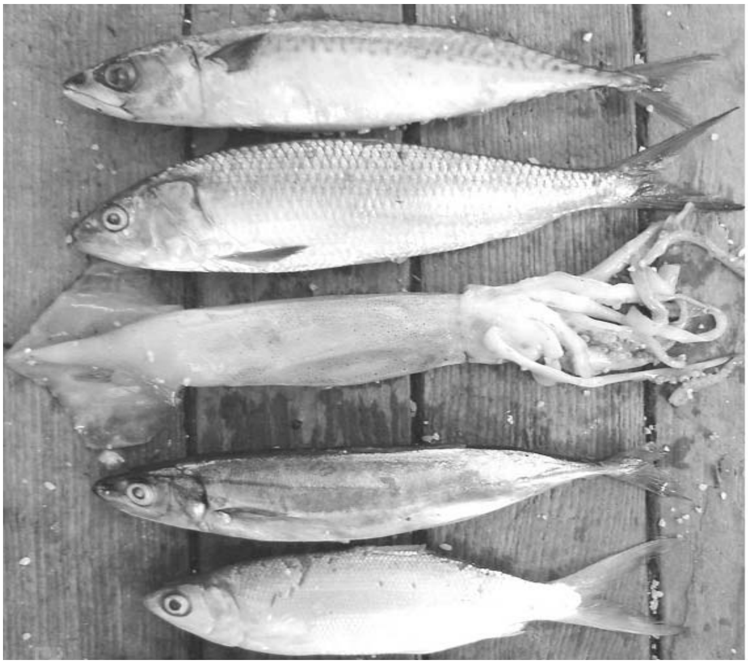

Fig. 4. Five types of bait used on the research longline cruise.

Table 1. Catch in number of tunas and billfishes by hook type

Species	Hook type				
	Total (%)	J4	C15	C16	C18
Bigeye tuna	507 (61.6)	120	140	119	128
Yellowfin tuna	78 (9.5)	15	16	21	26
Albacore	87 (10.6)	15	24	25	23
Skipjack	15 (1.8)	5	8	1	1
Swordfish	67 (8.1)	15	18	18	16
Blue marlin	18 (2.2)	7	2	5	4
Striped marlin	8 (1.0)	–	2	2	4
Shortbill spearfish	30 (3.6)	13	7	4	6
Sailfish	13 (1.6)	5	4	–	4
Total (%)	824 (100.0)	195 (23.7)	221 (26.9)	195 (23.7)	212 (25.8)

Table 2. Summary of bigeye tuna catch and CPUE (number per 1,000 hooks) by hook type caught on 28 longline sets

	Hook type			
	J4	C15	C16	C18
Number of bigeye tuna caught	120	140	119	128
Average CPUE	7.5	8.6	7.4	8.1

Table 3. Summary of bigeye tuna catch and CPUE (number per 1,000 hooks) by bait type caught on 28 longline sets

	Bait type				
	CM (chub mackerel)	MF (milkfish)	JM (jack mackerel)	SD (sardine)	SQ (squid)
Number of bigeye tuna caught	56	85	46	78	169
Average CPUE	4.2	11.9	6.8	5.9	12.1

(JM) and milk fish (MF), and were sequentially set in the order of CM, CM, SD, SQ, JM, SQ, SD, MF, MF, SD, SQ, JM, SQ, SD, CM and CM between two floats (Fig. 4).

Catch rate (bigeye tuna per 1,000 hooks) comparisons were statistically analyzed using GLMs and analysis of variance (ANOVA) tests in Splus (version 6.2.1 for Linux). Each GLM was fitted as a robust Poisson model with bigeye catch as the response variable and the number of hooks as an offset. A negative binomial error structure was also considered; however the robust Poisson was preferred. Predictors included longline set, hook and bait types categorized as factors. Hook number was also categorized as a factor or modeled as a linear or 2nd order (quadratic) polynominal. Hook numbers 1 to 16 were re-numbered from shallow (1) to deep (8) such that hooks 1 and 16 were 1, hooks 2 and 15 were 2 etc. GLMs were fit in forward and backward selection and reductions in the Akaike Information Criterion (AIC) were used to determine the order of entry for the predictors. ANOVA tests compared models that had different parameterizations of the hook number variable. The significance criterion for the ANOVA tests was $P < 0.05$.

RESULTS

1. Catch composition

A total of 824 tunas and billfish were caught on 62,464 hooks. Bigeye tuna was the dominant species with 507 fish captured and representing 61.6% of the total tuna and billfish (Table 1), Seventy-eight yellowfin were caught (9.5% of the total) with minor catches of albacore and skipjack tuna. Incidentally caught billfish were composed of swordfish (8.1%), blue marlin (2.2%) striped marlin (1.0%), shortbill spearfish (3.6%) and sailfish (1.6%).

Table 4. Summary of bigeye tuna catch and CPUE (number per 1,000 hooks) by hook number

	Hook number							
	1,16 (shallow)	2,15	3,14	4,13	5,12	6,11	7,10	8,9 (deep)
Number of bigeye tuna caught	27	39	27	89	99	99	56	56
Average CPUE	3.5	5.0	4.8	11.4	12.7	12.7	7.2	7.2

2. Bigeye tuna catch rate by hook number, hook and bait type

There was high variability in bigeye tuna catch rates between the 28 longline sets by hook and bait type (Figs. 5 and 6). Nominal catch and catch rates by hook and bait type and hook number are illustrated in Tables 2, 3 and 4. The GLM explained 33% of the deviance in bigeye tuna catch rates. Longline set number was always the initial variable included in the stepwise process and explained 19.6% of the deviance. The second variable was hook number and the two most probable models that

Table 5. Model comparison of a generalized linear model fit to big-eye tuna catch as a function of set number, hook number, and bait and hook type. Bold indicates the best fitting GLMs

Predictor	AIC	ΔAIC	ΔResidual deviance	Degrees of freedom	Pseudo-R^2
Set number	1030.7	96.3	135.5	420	0.196
Hook number	1079.1	137.7	66.8	440	0.097
Set number + hook number	**941.6**	**0.2**	**231.5**	**413**	**0.335**
Set number+poly (hook number, 2)	955.9	14.5	212.2	418	0.307
Set number+bait	945.5	4.1	224.6	416	0.325
Set number+hook type	1031.9	90.5	137.2	417	0.199
Set number+poly (hook number, 2)+bait type	**941.4**	**0**	**230.7**	**414**	**0.334**
Set number+poly (hook number, 2)+hook type	956.3	14.9	214.9	415	0.311
Set number+poly (hook number,2)+bait type+hook type	943.5	2.1	231.6	411	0.335

Null deviance=690.1451

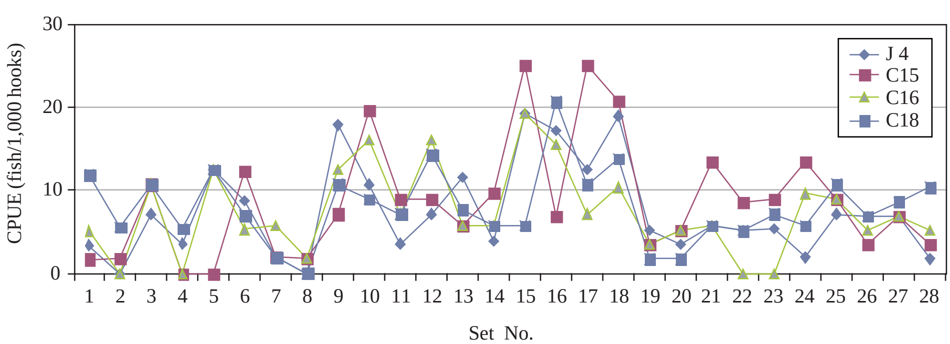

Fig. 5. Variation in bigeye tuna catch rate for each hook type and set number.

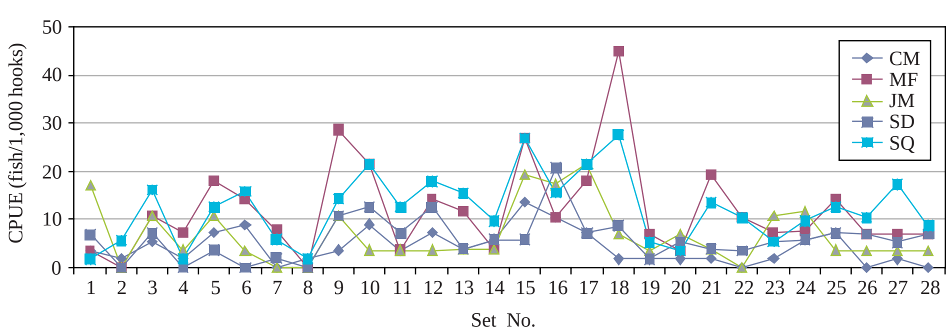

Fig. 6. Variation in bigeye tuna catch rate for each bait type and longline set number (CM: chub mackerel, MF: milkfish, JM: jack mackerel, SD: sardine, SQ: squid).

Table 6. Predicted CPUE (number per 1,000 hooks) by hook number from a generalized linear model of bigeye CPUE as a function of set number and hook number on 28 longline sets

	Hook number							
	1,16 (shallow)	2,15	3,14	4,13	5,12	6,11	7,10	8,9 (deep)
Predicted CPUE	2.0	2.9	2.7	6.7	7.6	7.4	4.2	4.2

Table 7. Predicted CPUE (number per 1,000 hooks) by bait type from a generalized linear model of bigeye CPUE as a function of set number, bait type and hook number (2nd order polynomial) caught on 28 longline sets

	Bait type				
	CM (chub mackerel)	MF (milkfish)	JM (jack mackerel)	SD (sardine)	SQ (squid)
Predicted CPUE	5.9	7.0	5.2	5.4	6.3

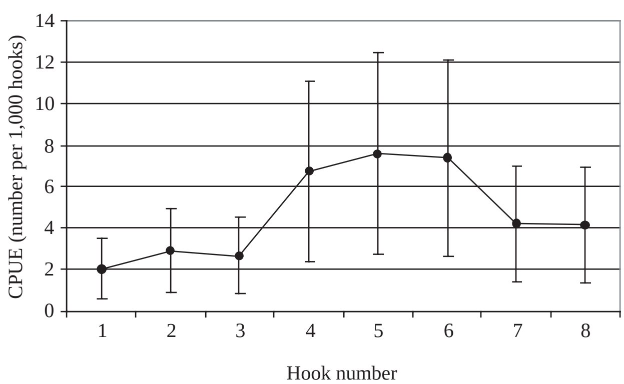

Fig. 7. Predicted CPUE (number per 1,000 hooks) by hook number (1=shallow, 8=deep) from a generalized linear model of bigeye CPUE as a function of set number and hook number on 28 longline sets. Vertical bars correspond to 95% confidence intervals.

were obtained (Table 5) differed in how hook number was parameterized (factor vs polynomial). When hook depth was included as a factor it was not possible to further evaluate models with bait type due to singularities or a lack of contrast. This resulted from the experimental design whereby the two shallowest and deepest hooks always had the same bait types chub mackerel and milkfish, respectively (Fig. 2). Therefore this GLM had no ability to determine an effect due to bait or hook number given the lack of contrast. When hook number was fit as a quadratic effect, a bait effect was evident, although the addition of bait only explained 2.7% of the deviance. The addition of hook type to this model was not significant (P=0.82).

Bigeye catch per unit effort (CPUE) as a function of hook number and bait type was predicted from the two most probable models while also incorporating the effect of set number. Hook number had the largest effect, with low catch rates on shallowest hooks, high catch rates on intermediate hooks and moderate catch rates on deepest hooks (Table 6, Fig. 7). While bait type was statistically significant when hook number was modelled as a quadratic effect, predicted effects of bait on CPUE resulted in much less variability than nominal CPUE (c.f. Tables 3 and 7) because set and hook number explain most of the deviance in the model. Both the nominal data and the model suggested that the best baits for catching bigeye tuna were milkfish and squid.

DISCUSSION

It can be seen that bigeye tuna catch rate was highly variable among the 28 set operations (Figs. 4 and 5). Although a study objective was to determine effects of hook type, hook position had the strongest influence on catch rate. The anticipated effect of depth was the reason that hooks types were ordered so that each hook type was deployed at all hook position depths in the study. This facilitated the finding that hook type had no significant effect on bigeye tuna CPUE. Unfortunately, the researchers were not in control of the hook positions chosen for the bait types, which was controlled by the fishermen. As bait type was confounded with hook position there may have been more or less effect of each variable than was determined here, and an unequal distribution of bait types among hook types and depths may have influenced the hook type results as well. Previous papers (Watson *et al.*, 2005, Gillman *et al.*, 2006) have shown the importance of bait type on the catch rates of target species and bycatch. It is important that future studies either control, randomize, or eliminate bait type as a variable, depending on the statistical power of the study to detect multiple effects.

In a review of studies evaluating catchability associated with circle hooks compared to other types of hooks, Kerstetter and Graves (2006) reported that yellowfin tuna exhibited significantly higher catch rates with circle hooks in the US Atlantic coastal pelagic fishery, In the Gulf of Maxico pelagic longline fishery, Hoey and Moore (1999) reported that vessels caught 32.9 fish (all species combined) per set using circle hooks and only 27.2 fish per set using J-style hooks. Falterman and Graves (2002) found a significant increase in CPUE for circle hooks relative to J-style hooks for both yellowfin tuna and all species combined. Cooke and Suski (2004) found that circle hooks more frequently hooked fish in the jaw and concluded that catchability was consistently higher for circle hooks than J-style hooks. These prior studies primarily addressed fisheries where hook depth was not a large source of variation, and their results suggest that further research on deep tuna longline methods, with better control of the variables and more statistical power might show significant effects of hook type.

No significant differences in catch rate in term of individuals per 1,000 hooks between traditional hooks and circle hooks indicates that introduction of circle hooks to replace traditional hooks in tuna longline fishing should not negatively affect the catch of bigeye tuna as the main target species of the Korean tuna longline industry. This may facilitate the application of the circle hooks in the tuna longline fishery, especially in eastern and central Pacific Ocean where bigeye tuna are most targeted.

The quadratic relationship found between catch rates and hook position number (Fig. 7) was realistic given the study area. During the day, bigeye tuna inhabit depths within the thermocline or at the bottom of the thermocline (Musyl *et al.*, 2003; Bigelow and Maunder, 2007). High catch rates at intermediate hook numbers are consistent with the tropical oceanography of the eastern and central Pacific Ocean where the thermocline and oxycline are relatively shallow compared to higher latitudes and the western Pacific. The deepest hooks in the longline monitoring study may have fished at depths of 300 m which is deeper than the thermocline and oxycline, thus resulting in lower catch rates compared to the higher catch rates obtained by hooks fishing at intermediate depths.

The catch rates by each bait type (Tables 3 and 7) suggested that milkfish (MF) and squid (SQ) baits had higher catch rates of bigeye tuna. Garrison (2003) also reported that bigeye tuna catch rates were highest in sets employing squid baits. Significant differences among baits, but no significant differences among the hooks indicates that selection of bait types may be more effective than selection of hook types for increasing the catch rate of bigeye tuna. The reduced bycatch and injury to sea turtles that results from the use of circle hooks (Watson *et al.*, 2005; Reed, 2007) combined with the evidence of greater bycatch of sea turtles in shallow fishing (Gillman *et al.*, 2006) suggests that using circle hooks on the shallower hook position (e.g., from the third branch lines away from the float to those closest to the float) may help protect sea turtles. The higher success in using squid as bait for bigeye tuna in the present study may conflict with the finding of higher sea turtle bycatch than when fish are used as bait (Watson *et al.*, 2005). Since milkfish were also found to have very high success in catching bigeye tuna, using fish baits on hook positions closest to floats, and keeping squid baits on deeper positions might also help to protect sea turtles while increasing the catch of bigeye tuna.

In conclusion, circle hooks do not appear to reduce the capture rate of bigeye tuna in the tuna longline fishery, using milkfish and squid as bait offers means of incleasing the capture rate of bigeye tuna, and strategic use of alternative hooks and baits at different depths could have benefits in reducing sea turtle bycatch while simultaneously increasing bigeye tuna catch.

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REFERENCES

Bigelow, K.A. and M.N. Maunder. 2007. Does habitat or depth influence catch rates of pelagic speices? Can. J. Fish. Aqu. Sci., 64: 1581-1594.

Cooke, S.J. and C.D. Suski. 2004. Are circle hooks an effective tool for conserving marine and freshwater recreational catch and release fisheries? Aquat Consev; Mar. Freshw. Ecosyst., 14: 299-326.

Falterman, B. and J. E. Graves. 2002. A preliminary comparison of the relative mortality and hooking efficiency of circle and straight shank (“J”) hooks used in the pelagic longline industry. Am. Fish. Soc. Symp., 30: 80-87.

Garrison, L.P. 2003. Summary of target species and protected resource catch rates by hook and bait type in the pelagic longline fishery in the Gulf of Mexico, 1992-2002. Contribution #PRD-02/03-08 of NOAA, National Marine Fisheries Service, Miami, FL, USA, pp. 1-10.

Gillman, E, E. Zollett, S. Beverly, H, Nakano, D. Shiode, K. Davis, P. Dalzell and I. Kinan. 2006. Reducing sea turtle bycatch in pelagic longline gear. Fish and Fisheries, 7: 2-23.

Hoey, J.J. and N. Moore. 1999. Multi-species catch characteristics for the US Atlantic pelagic longline fishery. Captain’s Report. National Marine Fisheries-NOAA-NMFS. Marfin Grant-NA77FF0543, (SK) Grant-NA86FD0113, pp. 1-78.

Kerstetter, D.W. and J.E. Graves. 2006. Effects of circle versus J-style hooks on target and non-target species in a pelagic longline fishery. Fish Res., 80: 239-250.

Kim, S.S., D.Y. Moon, C. Boggs, J.R. Koh and D.H. An. 2006. Comparison of circle hook and J hook catch rate for target and bycatch species taken in the Korean tuna longline fishery. J. Kor. Soc. Fish. Tech., 42: 210-216.

Lawson, T. (Editor) 2007. Western And Central Pacific Fisheries Commission Tuna Fishery Yearbook (Wes-

tern and Central Pacific Fisheries Commission, Pohnpei, Federated States of Micronesia, 2007), available at ww.spc.int/oceanfish/Docs/Statistics/TYB.htm.
Musyl, M.K., R.W. Brill, C.H. Boggs, D.S. Curran, T.K. Kazama and M.P. Seki. 2003. Vertical movements of bigeye tuna (*Thunnus obesus*) associated with islands, buoys, and seamounts near the main Hawaiian Islands from archival tagging data. Fish. Oceanogr., 12: 152-169.
Read, A.J. 2007. Do circle hooks reduce the mortality of sea turtles in pelagic longlines? A review of recent experiments. Biol. Conserv., 135: 155-169.
SCTB. 2003. Report of the sixteenth meeting of the standing Committee on tuna and billfish, pp. 31-34.
Trumble, R.J., S.M. Kaimmer and G.H. Williams. 2002. A review of methods used to estimate, reduce, and manage by catch mortality of Pacific halibut in the commercial longline groundfish fisheries of the Northeast Pacific. Am. Fish. Soc. Symp., 30: 88-96.
Watson, J., D. Foster, S. Epperly and A. Shah. 2005. Fishing methods to reduce sea turtle mortality associated with pelagic longlines. Can. J. Fish. Aqua. Sci., 62: 965-981.
Watson, J.W. and D.W. Kerstetter. 2006. Pelagic longline fishing gear: A brief history and review of reasearch efforts to improve selectivity. Mar. Tech. Soc. J., 40: 6-11.

다랑어 연승어업에서 눈다랑어 어획률에 미치는 낚시 및 미끼의 효과

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초 록 : 다랑어낚시 및 사용미끼에 따른 어획률을 비교하기 위해, 2006년 9～10월간 태평양 중동부 해역에서 다랑어연승 시험조사가 수행되었다. 일반선형모형(GLM)을 이용하여 재래식 다랑어낚시 1종(J4)와 환형낚시 3종(C15, C16, C18), 미끼 5종(고등어(CM), 전갱이(JM), 밀크피쉬(MF), 정어리(SD), 오징어(SQ)) 및 낚시심도를 나타내는 낚시 순번들이 눈다랑어 어획률(1,000낚시당 마리수)에 미치는 효과를 평가하였다. 총 28회 조업에서 낚시순번 간 눈다랑어 어획률에는 유의한 차이가 인정되었다. GLM분석에서 낚시순번에 의한 눈다랑어 어획률 편차는 33%로 나타났다. 미끼 종류 간 어획률 차이는 그 편차가 2.7%로 적게 나타났고, 낚시형 4종 간 그 차이는 매우 적어 유의하지 않게 나타났다. 따라서, 낚시형 및 미끼 종류의 선택은 다랑어 연승어업에서 눈다랑어 어획률 차이에 영향을 주지 않는 것으로 평가되었으나, 어획수심을 나타내는 낚시순번은 눈다랑어 어획률에 영향을 주는 요인으로 판단되었다.

찾아보기 낱말 : 다랑어낚시, 환형낚시, 낚시미끼, 어획률, 눈다랑어