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THE EFFECT OF CIRCLE HOOKS VS J HOOKS ON THE AT-HAULBACK SURVIVAL IN THE U.S. ATLANTIC PELAGIC LONGLINE FLEET

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SUMMARY

Observer data from the U.S. pelagic longline fleet was used to analyze the effect of circle and J hooks on the at-haulback survival of swordfish, shortfin mako, blue and white marlin. The probabilities of survival were estimated from odd ratios. Full models included water temperature, soak time, and fish length as continuous covariates. When only the effect of hook type is taken into consideration, circle hooks resulted in a significantly higher probability of survival for all species except for white marlin where the difference was not significant. Temperature, soak time, and fish length were significant depending on the species. When significant, in general these covariates had a negative effect on survival (i.e., higher values resulted in lower survival). The results show that circle hooks, which were adopted as a sea turtle bycatch mitigation measure by the U.S. pelagic longline fleet in both the Pacific and Atlantic oceans, also increase the at-haulback survival of other species and, therefore, it addresses some of the research needs to develop and implement Ecosystem Based Fisheries Management.

RÉSUMÉ

Les données des observateurs de la flottille palangrière pélagique des Etats-Unis ont été utilisées pour analyser l'effet des hameçons circulaires et des hameçons en forme de J sur la survie à la remontée de l'espadon, du requin-taupe bleu, du makaire bleu et du makaire blanc. Les probabilités de survie ont été estimées à partir de ratios de probabilités. Les modèles complets comprenaient la température de l'eau, le temps d'immersion et la longueur des poissons en tant que covariables continues. Lorsque seul l'effet du type d'hameçon est pris en considération, les hameçons circulaires ont entraîné une probabilité de survie significativement plus élevée pour toutes les espèces, sauf pour le makaire blanc où la différence n'était pas significative. La température, le temps d'immersion et la longueur des poissons étaient importants selon les espèces. Lorsqu'elles étaient significatives, ces covariables ont eu en général un effet négatif sur la survie (c'est-à-dire que des valeurs plus élevées entraînaient une survie plus faible). Les résultats montrent que les hameçons circulaires, qui ont été adoptés comme mesure d'atténuation des prises accessoires de tortues marines par la flottille palangrière pélagique des États-Unis dans les océans Pacifique et Atlantique, augmentent également la survie à la remontée d'autres espèces et, par conséquent, ils répondent à certains des besoins de recherche pour développer et mettre en œuvre la gestion écosystémique des pêcheries.

RESUMEN

Se utilizaron datos de observadores de la flota de palangre pelágico de Estados Unidos para analizar el efecto de los anzuelos circulares y en forma de J en la supervivencia en la virada del pez espada, el marrajo dientuso, la aguja azul y la aguja blanca. Las probabilidades de supervivencia se estimaron a partir de ratios de probabilidades. Los modelos completos incluían la temperatura del agua, el tiempo de inmersión y la talla de los peces como covariables continuas. Cuando sólo se tiene en cuenta el efecto del tipo de anzuelo, los anzuelos circulares dieron como resultado una probabilidad de supervivencia significativamente mayor para todas las especies, excepto para la aguja blanca, para la que la diferencia no fue significativa. La temperatura, el tiempo de inmersión y la talla de los peces eran significativos dependiendo de la especie. Cuando son significativas, en general estas covariables tienen un efecto negativo sobre la supervivencia (es decir, valores más altos dan como resultado una menor supervivencia). Los resultados muestran que los anzuelos circulares, que fueron adoptados como medida de mitigación de la captura fortuita de tortugas marinas por la flota palangrera

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pelágica de los Estados Unidos tanto en el océano Pacífico como en el Atlántico, también aumentan la supervivencia en el mar de otras especies y, por lo tanto, aborda algunas de las necesidades de investigación para desarrollar y aplicar la ordenación pesquera basada en el ecosistema.

KEYWORDS

Circle hooks, U.S. pelagic longline, at-haulback survival

Introduction

Shortfin mako shark (*Isurus oxyrinchus*), blue marlin (*Makaira nigricans),* white marlin (*Kajikia albida*), and swordfish (*Xiphias gladius*) are highly migratory species that occur in temperate and tropical waters around the globe. Pelagic longline fleets that operate in the Atlantic Ocean targeting tunas, swordfish, and other shark species, target or incidentally catch these species. The U.S. Atlantic pelagic longline fleet targets primarily swordfish and yellowfin tuna (*Thunnus albacares*). Shortfin mako are incidentally caught by the U.S. longline fleet and they are kept and sold, in the case of blue and white marlin their retention is prohibited and they must the discarded regardless of their status at haulback (i.e., dead or alive). The fleet operates mainly in the North Atlantic including the Grand Banks fishing grounds, the Gulf of Mexico, and the Caribbean. However, the fleet has shown a reduction in the area of operation and fishing effort over the past few decades.

The International Commission for the Conservation of Atlantic Tunas (ICCAT) manages 'tuna and 'tuna-like' species in the Atlantic Ocean and its Standing Committee on Research and Statistics (SCRS) is tasked with assessing the status of the stocks managed by ICCAT and providing management advice.

The last stock assessment of North Atlantic shortfin mako was conducted by the SCRS in 2018 and stock status projections were updated in 2019. The stock assessment results showed that the North Atlantic stock was overfished and undergoing overfishing (Anonymous 2017); while the projections indicated that even with zero mortality the stock only had a 60% probability of rebuilding by 2050 (Anonymous 2019a). Taking into consideration the pessimistic outlook of the projections, the SCRS recommended that ICCAT adopt a non-retention policy for this species regardless of the condition at haulback. Because a non-retention policy still results in some mortality due to incidental catches, the SCRS also advised ICCAT to consider adopting additional measures that can further reduce mortality such as gear restrictions/modifications and time/area closures (Anonymous 2019a).

Blue marlin and white marlin were last assessed by the SCRS in 2018 and 2019 (Anonymous 2018, 2019b), respectively. Both stocks were found to be overfished; while only blue marlin was undergoing overfishing. Following the SCRS advice, ICCAT adopted a management measure requiring that all marlin that are alive at haulback be promptly released (ICCAT Recommendation 19-05).

The SCRS conducted the last stock assessment for North Atlantic swordfish in 2017. The assessment results indicated that the stock is not overfished and overfishing is not occurring. As part of the management measures for this stock, ICCAT has adopted minimum size limits that require fish below that minimum size to be released regardless of their status (i.e., dead or alive), therefore resulting in significant amounts of regulatory discards (ICCAT Recommendation 90-02).

The efficacy of non-retention policies, minimum size limits, or the mandatory release of fish that are alive at haulback as management tools to rebuild stocks is dependent on the mortality at haulback and the post-release mortality (Coelho *et al*. 2013). Species or age classes that suffer high mortality in the longlines will see a reduced benefit from these management measures. Therefore, further implementation of fishing practices or gear modifications that can increase the likelihood of survival should be considered.

It has been shown that the survival of sharks caught in pelagic longlines can be affected by variables such as fish size, soak time, and water temperature (Diaz and Serafy 2005, Serafy *et al*. 2012, Coelho *et al*. 2013, Nunes *et al*. 2019). This paper investigates the effect of those 3 variables and hook type (i.e., circle and J hooks) on the at-haulback survival of North Atlantic shortfin mako, blue marlin, white marlin, and swordfish caught by the U.S. Atlantic pelagic longline fleet.

Materials and Methods

Data analyses were conducted using a portion of the U.S. Atlantic Pelagic Observer Program (POP) database for the period 1992-2019. The POP places trained scientific observers onboard pelagic longline vessels to record detailed information about each fishing set, the catch of target and bycatch species, and to collect biological samples. Recorded information includes individual fish size, boarding status (dead or alive), disposition status (kept, discarded dead, released alive), surface water temperature, vessel location at the start and end of the set and haulback operations, soak time, and details of the gear configuration including hook type and size. Data collected by the POP during experimental fishing operations were not included in these analyses, as they do not reflect typical commercial longline fishing operations.

The log odds of a captured fish being alive at haulback (vs. being dead) was modeled using a logistic regression model (Epperly *et al*. 2012) with terms of hook type, temperature, soak time, and animal length. Only the records that where within the range of fish length, water temperature, and soak time that contained 95% of the observations for each species were included in the model. All these three variables were modeled as continues covariates. Only individuals that were explicitly recorded as 'dead' or 'alive' at the time of haulback were included in the analysis.

The probability of being alive at haulback $Prob_{(A)}$was estimated from the log odds with the following equation:

$$Prob(A) = \frac{e^{(\beta 0+ \beta 1\, \mathrm{X}1+\cdots+ \beta\mathrm{n}\, Xn)}}{1+ e^{(\beta 0+ \beta 1\, \mathrm{X}1+\cdots+ \beta\mathrm{n}\, Xn)}} \quad (1)$$

And the standard error SE:

$$SE = \sqrt{Var(\beta o) + Var(\beta 1) - 2Cov(\beta o, \beta 1)} \quad (2)$$

Results

The POP contained information on 20,642 fishing sets, of which 14,804 fished with circle hooks, 4,357 with J hooks, and 1,481 sets did not have information on the hook type fished. **Table 1** shows the median values and the range of temperature, fish length, and soak time that contained 95% of the observations for each of the species considered. The number of sets that caught at least one individual of the species being considered, the total number of individuals used in the study for each species, and the range of number of individuals caught in individual fishing sets are presented in **Table 2**. As expected, the largest number of individuals included in this study corresponded to the target species swordfish (93,309 individuals); while the numbers for the other species were an order of magnitude lower. This was expected as these species are not targeted by the U.S. pelagic longline fleet and are only incidentally caught.

Table 3 shows the estimated odds with the associated 95% confidence intervals of an individual being alive at haulback with circle hooks and with J hooks without taking into consideration any other variables. In all cases, $Prob_{(A)}$was higher with circle hooks than with J hooks. The differences were statistically significant ($P<0.0001$) for all species except for white marlin ($P=0.3421$).Blue marlin and shortfin mako showed almost the same $Prob_{(A)}$ with circle hooks, 0.72 and 0.73, respectively, as well as with J hooks (0.66 for both species); swordfish showed the lowest with 0.3 for circle hooks and 0.20 for J hooks; while white marlin had $Prob_{(A)}$ in the range of 0.54-0.56 for the 2 hook types.

The variables considered in the full model have different effects (**Table 4**). As indicated above, circle hooks always resulted in higher $Prob_{(A)}$, but this difference was not significant for white marlin. In the case of soak time, it was significant for all species with the exception of white marlin. In the case of shortfin mako and swordfish, an increase in soak time resulted in a decrease in $Prob_{(A)}$l as shown by the negative slope. However, blue marlin showed the opposite effect where increases in soak time resulted in higher $Prob_{(A)}$ at haulback.

Fish length was significant for swordfish, blue marlin, and white marlin, but not for shortfin mako. In all cases where length was a significant variable, an increase in fish size resulted in a higher mortality at haulback.

The $Prob_{(A)}$ estimated using the full models showed a variable range of values. **Table 5** provides the $Prob_{(A)}$estimated using the upper and lower limit values (**Table 1**) of the significant variables included in each full model. For example, in the case of shortfin mako the estimated $Prob_{(A)}$when considering the soak time ranged from 0.66 to 0.78 for circle hooks and from 0.59 to 0.73 for J hooks. For white marlin, the range of range of estimated probabilities when including the effect of temperature and fish length was much wider. For circle hooks,$Prob_{(A)}$ ranged from 0.37 to 0.75 and for J hooks it ranged from 0.33 to 0.75. It is worth noting that in the case of swordfish, $Prob_{(A)}$ for the largest individuals and at the upper limit of the temperature range was estimated to be as low as only 0.13.

In summary, for a particular combination of fixed values of the significant variables in any of the full models, circle hooks always resulted in a significantly higher $Prob_{(A)}$ than J hooks with the exception of WHM where this difference was not significant.

Discussion

Ecosystem Based Fisheries Management (EBFM) is being advance in many RFMOs and other management bodies despite the challenges to development and implementation of EBFM. As a result, there is a need to explore the potential effects that mitigation measures adopted to protect one taxonomic group will have on other species. In 2004, the U.S. adopted the mandatory use of circle hooks in its Atlantic pelagic longline fleet as a sea turtle bycatch mitigation measure (U.S. Department of Commerce 2004 Fed. Regist. 69:40,734-40,758).The adoptionthis management measuremay have also influenced the capture rates and survival of other bycatch and target species. This study looks into the effect of the adoption of a specific terminal gear designed to mitigate sea turtle bycatch (circle hooks) on the at haulback survival of three bycatch (shortfin mako, white marlin, and blue marlin) and one target (swordfish) species caught by the U.S. Atlantic pelagic longine fleet.

Some of the effects of circle hooks on species other than sea turtles that interact with the U.S. Atlantic pelagic longline fleet have already been investigated (e.g., see Watson *et al*. 2005, Diaz 2008, Epperly *et al*. 2012, Foster *et al*. 2012, Serafy *et al*. 2012).Epperly *et al*. (2012) also looked at haulback mortality for 2 species of sea turtle (leatherback [*Dermochelys coriacea*] and loggerhead [*Caretta caretta*]), 3 species of tunas (bluefin, albacore, and bigeye), swordfish, and 3 species of sharks (shortfin mako, porbeagle, and blue sharks). Like the present study, in their study Epperly *et al*. (2012) showed that $Prob_{(A)}$ is higher for circle hooks compared to J hooks except for albacore tuna and porbeagle sharks and at haulback survival for leatherback and loggerhead sea turtles was 100% for both hook types. In the case of shortfin mako, Epperly *et al*. (2012) estimated $Prob_{(A)}$ of 0.73 and 0.76 for J and circle hooks, respectively, and they also found that soak time was a significant variable in the shortfin mako full model. However, the $Prob_{(A)}$ for shortfin mako estimated by Epperly *et al*. (2012) for each hook type were not significantly different. This study found that for shortfin mako the overall $Prob_{(A)}$ were 0.66 and 0.73 for J and circle hooks, respectively, and the difference was significant. There are several differences between this study and that of Epperly *et al*. (2012) that can explain the differences. Firstly, their study was a controlled experiment and the study was conducted only in the Grand Banks fishery grounds. In contrast, this study used the U.S. pelagic observer data collected from regular fishing operations from 1992 to 2019 and these data covered the entire area of operation of the U.S. fleet. Secondly, their study looked only at the effect of 18/0 circle hooks while the results in this study considered the 2 types circle hooks used by the pelagic longline fleet (16/0 without offset and 18/0 with 10º offset) without looking at the effect of circle hook type. Thirdly, the sample sizes were smaller in the Epperly *et al*. (2012) study. For example, the analysis for shortfin mako included only 500 individuals while this study included almost 6,000 individuals. However, the results of this study are similar to those of Epperly *et al*. (2012) in that $Prob_{(A)}$ is lower with J hooks when compared to circle hooks, suggesting a higher rate of survival at haulback when using circle hooks. The quantitative differences between both studies are most probably due to the different nature of the data used.

Due to the diversity of studies conducted to assess the effect of circle hooks on target and bycatch species and the variety of results, several authors conducted meta-analysis in an attempt to summarize the results (e.g., see Godin *et al*. 2012, Reinhard *et al*. 2017, Rosa *et al*. 2020). Like the present study, the meta-analysis conducted by Reinhard *et al*. (2017) also indicated that for the species included in this study $Prob_{(A)}$was higher with circle hooks compared with J hooks. The only difference was for white marlin where this study found that, in contrast to Reinhard *et al*. (2017), the difference in $Prob_{(A)}$ was not significant. The meta-analysis conducted by Rosa *et al*. (2020) also found that $Prob_{(A)}$of shortfin mako was significantly lower with circle hooks when compared to J hooks. The Rosa *et al*. (2020) meta-analysis did not include results of $Prob_{(A)}$for any of the other species considered in this study.

Like this study, Serafy *et al.* (2012) also looked at survival at haulback for each hook type and the effect of several covariates. Serafy *et al.* (2012) results were similar to the present study in that they found significant higher $Prob_{(A)}$ with circle hooks for swordfish and blue marlin, but their results for white marlin were mixed and they did not include shortfin mako in their analyses. This study is unique in that it estimated $Prob_{(A)}$ under a variety of conditions besides hook type (**Table 4**). It is of particular interest the results for swordfish. The probability of survival at haulback for this species was the lowest compared to all the other species under all conditions considered. The lowest $Prob_{(A)}$was only 0.13 for the largest animals at the warmest temperatures and with J hooks and it only increased to 0.19 for circle hooks. These particular conditions are met when large mature Northern swordfish migrate south to warmer waters to spawn (Schirripa *et al.* 2017). However, this low probability of survival increases up to 0.46 and 0.35 for circle and J hooks, respectively, for the smallest animals caught in cooler waters. This is significant because, as explained before, the minimum size limits adopted by ICCAT for swordfish result in a significant amount of regulatory discards of which at most only less than 50% appear to be alive at haulback. Further studies are required to fully investigate the probability of survival of fish below the size limit and its impact as a management measure. High at haulback mortality of fish below the size limit can hamper the effectiveness of minimum size as a conservation measure.

Longer soak time resulted in higher mortality, which was an expected result that has been observed in other studies (Nunes *et al*. 2018, Diaz and Serafy 2005). The exception was blue marlin, where soak time had a positive effect on the probability of survival. This could be due to the fact that, due to the nature of deploying a pelagic longline, not all deployed hooks are in the water for the same period of time. Fish that are caught earlier after the longlines are set will experience longer soak time than those caught, for example, during the haulback. Therefore, longline sets that caught more fish during the haulback will show higher $Prob_{(A)}$ than those were most fish were caught while setting the longlines regardless of the soak time. This confounding effect might partially explain the unexpected result with blue marlin.

One aspect that was not considered in this study is the effect of circle hooks on catch rates. Particularly for bycatch species, the conservation benefits resulting from increases in $Prob_{(A)}$due to the use of circle hooks could be overridden by increases in catch rates. In the U.S. pelagic longline fleet, the use of circle hooks has resulted in either decreases or no significant changes in catch rates of blue and white marlin (Diaz 2008, Serafy *et al*. 2012). Therefore, the use of circle hooks and the associated higher $Prob_{(A)}$ have a clear conservation benefit. In the case of swordfish, studies have shown that catch rates can decrease (Watson *et al*. 2005, Piovano *et al*. 2009) or remain unchanged (Foster *et al*. 2012) with circle hooks compared to J hooks. This perceived negative effect is one of the reasons why ICCAT still has not adopted the mandatory use of circle hooks. However, the increase $Prob_{(A)}$ with circle hooks would reduce mortality of swordfish that have to be discarded due to minimum size limits. The use of circle hooks as a conservation measure for shortfin mako, and sharks in general, still requires further research. It has been hypothesized that the lower retention rates found in several shark species when J hooks were used could be the result of bite-off (Rosa *et al*. 2020, Afonso *et al*. 2012). In other words, when using J hooks it is possible for sharks hooked deeply in the mouth or stomach to bite the leaderoff andrelease themselves from the gear. Sharks are more likely to be hooked in the jaw with circle hooks than with J hooks (Epperly *et al*. 2012), which could explain the higher retention rates (Rosa *et al*. 2020). Afonso *et al*. (2012) estimated that if in their study all bite-offs were due to sharks, then the catch rates between circle and J hooks would be the same. Up to today, there are no data on the survival of sharks that bite off the leader and escape capture and swim away with a hook in their guts and a trailing leader. In general, it has been shown that fish caught in the jaw have lower mortality than those deep hooked (Epperly *et al*. 2012, Nunes *et al*. 2019). The sharks that bite off the leaders might experience a level of post-release mortality that might override any conservation benefit of the apparent lower catch rates when J hooks are used.

In summary, the use of circle hooks increases the at-haulback survival of the species considered in this study when all the covariates in the models remain constant. However, these covariates significantly affect the estimated probabilities so they must be taken into account when considering the adoption of circle hooks as a measure to increase at haulback survival. This study also showed that the circle hooks, which were adopted as a sea turtle bycatch mitigation measure by the U.S. pelagic longline fleet in both the Pacific and Atlantic oceans, also increase the at-haulback survival of other species and, therefore, it addresses some of the research needs to develop and implement Ecosystem Based Fisheries Management.

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Table 1. Lower (LL) and Upper (UL) limit of the range of temperatures (Cº), fish length in centimeters (FL = fork length, LJFL = lower jaw – fork length), and soak time (hours) used in the analyses for each species.

		LL	UL	Median
Shortfin mako	Cº	15	28	21
	FL	75	212	141
	Soak	4.3	12.4	8.3
Swordfish	Cº	16	30	25
	LJFL	80	201	131
	Soak	5.2	11	8.3
Blue marlin	Cº	23	31	28
	LJFL	129	270	200
	Soak	5	11.2	8.1
White marlin	Cº	23	31	27
	LJFL	120	180	150
	Soak	5	11.3	8.2

Table 2. Number of sets that caught at least one individual and total number of individuals used in the analysis, range of number of fish caught in one set and median value.

Species	No. Sets	Total No. Individuals	No. of fish per set	Median
Shortfin mako	2,358	5,986	1-51	1
Swordfish	12,162	93,309	1-145	1
Blue marlin	2,414	3,282	1-10	1
White marlin	2,218	3,774	1-30	1

Table 3. Odd ratios for each hook type, associated confidence interval, $Prob_{(A)}$ is the probability of being alive at haulback, and SE is the estimated standard error of $Prob_{(A)}$the species considered in this study.

		Odds ratio	95% Wald Confidence interval	$Prob_{(A)}$	SE
Shortfin mako	Circle Hook	1.342	1.155 – 1.561	0.73	0.070
	J Hook	0.745	0.641 – 0.866	0.66	0.031
Swordfish	Circle Hook	1.677	1.623 - 1.732	0.30	0.014
	J Hook	0.596	0.577 – 0.616	0.20	0.009
Blue marlin	Circle Hook	1.350	1.142 – 1.595	0.72	0.072
	J Hook	0.741	0.627 – 0.876	0.66	0.045
White marlin	Circle Hook	1.050	0.910 – 1.211	0.56	0.053
	J Hook	0.953	0.826 – 1.099	0.54	0.049

Table 4. Estimated significant parameters, standard errors, and probabilities of the logistic regressions for (a) shortfin mako, (b) swordfish, (c) blue marlin, (d) white marlin.

(a)

	Estimate	Standard Error	Wald Chi-Square	Pr>ChiSq
Intercept	1.4594	0.1550	88.629	< 0.0001
Hook type (circle)	0.1450	0.0385	14.178	0.0002
Soak time	-0.0749	0.0178	17.694	< 0.0001

(b)

	Estimate	Standard Error	Wald Chi-Square	Pr>ChiSq
Intercept	1.0508	0.09430	124.195	< 0.0001
Hook type (circle)	0.3999	0.05610	50.8037	< 0.0001
Length	-0.0022	0.00027	65.5632	< 0.0001
Soak time	-0.0416	0.00676	37.8624	< 0.0001
Temperature	-0.0620	0.00125	831.397	< 0.0001
Hook Type * Soak	-0.0204	0.00669	9.30090	0.0023

(c)

	Estimate	Standard Error	Wald Chi-Square	Pr>ChiSq
Intercept	0.687	0.3250	4.4680	0.0345
Hook type (circle)	0.167	0.0430	15.040	0.0001
Length	-0.0029	0.0012	5.5303	0.0184
Soak time	0.0863	0.0272	10.091	0.0015

(d)

	Estimate	Standard Error	Wald Chi-Square	Pr>ChiSq
Intercept	14.859	4.8001	9.5833	0.0020
Temperature	-0.4278	0.1774	5.8176	0.0159
Length	-0.0083	0.0317	7.7443	0.0054
Temperature*Length	0.0025	0.0012	4.5615	0.0327

Table 5. Estimated probabilities of survival at haulback (*Prob*$_{(A)}$) for the upper limit and lower limit values of the significant variable in each full model. Variables with blank cells correspond that those that were not significant in a particular full model.

SPECIES	HOOK	LENGTH	TEMP	SOAK	PROB
Shortfin mako	Circle			12.4	0.66
	Circle			4.30	0.78
	J			12.4	0.60
	J			4.40	0.73
Swordfish	Circle	193	30	10.5	0.18
	Circle	105	16	5.7	0.47
	J	195	30	10.6	0.13
	J	80	17	5.3	0.34
Blue marlin	Circle	270		5	0.62
	Circle	150		11.1	0.80
	J	250		5.2	0.56
	J	150		11.1	0.74
White marlin	Circle	176	30		0.38
	Circle	120	23		0.79
	J	180	31		0.38
	J	120	23		0.79