Field study to assess some mitigation measures to reduce bycatch of marine turtles in surface longline fisheries

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"Assessment of turtle bycatch"

Final Report

Submitted by

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Lamans s.a. Management Services
and
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1 General Summary

1.1 Background

There are growing concerns about the numbers of turtles being caught in longline fisheries and the impact this might have on their populations worldwide. All species of marine turtles are protected reptiles and are considered to be endangered or threatened. Depending on geographic region, the two species most commonly caught in longlines are loggerhead turtles (*Caretta caretta*) and leatherback turtles (*Dermochelys coriacea*). Turtles become caught on longlines mainly due to their general ecology, feeding behaviour and the overlap in their geographical and depth distributions with the target species of major longline fisheries — tuna, swordfish and other billfish.

A number of previous studies have shown that turtle bycatch may be reduced by changing the type of hook from the traditional 'J hooks' (a hook shaped like a J) to circle hooks, which may be more difficult for turtles to swallow, or by using different bait, for example mackerel, which may come free of the hook more readily than squid bait, which is swallowed whole together with the hook.

J-hook and circle hook

Mackerel bait thawing

Squid bait

This project worked with fishermen to test hook and bait types in European surface longline fisheries in the Atlantic, eastern and western Mediterranean with the aim of assessing whether they reduce turtle by-catch. Clearly, gear modifications to reduce turtle bycatch may also have an effect on the ability of the gear to catch the target species, swordfish. This is obviously a prime concern of fishermen, so the effect of gear modifications on target species catch rates were also assessed, allowing potential measures to be identified which not only reduce turtle bycatch but also minimise any detrimental effect on catches of swordfish.

The project was funded by the European Commission Directorate-General for Fisheries, and was undertaken by a consortium led by MRAG Ltd (UK), with AZTI Tecnalia (Spain) and Lamans s.a. (Greece).

1.2 Approach

An initial review of previous studies on reducing turtle bycatch in surface longline fisheries enabled a robust experimental design to be developed for three at-sea experiments using commercial fishing vessels. A survey of fishermen was also undertaken in the three areas to investigate the current gears in use, fishermen's perception of the problem of turtle bycatch and their attitude to potential changes in hook and bait type.

The fishing experiments tested the effects of different hook and bait types on both turtle and swordfish catch rates. The trials were conducted in collaboration with the fishing industry in the following fisheries:

- Greek longline fishery in the eastern Mediterranean, between 30 May and 8 September 2007;
- Spanish longline fishery in the western Mediterranean, between 11 July and 17 September 2007;
- Spanish distant water longline fishery in the south-east Atlantic Ocean, between 28 February and 4 April 2007.

Experimental fishing was carried out by one vessel in each region with observers collecting data on turtle bycatch and on target species weights and catch rates. Two longlines were set each day, one with squid bait and one with mackerel bait, and each with alternating magazines of J hooks, 0^{o} offset 16/0 circle hooks and 10^{o} offset 18/0 circle hooks. 35 trials (70 lines) were carried out in the Atlantic, and 60 trials in each of the eastern and western Mediterranean fisheries.

1.3 Results

1.3.1 Turtle catches

A total of 124 turtles were caught in the trials — 9 leatherback turtles and 115 loggerhead turtles. More loggerhead turtles were caught in the Atlantic and western Mediterranean (36 and 77 respectively) than in the eastern Mediterranean (2). Most turtles were released alive, but 8 loggerhead turtles died. 37 of the released turtles had injuries caused by interaction with the fishing gear.

Bycatch rates of turtles were different in each region, and were lowest in the eastern Mediterranean where 2007 was an unusual year with very low catches of both swordfish and turtles in the fishery in general. The results from this region should therefore be treated with caution, as the catches of turtles were too low to undertake meaningful statistical analysis.

Turtle bycatch was significantly affected by bait type. Turtles were consistently caught more frequently on squid bait than on mackerel bait, and 82% of all loggerhead turtles were caught with squid.

There was no significant difference in turtle bycatch rates between circle hooks and J hooks, although there was an indication that 18/0 circle hooks were less likely to be swallowed than J hooks or 16/0 circle hooks and, in the western Mediterranean, that turtle catch rate on circle hooks was slightly lower than on J hooks.

1.3.2 Swordfish catches

Swordfish catch rates were not significantly affected by bait type in any region. However, hook type did have an influence in the western Mediterranean, with significantly higher catch rates of swordfish on J hooks compared to circle hooks.

The size of swordfish caught was not affected by hook type, but bait type did have an effect in the western Mediterranean, where larger swordfish were caught on squid bait compared to mackerel bait.

Effects of hook and bait on other species caught during the trials as secondary target species or bycatch were also monitored. Bluefin tuna catches were significantly lower on mackerel compared to squid bait in the western Mediterranean.

We found that the combination of hook and bait type that resulted in the lowest bycatch of turtles and the highest catches of swordfish was J hooks with mackerel bait.

1.4 Questionnaire results and fishermen's opinions

92 questionnaires were carried out with fishermen from the Atlantic, eastern and western Mediterranean fisheries, representing 7% of the vessels fishing. Their primary fishing activity was swordfish, with albacore and other tuna of secondary importance.

Attitude to and awareness of the turtle bycatch problem reflected its severity — in the region with highest number of encounters (the western Mediterranean) the majority of respondents (75%) considered that something should be done to reduce turtle bycatch. Although most did not have a clear idea what should be done, some suggestions included changing from squid bait to mackerel in the summer; setting the gear deeper; and stopping fishing in the months when catches of turtles are highest (with some compensation from EU funds), generally July and August.

Fishers were generally resistant to the idea of changing from J hooks to circle hooks, as they regarded circle hooks to be less effective in catching swordfish. Most fishermen use a combination of mackerel and squid bait, and although they were also resistant to changing bait to other species, changing the relative proportions of mackerel and squid is likely to be more acceptable to them.

1.5 Conclusions

Our results suggest that in all regions the greatest reduction in turtle bycatch rates, with the least effect on swordfish catch rates, would be achieved by using only mackerel bait instead of squid bait and continuing to use J.

Since most turtles are caught in the summer months (June - September) in the Mediterranean, the greatest benefit to turtles would be from a requirement to use only mackerel bait in these months. Avoiding fishing for swordfish in the peak months of July and August was also suggested by a few fishermen, if compensations were provided for the negative economic impact of such a measure. Our results suggest that turtle catches could be reduced by several thousand a year in the Mediterranean simply with a move from mixed bait to mackerel bait on J hooks in the summer.

Our results do not support a move from J hooks to circle hooks as a way of reducing turtle bycatch. Although we did not find any significant differences in catch rates between hook types, other studies have suggested large 18/0 circle hooks are less likely to be swallowed by turtles than J hooks and cause lower mortality to turtles overall. This is one reason they are advocated. There is some evidence from these trials however, that it is more difficult to release turtles from circle hooks than J hooks, which could also affect turtles' chances of survival and requires further investigation

2 Executive Summary

2.1 Introduction

1. The project FISH/2005/28A had as its objective an evaluation of the applicability, and an assessment of the consequences, of adopting some technical solutions to reduce the bycatch of turtles in EU surface longline fisheries. The specific technical solutions to be tested were the bait and type of hook used in swordfish fisheries, which in previous studies have been shown to be effective in reducing turtle bycatch.

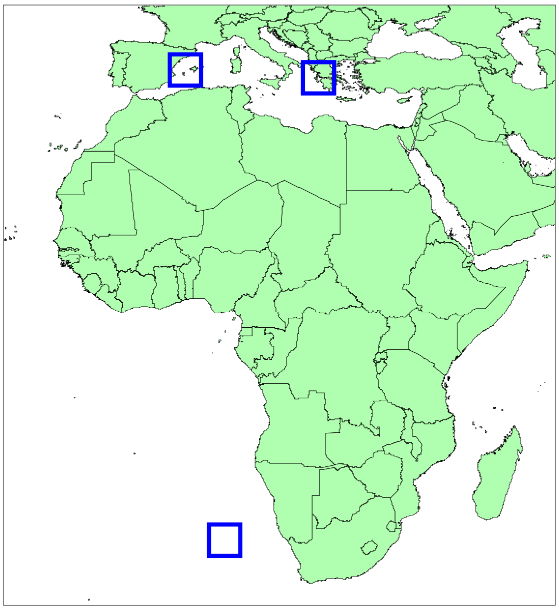
2. An initial review of previous studies on mitigation measures for reducing turtle bycatch allowed a robust design to be developed for a series of three at-sea experiments on board commercial fishing vessels. These took place in swordfish fisheries in three sea areas, the southeast Atlantic, the eastern Mediterranean and the western Mediterranean and rigorously tested three types of hooks and two types of bait. A survey of fishermen was also undertaken in the three areas to investigate the current gears in use, fishermen's perception of the turtle bycatch problem and their attitude to changes in gear.

2.2 Experimental trial results

3. All trials used the same experimental design. Two longlines were configured and set each day, each comprising a line suspended at intervals from floats. The number of hooks between floats was 5, and the groups of 5 hooks had different experimental hook configurations, alternating repeatedly along the line, of either J hooks, 0° offset 16/0 circle hooks or 10° offset 18/0 circle hooks. The two longlines had different bait, either mackerel or squid.

4. Test bait and hook types were standardised between the three different experimental regions. Other elements of longline configuration were standardised as far as possible. However, in order to learn the most about the effect of gear changes on local fishing methods, each of the three regional trials also attempted to conform to the most frequently used commercial longline gear and configuration in that area. Mean setting depth was 45m in the Atlantic, 33m in the eastern Mediterranean and 32m in the western Mediterranean.

5. A total of 35 experimental fishing trials (70 lines) were set in the Atlantic, between 28 February and 4 April 2007, in an area off the Namibia/South African border at approximately 28°S 5°E on a Spanish longliner. Between 30 May and 8 September 2007, 60 trials were undertaken in Greek waters on a Greek longliner in the eastern Mediterranean, and between 11 July and 17 September 2007 the same number of trials were undertaken in the area of the Balearic Islands in the western Mediterranean on a Spanish longliner. The total number of hooks set in the Atlantic, eastern and western Mediterranean was 44 705, 60 000 and 71 100 respectively.



Trials for the impact of different bait and hook types took place in three regions – the south Atlantic, eastern Mediterranean and western Mediterranean.

6. A total of 124 turtles were caught, 9 leatherback turtles and 115 loggerhead turtles. Greater numbers of loggerhead turtles were caught in the Atlantic and western Mediterranean (36 and 77 respectively) than in the eastern Mediterranean (2). The majority of turtles were released alive, but 8 loggerhead turtles died. 37 of the released turtles had injuries caused by interaction with the fishing gear. Because of the scarcity of leatherback turtle catches in our data, only loggerhead data were subjected to statistical analysis.

7. Data were analysed using generalised linear models (GLM). Turtle capture events were rare, and were analysed using GLMs with a logit link to investigate the importance of hook and bait effects on the probability of capturing a turtle on a hook. The effect of other factors, such as sea surface temperature and hook position within a magazine, and other responses such as the anatomical position of hook location, were also investigated. Swordfish capture events were analysed using binomial GLMs on the probability of capture of swordfish on individual hooks, and also delta-lognormal models for swordfish catch weight by set.

8. Catch rates of turtles were different between the different regions, with catch rates in the eastern Mediterranean being particularly low. 2007 was an unusual year in the eastern Mediterranean with unusually low catches of swordfish experienced in the fishery in general. The results from this region should therefore be treated with caution, as the catches of turtles were too low to undertake meaningful statistical analysis.

9. Bait type had a significant effect on turtle bycatch in both the Atlantic and the western Mediterranean, with squid bait consistently catching more turtles than mackerel bait. 82% of all loggerheads caught were hooked with squid bait. Catches of turtles were often aggregated, with one set catching 13 turtles. Two longlines were set each day, one with squid and one with mackerel bait, and those sets that caught more than four turtles were always baited with squid.

10. There was no evidence for different catch rates of turtles with hook type in the Atlantic, but the trend in the western Mediterranean was for lower turtle catch on both circle hook types compared with J hooks, with 16/0 circle hooks decreasing the probability of turtle capture. However, these trends were not significant (p<0.01).

11. Although neither hook type nor bait had a significant effect on anatomical hooking location on turtles, there was evidence that 18/0 circle hooks were less likely to be swallowed than J hooks or 16/0 hooks (all regional data combined).

12. Swordfish catch rates by number were greatest in the western Mediterranean, where there were statistically significant hook effects (highest catch rates being on J hooks) but no significant bait effects (p>0.01). Neither hook nor bait had a significant effect on catch rates in the Atlantic, and overall, although swordfish catch rates were slightly lower on mackerel than squid this was not significant. Larger fish were caught on squid bait, but this effect was only significant in the western Mediterranean and hook type did not have a significant effect on swordfish size in any area alone.

13. Examining the effect of gear combinations on bycatch, bluefin tuna bycatch was significantly lower in the western Mediterranean with mackerel bait. There was a non-significant trend for lower catches of bluefin tuna on 16/0 and J hooks in the western Mediterranean, and for lower catches of blue shark and billfish on squid bait in the Atlantic.

14. When the data on turtles and swordfish were combined it was clear that the lowest number of turtles caught per kg of swordfish was predicted to be for mackerel bait combined with J hooks in both the Atlantic and western Mediterranean, and significantly lower than squid bait combined with either 16/0 or 18/0 circle hooks.

2.3 Questionnaire results

15. A total of 92 questionnaires were returned from fisheries in the Atlantic, eastern and western Mediterranean, overall representing 7% of the vessels fishing. The primary activity of most of these vessels was swordfish, with albacore and other tuna being of secondary importance. Most fishers use light sticks as an attractant device when fishing for swordfish, and the most popular colours are blue and green.

16. Fishers in the western Mediterranean were most resistant to the idea of using circle rather than J hooks to catch swordfish, 89% saying that it would not be possible to change and citing previous experience of trials in which circle hooks had not proved effective at catching swordfish, but about half of respondents in the other fisheries indicated that it might be possible to change if tests demonstrated their effectiveness. Catch rates of swordfish by hook type observed during the western Mediterranean trials corroborate the previous trial results, being lower for circle hooks than for J hooks.

17. All respondents used both fish and squid bait, those in the Atlantic and western Mediterranean generally using mixed bait on single lines. In the eastern Mediterranean a higher proportion of fishers use single bait types and

most of those use fish. In the western Mediterranean, a higher proportion of squid is used in the summer, possible reasons being faster disintegration of fish bait in warmer water and resultant ease of removal from hooks. Again there was resistance to change; in all areas more than 60% of fishers indicated that it would not be possible to change their bait, but the alternatives being considered here were generally other fish. Fishers already mostly use mackerel and squid, and appeared to be equally happy with the effectiveness of these two bait types, so their resistance to moving to a majority of one or other bait type may not be great, subject to market availability and price.

18. Attitude to and awareness of the problem reflected the severity of the turtle bycatch problem. In the region with highest number of encounters (the western Mediterranean) the majority of respondents (75%) considered that something should be done to reduce turtle bycatch. Although most did not have a clear idea what should be done to reduce turtle bycatch, some suggestions included changing from squid bait to mackerel in the summer; setting the gear deeper; and stopping fishing in the months when catches of turtles are highest (with some compensation from EU funds), generally July and August.

2.4 Conclusions

19. Our results suggest that the action that would create the largest reduction in turtle catch rates and have the least effect on swordfish catch rates would be to stop using squid bait and use only mackerel bait. This result was consistent across all regions.

20. Our results do not support a move from J hooks to circle hooks as a means of reducing turtle bycatch rates. Hook type did not significantly affect turtle catch rates in any region, whereas swordfish catch rates were significantly lower on circle hooks in the Mediterranean.

21. The results from other studies of this problem in other geographical areas have not been consistent. Some have found that mackerel bait would reduce turtle bycatch rates, and some have found that circle hooks create significant reductions in turtle bycatch compared to J hooks. Results have also been mixed in relation to whether 16/0 or 18/0 hooks create the most significant effect. Although there was some indication in our results that 16/0 circle hooks did result in lower catches of turtles, we found that hook effects were rarely significant in our experiments whereas bait effects were consistently statistically significant ($p<0.01$).

22. There are several potential causes for the variety of hook type effects in such experiments, including the fact that there are quite a variety of traditional hooks in use around the world and that the circle hooks tested have not always been the same. Thus it would appear that unlike bait effects, hook effect results are quite fishery specific.

23. Extrapolating our results to the whole fishery suggests that for the western Mediterranean, the area with the highest turtle catches, turtle catches could be reduced by several thousand a year simply with a move from mixed bait to mackerel bait on J hooks. The greatest gains in all regions would be to use only mackerel bait at times when turtles are most abundant, i.e. for the

Mediterranean, the summer months June – September, and to consider restrictions on fishing in the most vulnerable months (July and August). It should be pointed out, however, that shifting from mixed mackerel/squid to mackerel bait would imply, from our results, a decrease in swordfish kg catch rate of about 20% (implying that fishing effort would have to increase by 20% to catch the same tonnage of swordfish) and that the average size of swordfish may be reduced.

24. There is some evidence that the large 18/0 circle hooks are less likely to be swallowed than J hooks, and therefore may cause lower mortality to turtles overall. However, anecdotal information gathered during the trials indicates that once hooked, it is more difficult to release turtles from circle hooks than J hooks, and that this would also affect post-release mortality rates. It was not the object of this study to establish mortality rates of released turtles, but clearly the issue would have to be considered alongside the reduction in bycatch rates that we have investigated in order to understand the overall gains in turtle survivorship from changes to fishing gear. Such studies should be considered in the future.

3 Introduction and literature review

The purpose of this study was to evaluate the applicability and assess the consequences for EU surface longline fisheries of some technical changes in fishing operations that have already shown positive results in reducing the bycatch of turtles in other longline fisheries.

The objectives were:

1. to test the effects of different combinations of hooks and baits on catch rates of turtles and of target species in surface longline fisheries targeting primarily swordfish in the Atlantic and Mediterranean;
2. to identify the positive and negative consequences of modifications to hook or bait type;
3. to identify possible solutions and make recommendations for further actions to reduce bycatch rates of sea turtles whilst maintaining economically viable surface longline fisheries.

The approach to addressing these objectives has been implemented in three phases, all of which have now been successfully completed. In Phase 1 a review was carried out on previous studies of mitigation measures to reduce turtle bycatch in surface longline fisheries (selected parts of which form section 3.1 of this introduction). This phase also involved meetings between coordinators from each region and the fishing companies to be involved in the trials in order to refine and finalise the gear configurations for the experimental design. Databases for the processing and storage of data, development and initiation of a questionnaire survey targeted at vessel crews, and the setting up of a project website were also carried out in this initial phase. The Interim Report, which was endorsed by the Commission on 22nd February 2007, summarises in more detail activities carried out during this Phase and is included in Appendix 1: Details of Phase 1 activities from Interim Report.

Phase 2 involved the implementation of experimental fishing trials in the Eastern and Western Mediterranean and the Atlantic Ocean on board commercial fishing vessels chartered for the purpose and continuation of the questionnaire survey. Phase 3 has been recently completed and involved entry of data from the fishing experiments into a purpose designed database and analysis of those data using advanced statistical techniques. This Final Report presents conclusions and recommendations related to turtle bycatch mitigation measures in surface longline fisheries in the Mediterranean and Atlantic, supported by the results from both the experimental fishing trials and the fisher questionnaire survey.

3.1 Results of previous studies assessing mitigation measures

A considerable amount of research has been carried out into mitigation measures to reduce turtle bycatch in longline fisheries, by both academic researchers and national government institutions, focusing efforts within a number of different longline fisheries around the world including US fleets in Atlantic north east distant waters (Watson et al 2005) and the Gulf of Mexico (Watson et al. 2004); Canadian Northwest Atlantic tuna fisheries (Javitech Limited, 2002; 2003); Azores swordfish and shark fishery (Bolten et al. 2002; 2003; Bolten and Bjorndal 2003; 2004; 2005); Hawaii swordfish fishery (Boggs 2004; Dalzell and Gilman, 2006; Gilman et al., 2006; Kobayashi and

Polovina, 2005); Australia longline fisheries (Robins et al., 2002; Stobutzki et al., 2006; Ward et al., 2005); Japan longline tuna and swordfish fishery (refs from Gilman et al., 2005; Minami et al., 2006); Korea tuna longline fishery (Kim et al., 2006); Ecuador, Peru, Costa Rica and Chile mahi mahi, tuna and shark fisheries (IATTC 2006a; 2006b); Spanish swordfish fleets in the Mediterranean (Camiñas, pers.com, 2006; Sagarminaga, pers. com. 2006) and in the Southwest Indian Ocean (Ariz et al., 2006).

However, there has been some level of coordination amongst these separate research groups and their studies (Watson et al. 2002; 2003; 2004) through workshops (Anon, 2003; Balazs and Pooley,1994; FAO, 2004; 2005; Long and Schroeder, 2003) and RFMO working groups (WCPFC, 2004; IATTC, 2006b). Research can be split primarily into two areas – research assessing variations in turtle bycatch due to gear type and setting procedures through analysis of national observer programme data (Garrison, 2003; Gilman et al., 2006; Javitech Limited, 2002; 2003), and research specifically testing alterations to gear configuration and setting procedures onboard chartered or collaborating fishing vessels (Bolten et al., 2005; Watson et al., 2005).

Gilman et al (2006) reviewed work already completed by May 2005 and also summarized planned future studies. In doing so a number of common mitigation measures amongst these studies have been determined, including hook type; setting depth; plus day versus night setting, bait type, blue dyed versus untreated bait. This review focuses primarily on studies testing hook and bait types in fisheries relevant to the trials planned for this study.

3.1.1 Alterations to gear configuration and gear used

3.1.1.1 Hook type and/or size

Hook shape and size can influence turtle bycatch in a number of ways. Firstly, the size influences the probability that the hook is swallowed and the turtle becomes hooked internally in any situation where a turtle is attempting to take bait. It has been suggested that this in turn can seriously increase post-hooking mortality (FAO, 2005; Løkkeborg, 2004; Gilman et al., 2006); however, there is some discussion of the scientific data supporting this claim (SEC, 2005). The influence of hook size is also dependent to a certain extent on the size of turtle interacting with it (SEC, 2005; Watson et al., 2003), and adds a further complication in choosing a hook size effective in reducing turtle bycatch across large geographical areas where species and average size of turtles predominating is likely to vary (Watson et al., 2005).

Behavioural studies on captive turtles carried out by NOAA (Watson et al., 2004) testing the effect of hook size on the likelihood turtles will swallow them indicated that loggerhead turtles had a much lower tendency to ingest hooks larger than 51mm in width, than smaller hooks. (from Løkkeborg, 2004)

The shape of the hook can also influence the likelihood of it being swallowed, and for this reason considerable attention has been given to circle hooks – hooks which have a point turned back to the shank (Kerstetter and Graves, 2006). Circle hooks tend not to get snagged on soft tissue when swallowed, only becoming hooked on the jaw as the hook rotates and exits the mouth (Kerstetter and Graves, 2006) as opposed to being hooked in the pharynx, oesophagus or stomach (Watson et al., 2005); for this reason they have already been favoured in a number of longline fisheries, such as US Pacific Northwest and Japanese tuna fisheries (Watson et al., 2005) as both target and bycatch species are landed in better condition. If animals are hooked in the mouth only, they are often still alive on haul-back as they have been able to keep swimming whilst hooked, and therefore any fish by-catch species have a better chance of survival on release (Kerstetter and Graves, 2006; Watson et al., 2005). Circle hooks also minimize foul hooking (e.g. becoming hooked externally) and internal/external bleeding (Garrison, 2003; Javitech, 2002; Watson et al., 2005). Both circle and J hooks may also be 'offset' – where the hook point is bent sideways relative to the shank and are thought to retain fish better than straight hooks (0º offset) and are also easier to bait (Watson et al., 2005) (Figure 1).

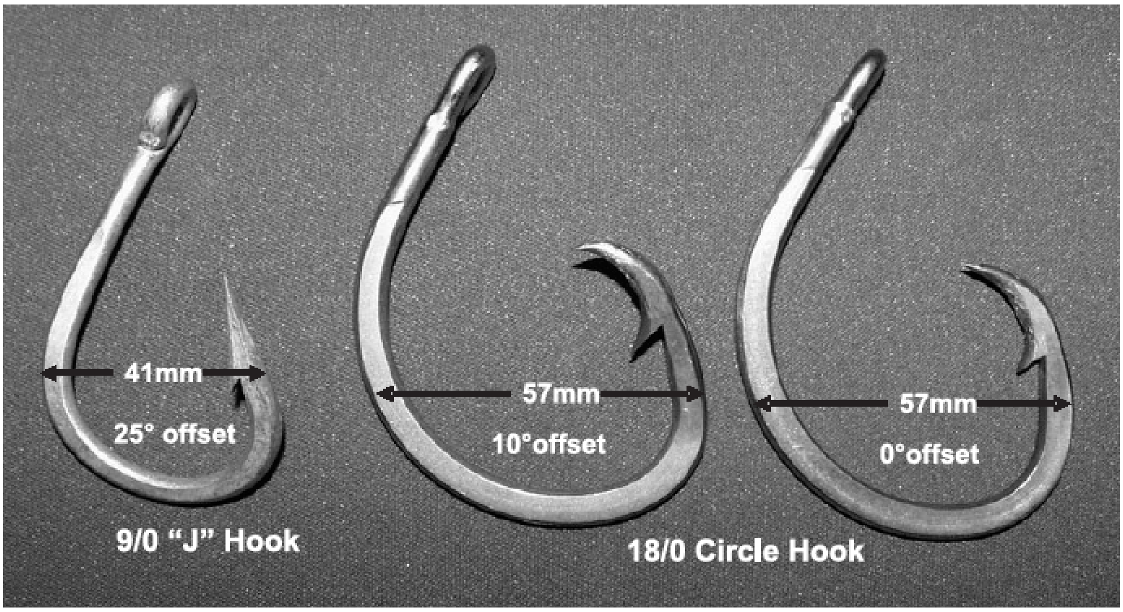


Figure 1 **Examples of hook designs, illustrating 9/0 J hook with 25° offset and 18/0 circle hook with 0° offset and 18/0 circle hook with 10° offset (taken from Watson et al., 2005).**

3.1.1.1.1 Experiments testing circle versus J-type hooks

A number of experimental studies have been carried out by Bolten et al (2002; 2003) and Bolten and Bjorndal (2003; 2004; 2005) testing various hook types on industrial fishing vessels operating in the swordfish and blue shark directed fisheries around the Azores. The work has so far consisted of 4 research phases carried out in 2000 (Phase 1) when straight 9/0 J-hooks, 25 º offset 9/0 J-hooks and 0º offset 16/0 circle hooks were tested (Bolten et al., 2003); in 2001 (Phase 2) when straight 9/0 J-hooks, 0º offset 16/0 circle hooks and 0º offset 18/0 circle hooks were compared (Bolten et al., 2003); in 2002 (Phase 3) when 0º offset 16/0 circle hooks, offset 16/0 circle hooks and offset 18/0 circle hooks were compared (Bolten and Bjorndal, 2004); and in 2003 (Phase 4) when 0º offset 16/0 circle hooks, 0º offset 18/0 circle hooks and Japanese tune hooks (3.6 mm) were tested (Bolten and Bjorndal, 2005). Squid was used as bait in all sets in all phases, and hooks were configured alternately on the lines (e.g. A, B, C, A, B, C) so that hook position varied with hook type (Bolten et al., 2003; Bolten and Bjorndal, 2004; Bolten and Bjorndal, 2005).

Data has been analysed both separately and combined over the years with the following results. There were no significant differences in catch rates of loggerheads between hook types compared in phase 1, 2, or 3 (Bolten and Bjorndal, 2005); but other authors suggest this may be a result of the relatively small sample size compared to other trials (Gilman et al., 2006c). However, in phase 4, the Japanese tuna hooks caught significantly more turtles than the other two hook types, and significantly fewer turtles were caught with the 18/0 circle compared only with the 16/0 circle hook. For Phases 1-4 combined, there was a significant difference in the location of hooking among circle, Japanese tuna and J-type hooks (Bolten and Bjorndal, 2005). 60% of loggerheads caught on J-type hooks and 52% of loggerheads hooked on Japanese tuna hooks were hooked in the throat, whilst only 13% of loggerheads caught on the circle hooks were hooked in this way. Most of the few leatherbacks caught were entangled in lines, although 2 were hooked in the mouth on 16/0 circle hooks. These higher deep-hooking rates for J-type and Japanese tuna hooks have important implications for sea turtle mortality. The size ranges of turtles caught by longlines were significantly different to the overall size distribution of loggerheads found in Azorean waters, and were more similar in size to those which are reported to recruit to the neritic foraging grounds of the western Atlantic (Bolten and Bjorndal, 2005).

There was some indication that catch rates of blue shark were elevated with circle hooks in Phase 1 and 2, but the authors suggested that this needs further investigation (Bolten and Bjorndal, 2004).

The most extensive trials (with respect to fishing effort) testing mitigation measures to reduce turtle bycatch in swordfish fisheries have been carried out in the Atlantic by NOAA Southeast Fisheries Science Centre (SEFSC) in cooperation with the U.S. Pelagic longline fishing industry over a 3 year period at Grand Banks (NED waters) between 2001 and 2003 (Watson et al; 2003; 2004; 2005).

The trials were designed to test both circle hooks and mackerel bait against the traditional gear used in the U.S. western Atlantic longline fishery for swordfish which were 20º-25º offset 9/0 J hooks and whole squid bait (Watson et al., 2005). The four treatments tested (each of ~71 000 hooks) against this control gear (of ~142 000 hooks) were 0º offset 18/0 circle hooks with squid bait; 10º offset 18/0 circle hooks with squid bait; 20º-25º offset 9/0 J hooks with mackerel bait; and 10º offset 18/0 circle hooks with mackerel bait. Here we summarize only the effects of hook type; results for bait types in combination with hook types are given below in 3.1.1.2.

When compared to the control hook (20º-25º offset 9/0 J hooks) and bait, 0º offset 18/0 circle hooks with control (squid) bait significantly reduced loggerhead catch by 87% (CI = 65-96%) and leatherback catches by 64% (CI = 32-81%), while 10º offset 18/0 circle hooks with control (squid) bait significantly reduced loggerhead catches by 85% (CI = 65-94%), and leatherback catches by 50% (CI = 12-72%). CPUE of loggerheads and leatherbacks for sets using control hooks with control bait were both ~0.5 turtles per 1000 hooks (n = 142 701 hooks). When data for both test circle hooks were combined on sets using control bait (squid), CPUE was ~0.05 turtles per 1000 hooks for loggerheads and ~0.22 turtles per 1000 hooks for leatherbacks Watson et al., 2005).

Additional results worth noting from this study are that target species (e.g. swordfish) catch rates were significantly reduced by 33% (CI = 19-46%) on 0º offset 18/0 circle hooks with control (squid) bait and by 29% (CI = 14-44%) on 10º offset 18/0 circle hooks with control (squid) bait (Watson et al., 2005). Bigeye tuna and blue shark catches were slightly increased with circle hooks and squid bait, but these differences were only significant for shark catches (Watson et al., 2005).

Lower target catch was also illustrated by trials in the Hawaii longline fishery for swordfish, where swordfish caught on 18/0 circle hooks were significantly smaller in size that those caught on J-hooks (Boggs, 2003), and as early research developed it was suggested that offset hooks might retain more of the target species catch, whilst still being too large for most turtles to swallow. Research is also underway to determine whether these results might be a reflection of baiting techniques and feeding behaviour of both target and turtle species (Gilman et al., 2006a).

NOAA Fisheries Southeast Fisheries Science Centre also conducted experiments in the Gulf of Mexico (GOM) in February-April 2004, to evaluate 0º offset 18/0 circle hooks in the directed fishery for yellowfin tuna (Watson et al., 2004). These hooks were tested against 0º offset 16/0 circle hooks using sardines as bait on 3 commercial pelagic longline vessels over 61 research sets with a total of 29, 570 hooks. However, no loggerhead turtles were caught in the entire experiment and only 3 leatherbacks were caught, all foul hooked, 2 on 18/0 circle hooks (CPUE = 0.13 per hook hooks) and one on a 16/0 circle hook (CPUE = 0.068 per hook hooks) (Watson et al., 2004). The trials also indicated that 18/0 circle hooks were less efficient at catching yellowfin tuna than the 16/0 circle hooks (Watson et al., 2004).

Inter-American Tropical Tuna Commission (IATTC) began a program in the eastern Pacific in 2003 to allow coastal fishers to test circle hooks with their usual fishing practices (IATTC, 2006b). The program was initiated in Ecuador and has spread to other countries since, and is currently active in Peru, Ecuador, Columbia, Panama, Costa Rica, El Salvador and Guatemala development in Nicaragua and Mexico (IATTC, 2006b). The program involved exchange of J hooks or tuna hooks with circle hooks (mostly 16/0 circle hooks) in the two predominant longline fisheries in the region – targeting dorado (*Coryphaena hippurus*) and tunas, billfishes and sharks (TBS), and it was from the latter that most data was obtained (IATTC, 2006b). Results from the corresponding observer program are preliminary at this stage as not all data has been included and there is considerable variation between years, but an important feature at this stage is the consistency in results across countries and fleets.

Turtle catch rates on J hooks were consistently higher than 16/0 circle hooks for all regions except the southern of Peru (Figure 2). In Ecuador in 2004, 16/0 circle hooks caught 40% fewer turtles than J hooks, while in 2005 the reduction in catch rates was approximately 60%, with a sample size 3 times that of 2004 data (IATTC, 2006b). Another encouraging result, was similar hooking rates for target species in the TBS fisheries between circle and J hooks.

The largest hook offered, an 18/0 circle hook, was not accepted by the fishers, because it requires larger bait and lower catch rates have been reported (ICCAT, 2006b). Unfortunately no information on bait type is given, therefore it was difficult to ascertain whether similar problems in baiting 18/0 circle hooks to the Pacific fisheries would be experienced in our trials. Bait in our trials was a compromise between the standard size used in each of the regions and as similar size as possible amongst the regional types. The discussion of this report includes some consideration of the practicalities and efficiency of bait types when used in combination with different hooks.

Experiments comparing J-hooks (size 4.0) and circle hooks (C-15 and C-18) in the Korean Pacific tuna longline fishery (of 21 sets and 44, 100 hooks), caught 3 Olive Ridley turtles, all on J-hooks (CPUE 0.2 turtles per 1000 hooks) (Kim et al., 2006). During trials of 52 sets and 48, 600 hooks in May-September 2005, in the north western Pacific Japanese longline fishery using only squid bait, no difference in loggerhead hooking rates occurred between tuna hooks (3.8-*sun*) and small-sized circle hooks (Mutsu Hokubei type 4.3); however, loggerhead catch rates on large-sized circle hooks (5.2-*sun* – approximately the same as 18/0 circle hooks) were significantly lower (Minami et al., 2006). Ingestion rates for the larger circle hooks

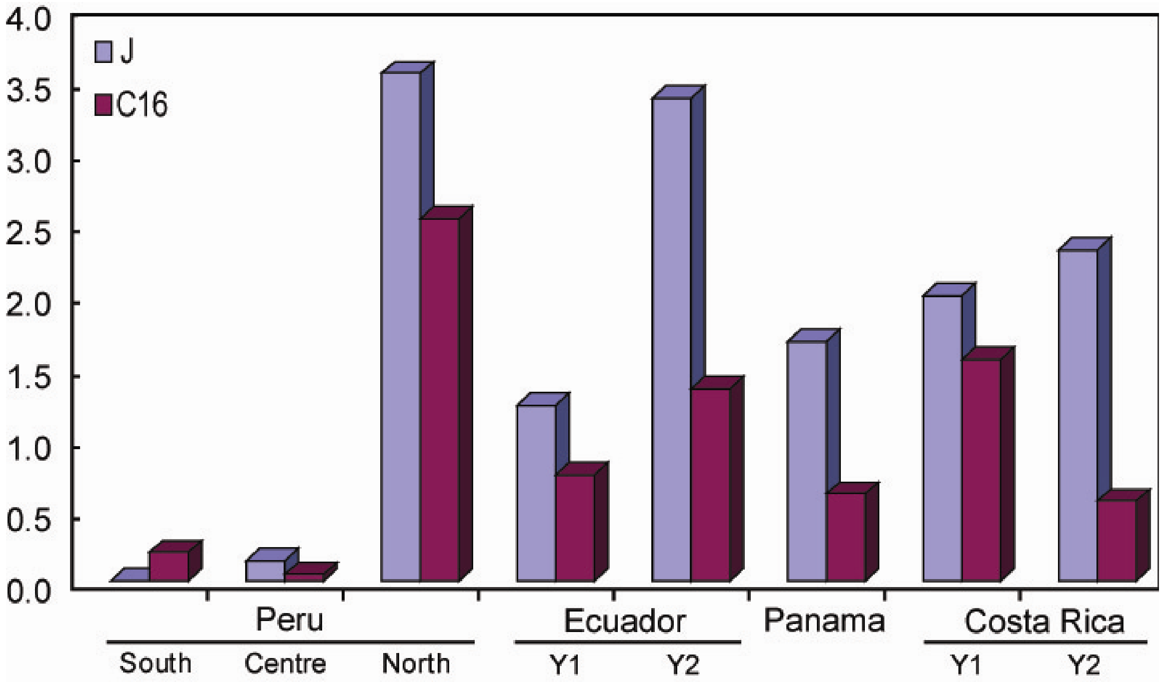


Figure 2 CPUE Sea turtles per 1000 hooks for J hooks and 16/0 circle hooks in TBS fisheries taken from IATTC (2006b). Data for Peru are from one year, For Ecuador and Costa Rica Y1 = 2004, and Y2 = 2005.

were also lower for the larger circle hooks, and in addition turtles caught in this study were larger than those caught in the Atlantic NED trials (Watson et al., 2005). The larger size frequency of turtles caught in these trials (70.3 cm average straight carapace length, 57.2-81.3 cm range) is suggested as a reason for the lack of difference in catch rates between the smaller circle hook and the tuna hooks; both these hook types are too small to prevent larger turtles swallowing them (Minami et al., 2006). However, it also indicates that the larger (5.2-*sun*) circle hooks may still be effective in reducing bycatch of turtles larger than those caught in the NED Atlantic trials which averaged 56.8cm straight carapace length, ranging from 32.4-68 cm. The 5.2-*sun* circle hooks exhibited lower billfish catch rates, but similar tuna catch rates to the smaller circle and tuna hooks (Minami et al., 2006).

3.1.1.1.2 Analysis of observer data

Statistical analysis of observer data is often hampered by confounding of factors arising from variations in setting procedures at a variety of hierarchical levels. Variations can arise amongst sets from a particular vessel; amongst fishing trips carried out by a single vessel; amongst vessels within years and between years as a result of vessels accommodating weather conditions, target species behaviour and in some cases legislation (Garrison, 2003; Gilman et al., 2006; Javitech Limited, 2002; 2003). However analysis of the data can provide useful information across large temporal and geographical ranges and highlight factors or variables in gear technology and setting procedures which can be further explored through experimental work.

For example, analyses of observer data from the Canadian longline fishery (from Canadian Atlantic waters and North East Distant (NED) waters) indicated that leatherback turtle interactions were higher with J hooks than with 10º offset 16/0 circle hooks (Javitech Limited 2002; 2003), but the data did not allow for independent statistical assessment of the influence of hook and bait type (which varied) (Gilman et al., 2006a). However, of 64 leatherbacks caught in 2001 and 2002 combined (28 and 33 respectively), 47.4% were entangled in gear; 17.7% were foul-hooked, 7.8% were hooked in the mouth, and 13.5% swallowed the hook (none in 2001). Meanwhile, of 344 hard-shelled turtles caught in both years (199 in 2001 and 145 in 2002), 62.3% were hooked in the mouth, 35.3% swallowed the hook, and 1.8% were foul-hooked or entangled (calculated from Gilman et al., 2006a). Although hook types were not distinguished in these results, they give some indication of the manner in which different turtle species are hooked by longlines in these regions.

Garrison (2003) produced a summary of variation in catch rates of target species and protected species (e.g. turtles) in U.S. pelagic longline fisheries (targeting both tuna and swordfish) between 1992 and 2002 in regions outside the NED waters by hook type and bait type. In a total of 4209 sets, hook brand and model was recorded making it possible to assign at least circle or J types to hooks as well as size (Garrison, 2003). Along the US east coast and in distant waters of the tropical north Atlantic fleets used J hooks almost exclusively, and only in the Gulf of Mexico were both circle (predominantly of 16/0 size) and J hooks (predominantly 7/0 or 8/0 size) used (Garrison, 2003). Although the paper presents some interesting data, they are difficult to interpret with considerable confounding of factors. For example, there was a strong association between bait type and hook type; with J hooks set primarily with squid baits, but sometimes in combination with various fish types, while circle hooks were set predominantly with fish baits (e.g. sardine) (Garrison, 2003). In addition, sets targeting swordfish (J hook plus squid) were typically soaked at night, while those targeting tunas (typically circle hooks and/fish baits were soaked during the day.

Bearing these factors in mind the results are summarised by Garrison (2003) as follows. Sets using J hooks had higher average catch rates of marine turtles, swordfish, bigeye tuna and bluefin tuna, whilst those with circle hooks had higher average catch rates of yellowfin and other tuna species. The highest catch rates for leatherback turtles occurred on smaller (7/0) J hooks on sets baited with squid or a mixture of squid and fish, and loggerheads were caught exclusively on sets with J hooks baited with squid (n = 416 sets) (Garrison, 2003). Swordfish catch rates were greatest on large J hooks (8/0) size), regardless of what the bait was. These results were generally consistent with results from the Watson et al., (2005) experiments in the NED waters. Although, lack of significance in the data analysis make it difficult to draw firm conclusions, comparison of vessel behaviour over time shifting to J-hooks combined with squid baits, corresponded with an increase in leatherback turtle catch rates (Garrison, 2003).

Regulations enforced within the U.S. Hawaii-based pelagic longline swordfish fishery in May 2004, changed the type and size of hook and bait used (from 9/0 J hook with squid bait to 10º offset 18/0 circle hooks with fish bait) (Dalzell and Gilman, 2006). This legislation enabled some comparative analysis over time of the U.S. National Marine Fisheries observer program database aimed at exploring effects on turtle bycatch as a result of these changes, despite some confounding factors caused by regulations brought in to reduce seabird interactions which came into effect in June 2001 (including night setting and use of blue-dyed bait). While it was not possible to determine single factor effects, the catch rates of loggerhead, leatherback and combined turtle species catch rates declined by 90%, 82.8% and 89.1% respectively from the period before the turtle regulations came into effect to the period afterwards (Dalzell and Gilman, 2006). The analysis also indicated that a larger proportion of turtles were lightly hooked (e.g. in the mouth or body) or entangled after the regulations came into force in 2004, but these differences were not significant when data for individual species were analysed (Dalzell and Gilman, 2006). Loggerhead turtles caught after May 2004 were on average larger in size than those caught before this date; this is suggested to be due incapacity of smaller turtles to swallow the wider 18/0 circle hook compared to the narrower 9/0 J hooks previously used (Dalzell and Gilman, 2006). It is possible that any of these post-regulation variations in turtle bycatch, may also be related to the changes in setting procedures (e.g. from day to night). However, general patterns reflect results from controlled experiments which tested wider circle hooks against J or Japan hooks, and fish compared to squid bait in the same fishery (Dalzell and Gilman, 2006).

3.1.1.2 Bait type and modifications

To date, the most extensive trials to test bait types as mitigation measures in swordfish fisheries were those carried out by NOAA SEFSC between 2001 and 2003 (Watson et al., 2005). Initial trials involved testing blue dyed squid bait versus natural squid, in combination with hooks adjacent to the float line or hooks 20 fathoms away from float lines, but there was no significant difference in catch rates amongst either of the treatments and the control (Watson et al., 2002). Studies on captive turtles (Løkkeborg, 2004) exploring feeding behaviour of turtles when presented with different bait types, illustrated that the turtles ignored blue-dyed squid bait.

The four treatments (each of ~71 000 hooks) tested in later more extensive trials included 0º offset 18/0 circle hooks with squid bait; 10º offset 18/0 circle hooks with squid bait; 20º-25º offset 9/0 J hooks with mackerel bait; and 10º offset 18/0 circle hooks with mackerel, against control gear (~142 000 hooks) of 20º-25º offset 9/0 J hooks and whole squid bait (Watson et al., 2005).

The highest reductions in loggerhead catch rates (reduction by 90%, CI 70-97%),were achieved with mackerel bait combined with the 18/0 circle hook, however even in combination with the control J-hooks, loggerhead catches were significantly reduced by 71% (Watson et al., 2005). Meanwhile, the largest reduction in leatherback catch rates was achieved with mackerel bait; J hooks with mackerel bait significantly reduced their catch rates by 66% and when circle hooks combined with mackerel bait significantly reduced their catch rates by 65% (Watson et al., 2005).

Analysis of the observer data from the Canadian longline fishery (from Canadian Atlantic waters and NED waters) illustrated that interaction rates were lower for both leatherback and loggerhead turtles with mackerel (*Scomber scrombrus*) bait compared with sets using squid bait (Javitech Limited, 2002). However, there was some confounding between bait and hook type in these observations (Gilman et al.,2006a).

Gilman et al., (2006a) also discuss the manner of bait hooking as a potential factor in the likelihood of turtles being caught, as preliminary research has indicated that single hooked (as opposed to threaded bait) results in higher swordfish catch rates and lower loggerhead incidental takes (Watson et el., 2003). Feeding studies have also indicated that fish bait tends to come free of the hook whilst the turtle takes small bites from it, while squid remains more firmly attached, requiring the turtle to take larger bites in order to swallow the bait in it's entirety and subsequently increase the chances of becoming hooked (Gilman et al., 2006a). It has therefore been suggested that using larger bait might deter or prevent turtles from swallowing bait and therefore the attached hook, but this remains to be tested (Gilman et al., 2006a).

3.1.2 Summary

Considerable variation exists among data reviewed here on the effects of J-hooks versus circle hooks and bait types on turtle and target species catch rates. In several studies, circle hooks have illustrated lower catch rates for turtles than J-hooks, but these have not always been statistically significant. Those studies which have illustrated significantly lower turtle bycatch with both circle hooks and fish baits have been carried out over a number of years. However, there appears to be some consensus among the studies of circle hooks resulting in lower frequencies of deep-hooking. Whether, light-hooking leads to a greater chance of post-hooking survival in turtles requires further investigation and although it is not to be explored under the terms of reference for this study, hooking location was monitored and is discussed in relation to bait and hook types being tested.

This review also highlighted additional factors to be monitored where possible during the trials and for discussion in light of the results in order to place them into a wider context. Factors include alterations to various other aspects of gear configuration and setting procedures which have also been studied as potential mitigation methods and a number of environmental variables.

For example, the depth at which lines are set has been reported to have significant effects on bycatch of turtles, with lower catch rates recorded for deep-set fisheries in the U.S. Japan, Spain, Costa Rica, and the Western tropical Pacific Pelagic long line fisheries (Gilman et al., 2006a). Analysis of observer data from the Pacific has illustrated that shallower set longline gear takes 10 times more turtles than deeper set gear (Løkkeborg, 2004). Additionally, leatherback turtles caught during the Atlantic trials in the NED waters were more often associated with the shallowest branch line closest to the float line (Watson et al., 2005). In the studies carried out in the Azorean swordfish fisheries, the effect of hook position on the mainline on loggerhead bycatch was not significant (Bolten and Bjorndal, 2005).

Loggerhead turtle catch rate increased significantly the later in the day the line was retrieved in trials carried out in the Azorean swordfish fisheries, however the target species catch rate remained constant (Bolten and Bjorndal, 2005). A similar pattern was illustrated for loggerheads caught during trials in the NED waters of the Atlantic, however neither total or daylight soak time influenced the catch rate of leatherbacks (Watson et al., 2005).

Cooler surface water temperatures have also been associated with lower turtle catch rates and greater-sized swordfish being caught in the Atlantic NED waters (Watson et al., 2003) Observations of turtles being caught in successive sets or particular areas has led to suggestions for turtle avoidance methods via communication between vessels to avoid high density areas (Gilman et al., 2006a).

These factors are considered in the discussion in light of the experimental fishing and questionnaire results.

4 Experimental fishing trials

The objectives of the experimental fishing trials were to evaluate, for fishing operations targeting swordfish in the Mediterranean and the Atlantic, the effects of several technological modifications to fishing gear which have shown promising results in reducing turtle bycatch in other longline fisheries. Because of their potential to reduce turtle bycatch, these different gear configurations needed to be tested for efficacy and economic viability in other fleets.

The gear modifications to be tested included the use of whole fish bait and circle shaped hooks with a low degree of offset, specifically:

- 0° offset 16/0 circle hooks and
- 10°offset 18/0 circle hooks

The experimental design of fishing trials, therefore aimed to test the effects on catch rates of combinations of each of these two hook types with whole fish bait compared with catch rates from traditional hook types and baits used in representative fisheries from both the Mediterranean and the Atlantic. Figure 3 details the experimental gear configuration used during each of the trials.

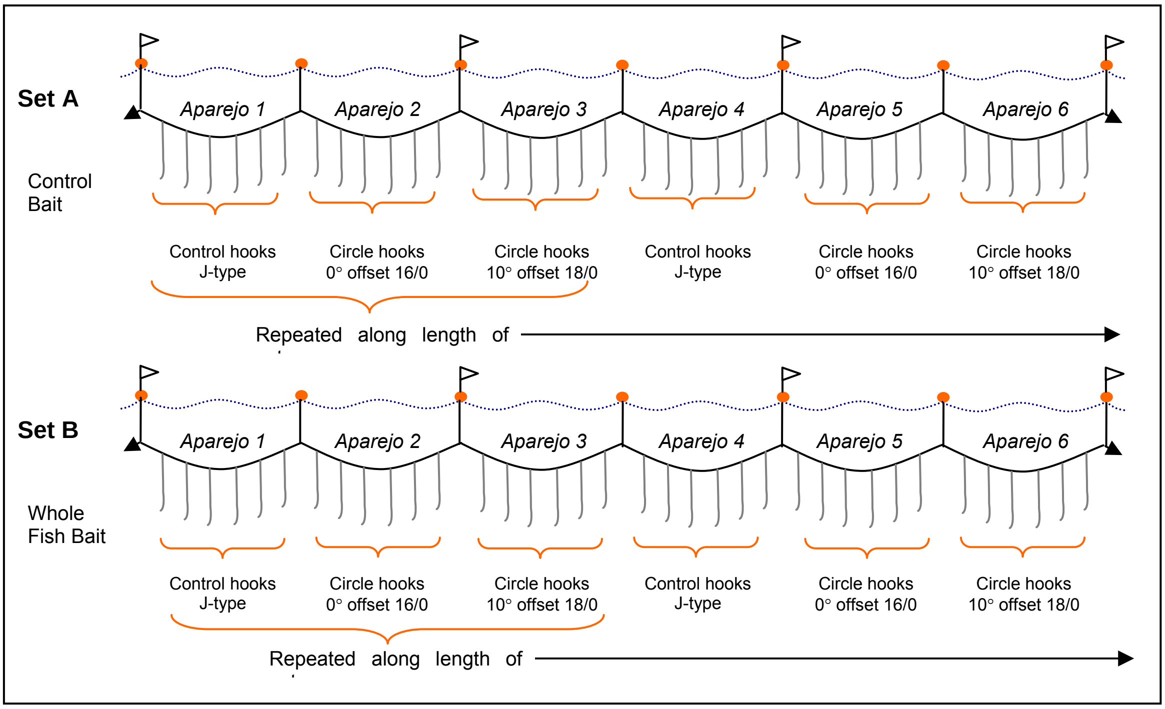


Figure 3 Experimental gear configurations.

Trials were carried out in the Western Mediterranean by a single vessel from the Spanish (Mediterranean) longline fleet, in the Eastern Mediterranean by a single vessel from the Greek longline fleet and in the Atlantic by a single vessel from the Spanish Atlantic longline fleet. Vessels from the Spanish and Greek fleet were selected for the Mediterranean trials, as these fleets represent the greatest fishing effort in the region with respect to longliners targeting swordfish. The timing of trials was planned to coincide, wherever possible, with the normal periods and grounds of fishing in each of these regions as well as the periods of highest turtle bycatch or locations where densities of turtles were expected to be high, in order to maximise statistical power of the experiment. This information was gathered from a number of sources, including information available from published literature, through personal communication with local specialists as well as personal experience of the skippers of vessels to be used in the trials.

4.1 Implementation

4.1.1 Atlantic

The date and location planned for the south Atlantic fishing trials was a compromise between the availability of the chartered vessel within its fishing activities often involving a number of 2-3 month trips to sea during the year, the location of swordfish fishing grounds in the period of the trials, and the expected likelihood of incidental catch of turtles. The latter was determined according to the skipper's experience in the South Atlantic and scientific information available on turtle ecology (Fretey, 2001[1]) and by-catch (Carranza *et al.*, 2006[2]), which in this region is rather scarce.

The trials began on the 26th of February 2007 when the vessel set sail from Cape Town, South Africa for the fishing grounds 600 nautical miles to the west of Namibian coast. After three days of sailing the vessel arrived at the fishing grounds known as Valdivia Bank and Walvis Ridge (Figure 4). The experimental fishing began the 28[th] of February and lasted for 35 days, encompassing 35 experimental fishing trials, finishing on the 10[th] of April when the vessel arrived in Cape Town.

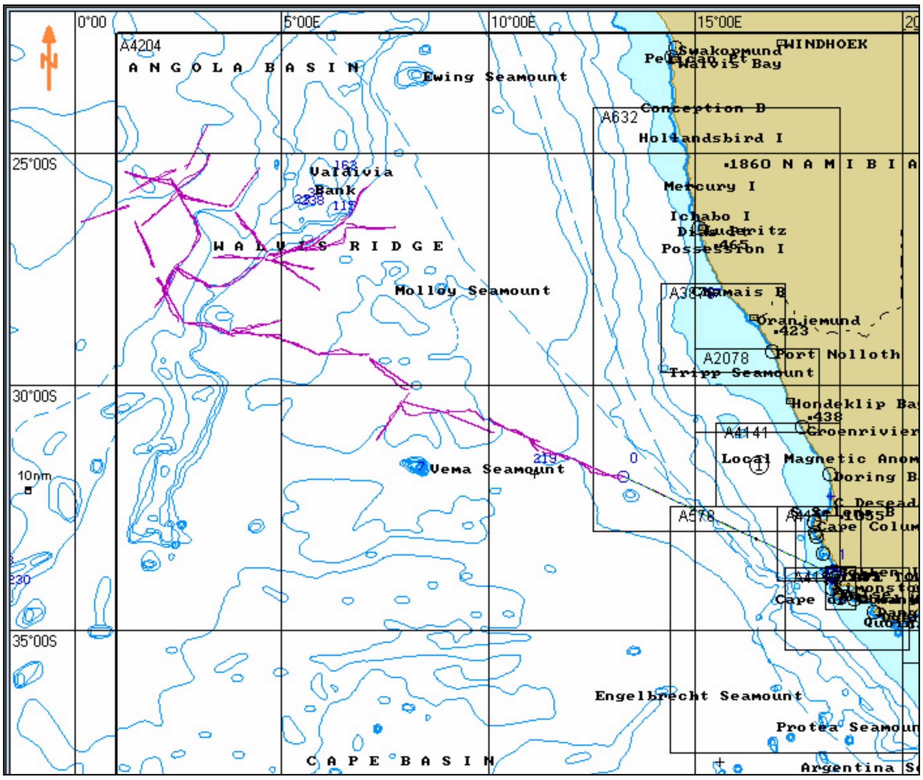


Figure 4 Plot of the fishing operations (screen shot of the plotter of the vessel).

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[1] Fretey, J. (2001) Biogeography and Conservation of Marine turtles of the Atlantic Coast of Africa/Biogéographie et conservation des tortues marines de la côte atlantique de l'Afrique. CMS Technical Series Publication Nº 6, UNEP/CMS Secretariat, Bonn, Germany, 429 pp.

[2] Carranza, A., Domingo, A., and A. Estrades (2006) Pelagic longlines: A threat to sea turtles in the Equatorial Eastern Atlantic. Biological Conservation 131 (2006): 52-57.

The fishing vessel used for the sea trials was the “Mar do Rostro,” a freezer vessel 40.3 meters in total hull length, and with an 898 horse power main engine, belonging to the Spanish surface longline fishing fleet with home port in Burela (Galicia). A smaller number of trials were implemented in the south Atlantic compared with trials in the Mediterranean. This was partly a result of the cost of chartering a vessel of this size, as it had to incur significant disruption to its usual fishing activity during the year. However, there was also a trade off in effort (e.g. number of hooks) per set with a vessel of this size, which enabled between 63-75% of the number of hooks set in each of the Mediterranean regional trials to be encompassed by 58% of the number of sets.

Figure 5 Fishing vessel “Mar do Rostro”

The vessel operated with an American longline fishing system and was equipped with two drums or haulers (Figure 6) for the mainline and a semiautomatic shuttle for setting the gear (Figure 7).

Figure 6 Mainline hauler.

Figure 7 Semiautomatic shuttle for setting.

The specifications of the fishing gear used in the South Atlantic fishing trials are detailed in Table 1. Chemical light sticks producing green light were used in every branchline in order to maintain the same conditions. Two bait species were used for every fishing operation (2 sets): Atlantic mackerel (*Scomber scombrus*) and Argentinian squid (*Illex argentinum*), and both weighed around 300 g (grade 3). Three different types of hooks were used during the fishing trials (see Figure 8 and Table 2):

- Circular hook 18/0: *A Poutada* APT size 18/0 offset 10^{o}
- Circular hook 16/0: *A Poutada* AP size 16/0 offset 0^{o}
- "J" hook 16/0: *Youvella* 722 A size 16/0 offset 10º (control hook)

Table 1 Gear Description

Item	
Length of the mainline (m)	**130 150**
Length of floatline (m)	**18**
Distance between floatline & 1st branchline (m)	**85**
Length of branchline (m)	**17**
Distance between branchlines (m)	**85**
Distance between floats (m)	**510**
Number of hooks between floats (n)	**5**
Method hook attached to branchline	**snapped**
Number of radiobuoys	**21**
Number of floats	**235**

Item	**Material**	**Colour**	**Diameter (mm)**
Mainline	Monofilament	White	3.6
Floatline	Monofilament	Blue	2.5
Branchline	Monofilament	transparent	2

Table 2 Main hook dimensions

Hook type	Length (mm)	Width (mm)	Gap (mm)
Circular hook 18/0	88	54	32
Circular hook 16/0	73	45	26
"J" hook 16/0	79	44	28

Every magazine (between two buoys) had five hooks, alternating the three types of hooks along the gear. 1,280 hooks were set daily, with 640 hooks in every set.

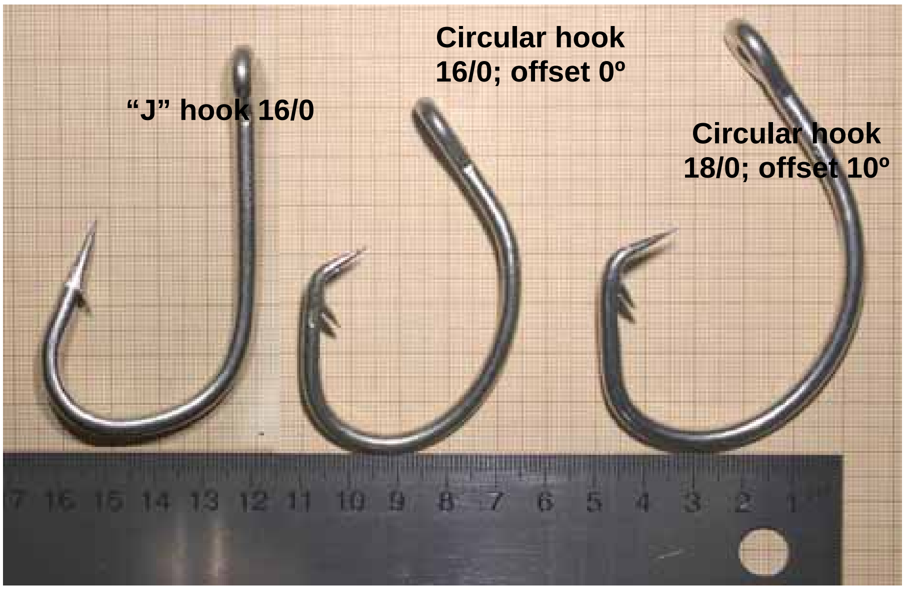

Figure 8 Hooks used during the South Atlantic trials.

4.1.1.1 Turtle handling equipment

Careful Handling and Release Equipment (Figure 9) for a vessel with a freeboard of 6' and higher was used. The kit was composed of:

- 12' (Breakdown/3-4' sections) Long Handled ARC Dehooker (for removing internal and external hooks).
- 12' (Breakdown/3-4' sections) Long Handled NOAA LaForce Line Cutter (for removing entangled gear).
- 36" J-Style Dehooker (for removing difficult external hooks and for "V" style release
- Short Handle ARC Bite Block Dehooker (for removing internal hooks from boated sea turtles).
- Short Handle ARC 16" J-Style Dehooker (for removing external hooks from boated sea turtles).
- 12' (Breakdown) Turtle Tether
- Tyre for the immobilization of the sea turtles
- Bolt cutters.

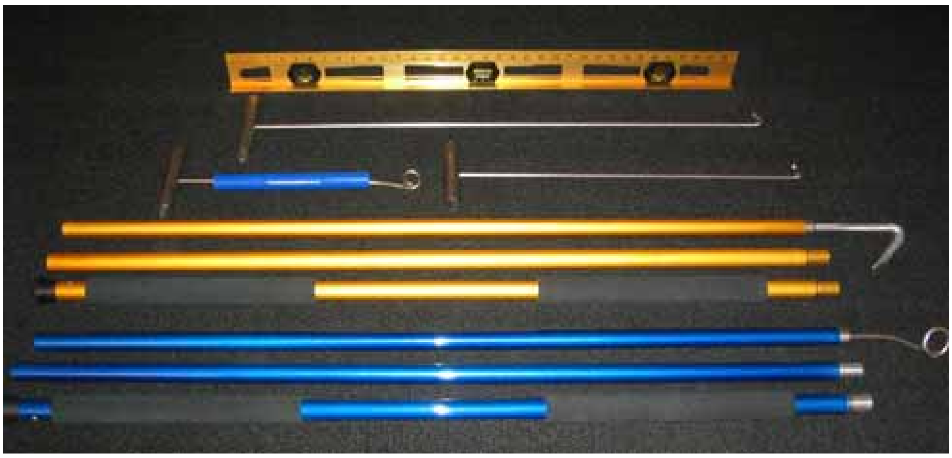

Figure 9 Turtle handling equipment

4.1.1.2 Setting the gear

Line setting was carried out from the stern of the vessel at a speed of 10 knots. The shuttle in the middle of the stern was used to measure the length of the mainline set and to program the number of buoys, number of floats between two buoys, number of hooks between two floats and the distance between the hooks. Once the shuttle was programmed, setting commenced and instructions were given to the fisherman as to what gear should be configured next e.g. hook, float, buoy, last hook before a float in order to make it easier for the crew to keep the experimental design intact over such long operations (from 16:00h till 23:00h).

In order to incorporate the circle hooks into the gear, all of the branch lines with the same type of hook were stored together in different containers next to the shuttle (Figure 10).

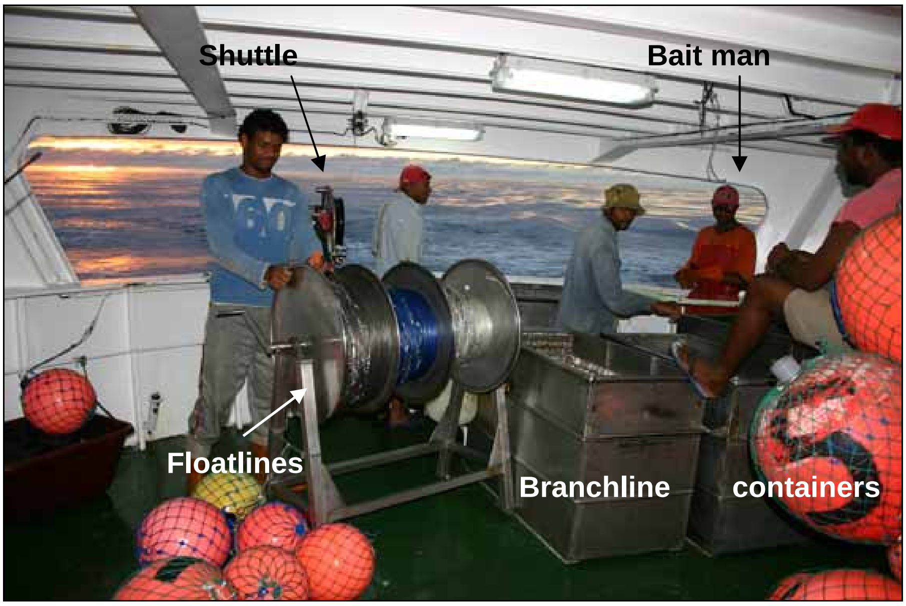

Figure 10 Setting the gear

The hook type on the line was changed every other buoy in order to achieve a uniform distribution of the hooks along the gear. Two sets with 640 hooks each were set daily. Each set had a different bait, on which the order was switched depending on the hauling procedure (normal or reverse) so that both baits had similar soaking time after the 35 days of fishing.

Location and time were recorded at the beginning, end and middle point during setting and the following environmental conditions were recorded at the beginning of each set:

- Air temperature (°C)
- Wind direction
- Visibility (m)
- Air pressure (mbars)
- Wind speed (knots)
- Cloud cover (%)
- Sea Surface Temperature, SST (°C)
- Sea State (Beaufort)

4.1.1.3 Hauling the gear

Hauling started early in the morning (around 05:00 am) and was carried out on the starboard side, at a speed between 8 and 10 knots depending on the weather conditions. The entire hauling operation took between 10 and 12 hours to complete depending on the number of catches. Target species such as swordfish, tunas and mako sharks were measured with callipers using fork length (from the lower jaw to the middle of the tail) as standard.

Figure 11 Boarding a large swordfish.

Location and time were recorded at the beginning, end and middle point during hauling. The same environmental conditions were recorded as during setting at the beginning of each haul.

Any loggerhead turtles (*Caretta caretta*) caught were boarded using a dip net and carefully handled according to the turtle de-hooking and release protocol. First, they were placed in a tyre to immobilize them so they could be measured with a calliper from notch to tip (Figure 12). Then the turtles were de-hooked if possible. Once the turtles recovered from the shock of being caught, they were returned to the sea. Leatherback turtles (*Dermochelys coriacea*) could not be boarded when caught due to their large size and activity, so the branch line was cut as near as possible to the hook (Figure 13).

Figure 12 Observer measuring a loggerhead

Figure 13 Leatherback turtle being released.

4.1.2 Eastern Mediterranean

The experimental fishing trials for the Eastern Mediterranean were carried out in the Ionian Sea (Western Greece), in the wider marine region of the island Zakynthos, which is considered to be the most important nesting region for marine turtle *Caretta caretta* in Greece and where the majority of sea turtles are encountered. The specific port of Kyllini was selected because an increased number of fishing boats from this port fish for swordfish in the area around Zakynthos. In total, 60 days of fishing operations were carried out in the time interval between 30 May 2007 and 09 September 2007. It should be mentioned that even if the fishery of swordfish was to be allowed from February until September, the actual fishing period begins substantially in May and closes in September since the majority of the vessels are relatively small and consequently are not able to operate under intense weather conditions.

The fishing vessel which was used in the experiments "Agios Nikolaos, NK 21", belongs to the Greek fleet. It's length is 14.88 metres, it carries an engine of 150 hp power and its main fishing gear is an American type surface longline for the fishing of swordfish (tool known as karoula). The home port of the vessel is Kyllini, in the Prefecture of Ileia, region of Western Greece.

The specifications of the fishing gear used in the Eastern Mediterranean trials are presented in Table 3. The basic characteristics of the longline remained the same during the fishing trials (length of branchline, number of hooks between floats, depth of hooks, number of light sticks, number of magazines), but there were small fluctuations in certain lengths. The total length of the longline ranged between 22 200 and 32 500 km.

Table 3 General specifications of the longline fishing gear used in the Eastern Mediterranean fishing trials (the values correspond to one individual set)

Length of floatline	15 m
Distance between floatline and the first branchline	50 - 65 m
Length of branchline	15 m
Distance between branchlines	50 – 65 m
Number of hooks between floats	5
Depth of hooks	33 m
Horizontal distance between floats	220 – 320 m
Number of light sticks in each set	500
Number of magazines in each set	100

Three different types of hooks were used during the fishing trials (Figure 14):

- 18/0 offset 10^o (test circle hook 1)
- 16/0 offset 0^o (test circle hook 2)
- J hooks. Size 2 (control hook)

Table 4 Main hook dimensions

Hook type	Length (mm)	Width (mm)	Gap (mm)
Circular hook 18/0	87	54	32
Circular hook 16/0	73	45	26
“J” hook 16/0	65	35	29

Figure 14 The three hook types used in the Eastern Mediterranean trials (circle 18/0, circle 16/0, J)

The vessel was also supplied with the following equipment for the configuration of the longline fishing gear:

- Mainline 2,00 mm monofilament material, white coloured
- Branchline 1,50 mm monofilament material, white coloured
- Chemical light sticks producing green light
- Branch line clips, swivel and snap INOX 3,0*125L + 6/0
- Floats
- Radio Buoys

Two different types of bait were used: Mackerel (*Scomber scomber*) and Squid (*Nototodarus sloani*), of 250 g (size grade 3).

The following equipment was available for the handling of the sea turtles:
- 17” Bite Block Deep-hooked (Sea Turtle) dehooker
- 16” J-style dehooker
- 6” Pole J-style dehooker
- Dip net for bringing the sea turtles on board
- Tyre for the immobilization of the sea turtles
- Bolt cutters for paring the hooks which are located in the mouth or flippers

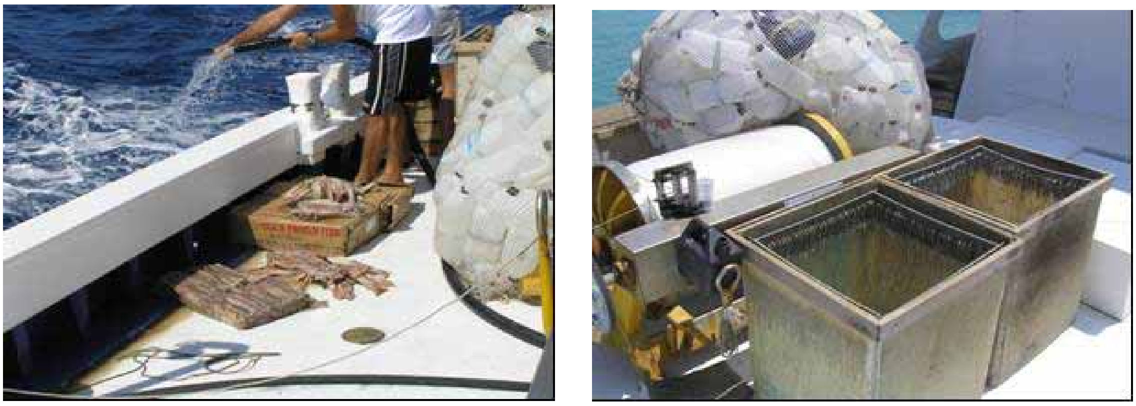

Figure 15 a) Thawing the bait (squid) and b) The hook baskets, the winch and the floats on the board of the vessel

As with all regional trials, test hooks and control hooks were incorporated on the same longline in each set by alternating magazines of each hook type (18/0 offset 10^{o}, 16/0 offset 0^{o} and control J-type hook) on the same longline.

In order to test between bait types two lines were set each fishing day, one baited with squid (whole) and the other with mackerel (whole). Each longline set, representing one sampling unit, held 500 hooks, allowing about 166 hooks per hook type in each set or the equivalent 33 magazines per hook type (Table 5).

Table 5 Number of hooks used in the Eastern Mediterranean fishing trials

Number of hooks per day	Test circle hook 1	Test circle hook 2	Control hook	Total
SET A (squid)	165	165	170	500
SETB (mackerel)	165	165	170	500
Total	330	330	340	1000

In addition the following interaction parameters were measured during the fishing trials:

- Air temperature (^{o}C)
- Wind direction
- Visibility (m)
- Air pressure (mbars)
- Wind speed (knots)
- Cloud cover (%)
- Sea Surface Temperature, SST (^{o}C)
- Sea State (Beaufort)

Figure 16 illustrates the configuration of the longline gear used in the Eastern Mediterranean fishing trials.

SET 1

Radio buoy 1		
mag	1	1
mag	2	2
mag	3	3
mag	4	1
mag	5	2
mag	6	3
mag	7	1
mag	8	2
mag	9	3
mag	10	1
mag	11	2
mag	12	3
mag	13	1
mag	14	2
mag	15	3
mag	16	1
mag	17	2
mag	18	3
mag	19	1
mag	20	2
Radio buoy 2		
mag	21	3
mag	22	1
mag	23	2
mag	24	3
mag	25	1
mag	26	2
mag	27	3
mag	28	1
mag	29	2
mag	30	3
mag	31	1
mag	32	2
mag	33	3
mag	34	1
mag	35	2
mag	36	3
mag	37	1
mag	38	2
mag	39	3
Radio buoy 3		
mag	40	1
mag	41	2
mag	42	3
mag	43	1
mag	44	2
mag	45	3
mag	46	1
mag	47	2
mag	48	3
mag	49	1
mag	50	2
mag	51	3
mag	52	1
mag	53	2
mag	54	3
mag	55	1
mag	56	2
mag	57	3
mag	58	1
mag	59	2
Radio buoy 4		
mag	60	3
mag	61	1
mag	62	2
mag	63	3
mag	64	1
mag	65	2
mag	66	3
mag	67	1
mag	68	2
mag	69	3
mag	70	1
mag	71	2
mag	72	3
mag	73	1
mag	74	2
mag	75	3
mag	76	1
mag	77	2
mag	78	3
mag	79	1
Radio buoy 5		
mag	80	2
mag	81	3
mag	82	1
mag	83	2
mag	84	3
mag	85	1
mag	86	2
mag	87	3
mag	88	1
mag	89	2
mag	90	3
mag	91	1
mag	92	2
mag	93	3
mag	94	1
mag	95	2
mag	96	3
mag	97	1
mag	98	2
mag	99	3
Radio buoy 6		
mag	100	1

SET 2

mag	1	1
mag	2	2
mag	3	3
mag	4	1
mag	5	2
mag	6	3
mag	7	1
mag	8	2
mag	9	3
mag	10	1
mag	11	2
mag	12	3
mag	13	1
mag	14	2
mag	15	3
mag	16	1
mag	17	2
mag	18	3
mag	19	1
Radio buoy 7		
mag	20	2
mag	21	3
mag	22	1
mag	23	2
mag	24	3
mag	25	1
mag	26	2
mag	27	3
mag	28	1
mag	29	2
mag	30	3
mag	31	1
mag	32	2
mag	33	3
mag	34	1
mag	35	2
mag	36	3
mag	37	1
mag	38	2
mag	39	3
Radio buoy 8		
mag	40	1
mag	41	2
mag	42	3
mag	43	1
mag	44	2
mag	45	3
mag	46	1
mag	47	2

mag	48	3
mag	49	1
mag	50	2
mag	51	3
mag	52	1
mag	53	2
mag	54	3
mag	55	1
mag	56	2
mag	57	3
mag	58	1
mag	59	2
Radio buoy 9		
mag	60	3
mag	61	1
mag	62	2
mag	63	3
mag	64	1
mag	65	2
mag	66	3
mag	67	1
mag	68	2
mag	69	3
mag	70	1
mag	71	2
mag	72	3
mag	73	1
mag	74	2
mag	75	3
mag	76	1
mag	77	2
mag	78	3
mag	79	1
Radio buoy 9		
mag	80	2
mag	81	3
mag	82	1
mag	83	2
mag	84	3
mag	85	1
mag	86	2
mag	87	3
mag	88	1
mag	89	2

mag	90	3
mag	91	1
mag	92	2
mag	93	3
mag	94	1
mag	95	2
mag	96	3
mag	97	1
mag	98	2
mag	99	3
mag	100	1
Radio buoy 10		

Figure 16 The configuration of the fishing gear used in the Eastern Mediterranean fishing trials

4.1.2.1 Setting procedures

The casting of the two longline sets per fishing day was carried out from the stern of the vessel, while maintaining a speed of 4,5 – 5 knots. The first magazine was set, using the vessel's winch, early in the afternoon (13.00 – 15.00) and the whole procedure lasted about four hours depending on the total length of the longline (Figure 17). The soaking time for each longline gear set averaged 12 hours.

Figure 17 Setting procedure of the longline using the winch

4.1.2.2 Hauling procedures

Hauling of the two longline sets was carried out in reverse order from the setting. This took place from the right lateral part of the vessel using the winch (Figure 18). The vessel's speed was 3,5 – 4 knots and the entire hauling procedure lasted about five hours in total (starting at approximately 6.00 a.m.).

Figure 18 Hauling procedure of the fishing gear

4.1.3 Western Mediterranean

The sea trials of the Western Mediterranean were carried out during Summer 2007, starting from the 10th of July and finishing the 16th of September, with a total of 60 fishing operations. The fishing areas used for the trials were the waters surrounding the Balearic Islands, with higher numbers of fishing operations occurring south of Mallorca Island and in the Ibiza Channel (Figure 19).

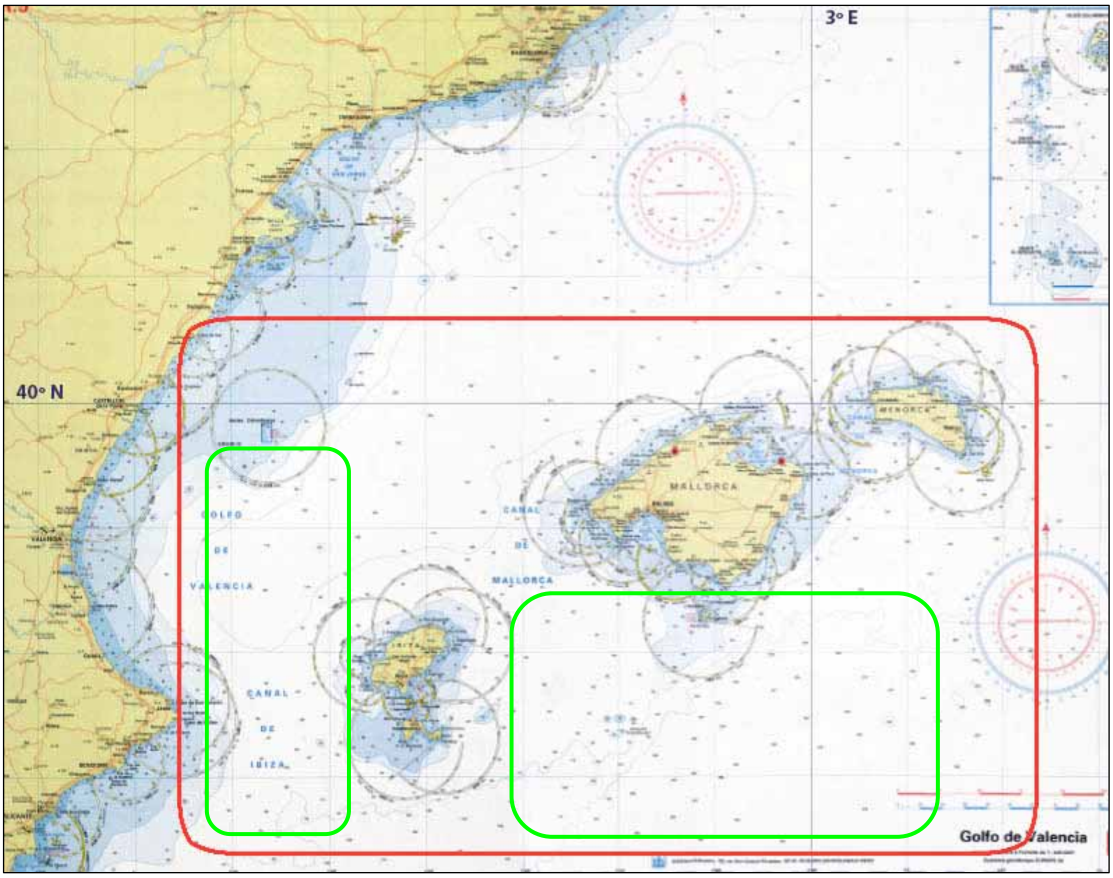

Figure 19 **Maritime chart of the Western Mediterranean (Gulf of Valencia and Balearic Islands). The overall fishing area for the sea trials is delimited in red colour, whereas the most frequent fishing areas are highlighted in green colour.**

The fishing vessel used for the sea trials was the “Hermanos Caparros Hernandez”. It is a vessel 20.6 meters in total hull length, with 140 horse power main engine, belonging to the Spanish surface longline fishing fleet with home port in Carboneras (Andalucía).

Figure 20 Fishing vessel "Hermanos Caparros Hernandez"

The vessel operates with the American longline fishing system and is equipped with a drum or hauler for the mainline and a semiautomatic shuttle for setting the gear.

The specifications of the fishing gear used in the Western Mediterranean fishing trials are described in Table 6. Electrical light sticks producing green light were used in every branchline in order to maintain the same conditions. Two bait species were used for every fishing operation (2 sets), Atlantic mackerel (*Scomber scombrus*) and Argentinian squid (*Illex argentinum*) and both weighed approximately 300g (grade 3). Three different types of hooks were used during the fishing trials (see Figure 21 and Table 7).

- Circular hook 18/0: *A Poutada* APT size 18/0 offset 10^o (test circle hook 1)
- Circular hook 16/0: *A Poutada* AP size 16/0 offset 0^o (test circle hook 2)
- "J" hook nº2: *Mustad* 2315 size nº2 offset 0º(control hook)

Table 6 Gear Description

Item	
Length of the mainline (m)	**90,000**
Length of floatline (m)	**18**
Distance between floatline & 1st branchline (m)	**75**
Length of branchline (m)	**14**
Distance between branchlines (m)	**75**
Distance between floats (m)	**430**
Number of hooks between floats (n)	**5**
Hook attachement method to branchline	**snapped**

Item	Material	Colour	Diameter (mm)
Mainline	Monofilament	White	3.2
Floatline	Monofilament	transparent	1.5
Branchline	Monofilament	transparent	2

Table 7 Main hook dimensions

Hook type	Length (mm)	Width (mm)	Gap (mm)
Circular hook 18/0	87	54	32
Circular hook 16/0	73	45	26
“J” hook nº2	81	33	29

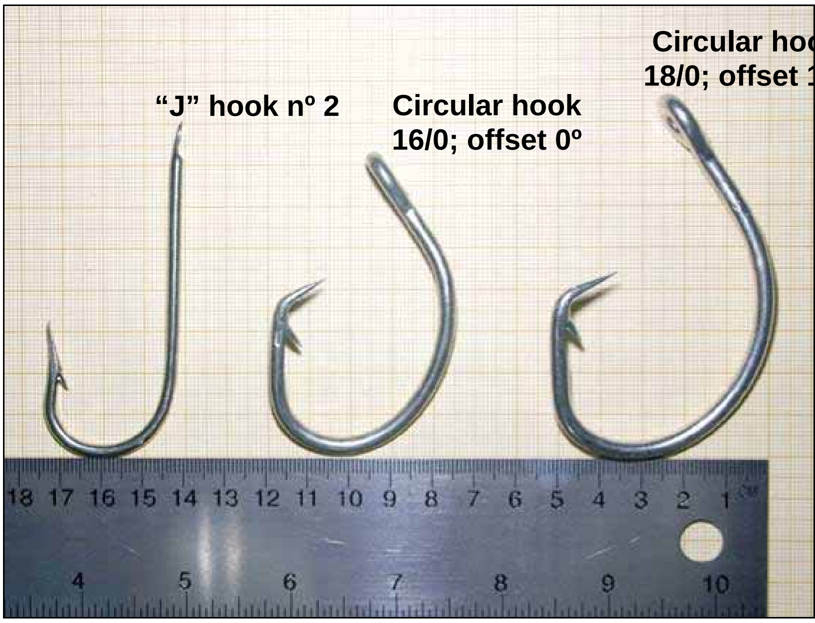

Figure 21 Hooks used during the Western Mediterranean sea trials

Every magazine (between two buoys) had five hooks, alternating the three types of hooks along the gear. 1,200 hooks were set daily; 600 hooks in every set.

4.1.3.1 Turtle handling equipment

Careful Handling and Release Equipment for vessels with a freeboard of 6' and higher was used as for the south Atlantic trials:

4.1.3.2 Setting and hauling the gear

Setting and hauling procedures were carried out in the same way as in the South Atlantic trials. The only difference was the speed, a bit lower in the Western Mediterranean (9 knots for setting and 8 knots for hauling) than in the Atlantic trials. Figure 22, Figure 23 Figure 24 illustrate fishing operations from the vessel used in the western Mediteranean trials.

Figure 22 Hook containers

Figure 23 Landing a swordfish.

Figure 24 **Setting the gear**

4.2 Statistical analysis

Data from all three regional trials were combined into a single database and error checked before analysis. Initially data were explored graphically to explore patterns in catch rates of both turtle and target species, swordfish, among regional trials.

Although there were slight differences in the dimensions and shapes of the J-hooks used in the trials (selected to be the traditional hook type used in each region), in analysis combining regional data, all three hooks were considered to represent a generic J-type hook. Dimension differences are minimal between these three hooks, particularly for the width of the gap between the hook point and shank (maximum of 3mm difference), which is one of the characteristics linked with differences in hooking efficiency between circle hooks and J hooks in general (Kerstetter and Graves, 2006, Gilman et al.,, 2006). Additionally when explored statistically there were no significant difference in catch rates among these three hook types over and above differences between these hooks and the circle hooks used.

The main set of analysis focused on hypotheses addressing treatment effects, namely hook and bait type effects on catch rates (4.2.1) and hooking location (4.2.2) of turtles and on catch rates of swordfish (4.2.3). Since a series of analyses had to be undertaken, in order to limit the experiment-wide rate of Type 1 error, we used the Bonferroni adjustment as a rule of thumb and aimed to achieve a Type 1 error rate of less than 0.1. This corresponded with an alpha level per analysis of approximately 0.01.

Additional, analyses were carried out for descriptive purposes on the size of turtles caught and effects of other factors on catch rates of turtles and swordfish, as well as the influence of bait and hook types on secondary target (bycatch) species.

4.2.1 Treatment effects on turtle catch

A generalised linear model (GLM) with logit link was used to predict the probability (ρ^t) of capturing a turtle given that a hook is set. With this model, the binomial response data (turtles caught / hooks without turtles, by set) are modelled by a linear combination of categorical effects consisting of 2 bait types (squid, mackerel), 3 hook types (J hook, 16/0 0º offset circle hook, 18/0 10º offset circle hook (J, 16/0 and 18/0 respectively from here in)) and 3 regions (Atlantic, eastern Mediterranean, western Mediterranean):

1. $\text{logit}(p_{o,b,h}) = \tau_i + \tau_o + \tau_b + \tau_h$

where τ are the linear effects[3] relating to the intercept *i,* the ocean region *o*, the bait type *b*, and the hook type *h* (see Appendix 2: Statistical Analysis Methods, 10.1 for the likelihood function).

---

[3] It is conventional to illustrate the influence of different levels of explanatory variables in terms of these linear effects. The graphs of marginal effects that are included in the results section below are presented on this scale (*i.e*. consistent with the τ terms of Equation 1). Importantly, this illustrates the positive or negative influence of each marginal effect on the probability of capturing a turtle. For example, where a marginal effect or a certain hook type is positive and does not strongly overlap with zero (see the Wald statistic below) this hook type can be interpreted as significantly increasing the probability of capturing a turtle.

2. $T_{o,b,h} \sim \text{bin}(H_{o,b,h}, p_{o,b,h})$

where *T* are the number of turtles observed, *H* is the number of hooks set, *n* refers to the total number of categories of each effect type. Again, the subscripts *o*, *b*, and *h* refer to the ocean region, bait type and hook type.

Separate analyses were also undertaken on the data for each ocean area in isolation in order to understand more fully, any possible interactions between ocean and bait type or ocean and hook type.

Analysis of variance and the chi-squared statistic is used to evaluate whether a factor (for example bait type) significantly explains the observed variability in capture rates. The Wald statistic is used to determine whether each treatment effect corresponds with an increased or decreased probability of catching a turtle. For any given effect, the Wald statistic is simply the mean of the marginal effect divided by its standard error. This transforms the mean so that it may be compared with the standard normal distribution of mean zero and standard deviation 1 (to test for a significant departure from zero). For example, were the Wald statistic for a given hook type to lie outside of the interval [-1.96, 1.96], it may be considered to significantly contribute (negatively or positively, respectively) to the likelihood of catching a turtle.

Model parsimony was approximated by Akaike information criterion (AIC), smaller values of which indicate 'better', more parsimonious, models (Quinn and Keough, 2002).

4.2.1.1 Effects of additional factors on catch of turtles

The effect of sea surface temperature, set depth, soak time and hook position (position in magazine) on turtle catch rates were also investigated. The hypotheses implicit in the analysis of hook position relate to the proximity to the end of the magazine and the depth of the hook. To evaluate this, the five hooks in each magazine were recoded such that hooks 1 and 5 (that are equally close to either end of the magazine) were coded as hook position 1, hooks 2 and 4 were coded as position 2 and hook number 3 was coded as hook position 3.

A series of polynomial models of differing degrees of complexity were investigated to understand whether these continuous explanatory variables exhibit a consistent pattern with the probability of recapturing a turtle. The polynomial models were added to the categorical predictors of the generalised linear model to form a generalised additive model (GAM). The parsimony of the models were again evaluated on the basis of AIC.

Based on the linear model of Equation 1, an example GAM that was investigated took the form:

3. $\text{logit}(p_{o,b,h}) = \tau_i + \tau_o + \tau_b + \tau_h + \tau_T$

where τ are the linear effects relating to the intercept *i,* the ocean region *o*, the bait type *b*, the hook type *h* and the sea surface temperature *T* that is modelled by the third degree polynomial function:

4. $\tau_T = aT^3 + bT^2 + cT^2 + d$

Where the parameters *a, b, c* and *d* are estimated and *T* is the continuous explanatory variable sea surface temperature.

4.2.1.2 Power analysis

The GLM modelling will not necessarily conclude that treatment effects significantly contribute to the model predicted probability of capturing a turtle given that a hook is set *(e.g.* that J hooks may not significantly increases or decrease the probability of capture). It may be the case that a genuine effect exists but could not be detected (a false negative or 'Type II error' that occurs with a probability β). A power analysis was undertaken in order to calculate the likely power (1-β) to detect a genuine treatment effect in the ocean specific GLM analyses of the Atlantic and Western Mediterranean. The detectable effect size was presumed to be that relating to odds ratios of 2 and 0.5 (the marginal effect more than doubles or halves the probability of recapture).

4.2.1.3 Predicted turtle catch rates by treatment effects

The estimated effects may be combined to calculate an expected probability of capturing a turtle given a hook is set, for each combination of ocean, hook and bait type. These predictions provide a transparent means of comparing the outcomes of the full range of management options.

4.2.2 Treatment effects on anatomical hooking location of turtles caught

In order to determine whether hook type and bait type have an effect on the anatomical hooking location a multinomial model was employed. Whilst detailed information regarding the hook location were available, the response was simplified into internal (swallowed), mouth and external hooking locations. Multinomial logit models are the multivariate extension of the binomial logit model used in the prediction of turtle catch rates above (Section 4.2.1, see Appendix 2: Statistical Analysis Methods, 10.1.1.1 for equations).

4.2.2.1 Treatment effects on size of turtles caught

Loggerhead turtle straight carapace length data were modelled by the linear combination of categorical effects corresponding to ocean, bait and hook types using a lognormal GLM. The likelihood function maximised was:

$L \sim \text{dnorm}(\mu_{o,b,h}, \sigma)$

where *L* is the length of each turtle in ocean area *o,* bait type *b,* and hook type *h.* The logarithm of the median length of turtles for each combination of treatments is predicted by the linear model:

$$\mu_{o,b,h} = \omega_i + \omega_o + \omega_b + \omega_h$$

Where ω_i is the intercept, ω_o is the ocean area effect, ω_b is the I bait effect and ω_h is the hook effect.

The lognormal standard deviation σ is estimated over all observations as a single free parameter.

4.2.3 Treatment effects on target catch, swordfish

To explore treatment effects on the numbers of swordfish caught, binomial GLMs (logit link) were used to predict the probability (ρ^t) of capturing a swordfish on a given hook or bait using the same methods as those used for turtles in 4.2.1.

As the response variable of interest to the commercial fleet is weight rather than numbers (which is more relevant to the conservation of turtles), we also explored the effect of hook and bait type on the size of swordfish caught in each of the trials. Lognormal GLM was used to explore the effects of ocean, hook and bait type on average size (by weight, kg) of swordfish caught during the trials, utilising the same methodology as outlined above in 4.2.2.1.

The catch weight per hook was also modelled by set in order to understand how hook and bait types might alter the catch weight of swordfish. In many cases a deployed set did not lead to the catch of swordfish. In order to account for these zero data points, a delta-lognormal model was specified. In such a model, the negative data are modelled by the binomial distribution:

5. $X \sim bin(S,p)$

where X are the number of sets that catch swordfish (*Xiphias* spp.) out of S sets. The probability of catching at least one swordfish on a set, p is modelled by a linear model and logit link, similar to that of Equation 1.

The positive data showed a pronounced negative skew that is typical of catch-per-unit-effort data, and were modelled by the traditional lognormal distribution (a linear model similar to that of Equation 6 was used to model the lognormal mean):

6. $W \sim dlnorm(\mu,\sigma)$

W is the average weight per hook of swordfish for each replicate set r (see Appendix 2, 10.1.1.3 for the joint likelihood function).

Similarly to the lognormal model on turtle length, the standard deviation σ is estimated over all observations as a single free parameter. Model parsimony was approximated by AIC.

4.2.3.1 Effects of additional factors on catch of swordfish

Additional factors were added to the binomial model exploring ocean, bait and hook effects detailed in Equations 1 and 2 and 7 in section 4.2.1,,to explore their effects on the probability of swordfish capture and any associated changes in model parsimony. These additional factors included mean sea surface temperature °C, averaged over corresponding set and haul records), mean depth of set (metres) and soak time (days).

4.2.3.2 Predicted swordfish catch rates by treatment effects

The estimated effects were combined as before to calculate an expected probability of capturing a swordfish given a hook is set, for each combination of ocean, hook and bait type.

4.2.4 Predicted number of turtles caught per Kg swordfish for each treatment combination

Finally, the estimated effects of both swordfish and turtle GLM models were combined to calculate the expected number of turtles caught per kg of swordfish.

4.2.5 Treatment effects on secondary target/bycatch species

To explore treatment effects on the numbers of secondary target and bycatch species caught, binomial GLMs (logit link) were used to predict the probability (ρ^t) of capture on a given hook or bait using the same methods as those used for turtles in 4.2.1.

4.3 Results

4.3.1 Trial summary

A total of 70 lines comprising 35 trials were set in the Atlantic between 28th February and 4th April 2007 while in the eastern and western Mediterranean 120 lines comprising 60 trials were set in each region between 30th May and 8th September and between 11th July and 17th September respectively. Table 8 provides effort data by hooks set for hook and bait type for each regional trial.

Table 8 Trial fishing effort by region, bait and hook type.

Trial Region	# Sets	Bait Type		Hook Type			
				J	**16/0**	**18/0**	**Total**
Atlantic	35	**Squid**	# hooks	7465	7395	7510	22370
	35	**Mackerel**	# hooks	7395	7440	7500	22335
			Total	14860	14835	15010	**44705**
Eastern	60	**Squid**	# hooks	9900	9900	10200	30000
Mediterranean	60	**Mackerel**	# hooks	9900	9900	10200	30000
			Total	19800	19800	20400	**60000**
Western	60	**Squid**	# hooks	11920	11920	11920	35760
Mediterranean	60	**Mackerel**	# hooks	11780	11780	11780	35340
			Total	23700	23700	23700	**71100**
						Total hooks	**175805**

Sea surface temperature averaged 22.5ºC ± 0.07 s.e. in the Atlantic (range 20.9-23.8ºC), 25.1ºC ± 0.2 s.e. in the eastern Mediterranean (range 20.5-28.2ºC), and 25.9ºC ± 0.05 s.e. in the western Mediterranean (range 24.3-26.9ºC). Soak times averaged 15.2 hours ± 0.4 s.e. in the Atlantic (range 4.3-27.4 hours), 15.6 hours ± 0.2 s.e. in the eastern Mediterranean (range 9.8-27.5 hours) and 16.6 hours ± 0.7 s.e. in the western Mediterranean (range 8.6-44.8 hours). Mean setting depth was greater on average in the Atlantic trials at 45.4 metres ± 0.5 s.e. (range 35-48m), while in the eastern and western Mediterranean trials mean setting depth was 33 metres ± 0 s.e. and 32 metres ± 0 s.e. respectively.

4.3.1.1 Catch composition

Although vessels in each of the three regions were targeting swordfish in the trials, there were differences in the overall catch compositions in each area. For each of the regional trials, Table 9 lists both target and secondary target species which were all kept for sale and bycatch species which were discarded by the vessels. Catch composition in the Atlantic and western Mediterranean was more diverse than that in the eastern Mediterranean which was composed of only 5 species (excluding turtles). Swordfish comprised the largest proportion of catch by numbers in both of the Mediterranean trials (84% and 74% in the eastern and western Mediterranean respectively); while in the Atlantic blue shark comprised 46% and swordfish made up 34% of the total catch by numbers. Table 9 gives the numbers caught for each species in the three regional trials.

4.3.1.2 Regional turtle by-catch

A total of 124 turtles were caught during the trials, with only two species, loggerheads (*Caretta caretta*) and leatherbacks (*Dermochelys coriacea*), contributing to this catch. All the leatherbacks (9) were caught in the Atlantic. Much greater numbers of loggerheads were caught in the Atlantic and western Mediterranean trials (36 and 77 respectively) than in the eastern Mediterranean trials in which only two loggerhead turtles were caught. The majority of turtles caught during the trials were released alive (116), however a total of 8 turtles (all loggerheads) died during the trials (2 in the Atlantic and 6 in the western Mediterranean). Three of these died subsequent to having been caught in a coma or injured, but one turtle recovered from a coma subsequent to capture and was released in good condition. Of those released alive, 37 of these had injuries caused by interaction with the fishing gear, one remained in a coma, 54 were uninjured, and the condition of 24 turtles was unknown.

Figure 25 illustrates the locality of turtle captures during the three regional trials.

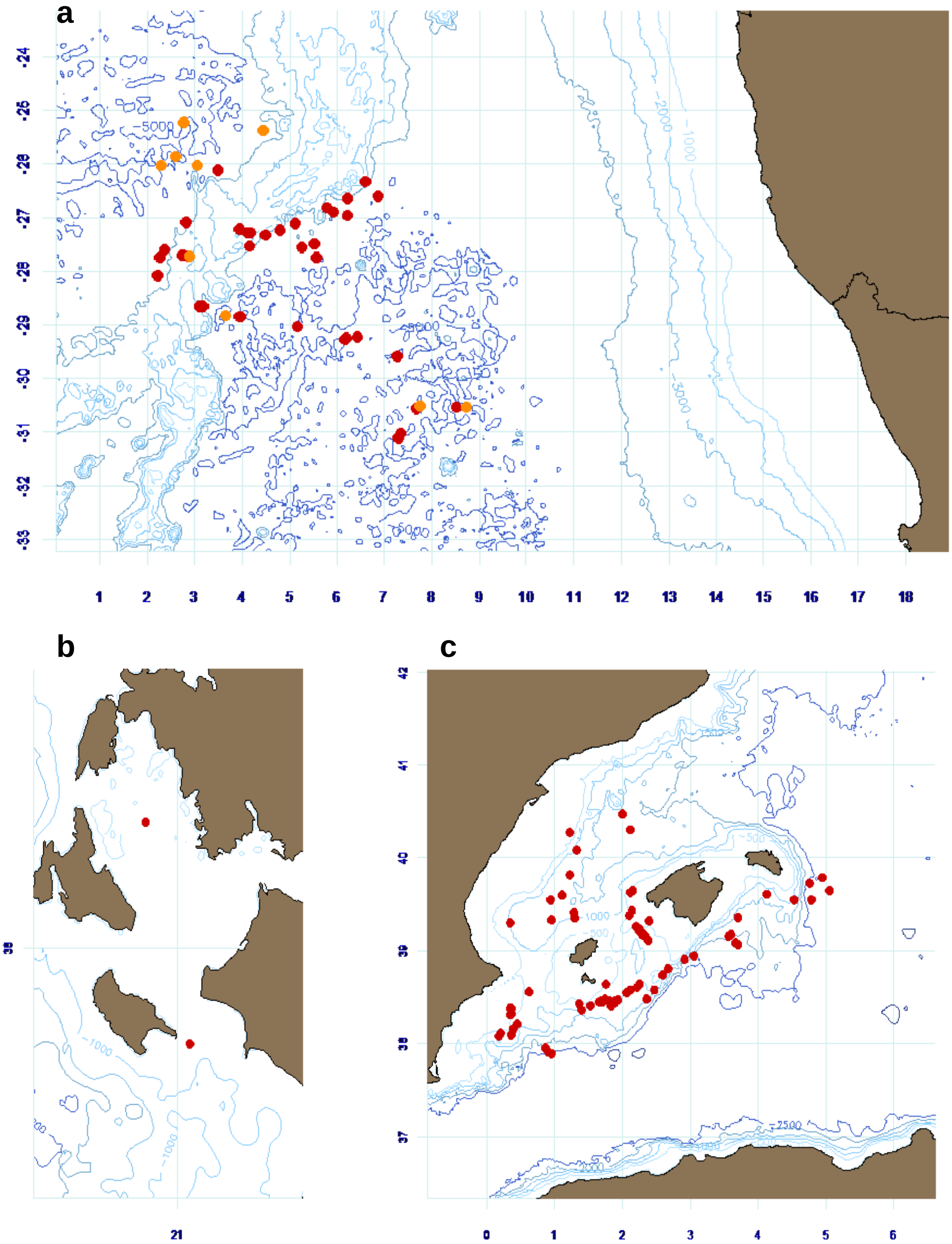

Figure 25 **Locality of turtle captures in a) the Atlantic (red discs represent loggerhead captures and orange discs represent leatherback captures), b) the eastern Mediterranean and c) the western Mediterranean.**

Table 9 Catch composition by species and number for each of the regional trials. Target and secondary target species were kept for sale, bycatch species were discarded.

				Atlantic			Eastern Mediterranean			Western Mediterranean		
Order	**Family**	**Scientific name**	**English name**	**Target**	**2º Target**	**Bycatch**	**Target**	**2º Target**	**Bycatch**	**Target**	**2º Target**	**Bycatch**
Aulopiformes	Alepisauridae	*Alepisaurus brevirostris*	Short snouted lancetfish			6						
	Alepisauridae	*Alepisaurus ferox*	Long snouted lancetfish			18						
Carcharhiniformes	Carcharhinidae	*Prionace glauca*	Blue shark	800				2			32	
	Sphyrnidae	*Sphyrna mokarran*	Great hammerhead		3							
Lamniformes	Alopiidae	*Alopias superciliosus*	Bigeye thresher		2							
	Lamnidae	*Isurus oxyrinchus*	Shortfin mako		47						3	
	Lamnidae	*Isurus paucus*	Longfin mako		3							
Lampriformes	Lampridae	*Lampris guttatus*	Opah			12						
Odontoceti	Delphinidae	*Globicephala spp*	Pilot whales nei									1
Percoidei	Bramidae	*Brama brama*	Atlantic pomfret									1
	Carangidae	*Parastromateus niger*	Black pomfret			18						14
	Coryphaenidae	*Coryphaena equiselis*	Pompano dolphinfish		3							
	Coryphaenidae	*Coryphaena hippurus*	Common dolphinfish		7			5				27
Rajiformes	Dasyatidae	*Dasyatis violacea*	Pelagic stingray			45						72
	Mobulidae	*Mobula hypostoma*	Lesser devil ray			4						9
Scombroidei	Gempylidae	*Lepidocybium flavobrunneum*	Escolar		63							
	Gempylidae	*Ruvettus pretiosus*	Oilfish			4						
	Istiophoridae	*Makaira nigricans*	Blue marlin		3							
	Istiophoridae	*Tetrapturus albidus*	Atlantic white marlin		12						2	
	Istiophoridae	*Tetrapturus pfluegeri*	Longbill spearfish		1							
	Scombridae	*Thunnus alalunga*	Albacore		19			18			7	
	Scombridae	*Thunnus albacares*	Yellowfin tuna		13							
	Scombridae	*Thunnus obesus*	Bigeye tuna		11							
	Scombridae	*Thunnus thynnus*	Atlantic bluefin tuna							73		
	Xiphiidae	*Xiphias gladius*	Swordfish	589			139			933		
Tetraodontiformes	Molidae	*Mola mola*	Ocean sunfish			3						4
	Tetraodontidae	*Lagocephalus lagocephalus*	Oceanic puffer			3						
Testudines	Cheloniidae	*Caretta caretta*	Loggerhead turtle			36			2			77
	Dermochelyidae	*Dermochelys coriacea*	Leatherback turtle			9						

4.3.2 Treatment effects on turtle catch

In the Atlantic and western Mediterranean higher catch rates of loggerhead turtles were observed on sets baited with squid (on average 1.02 ± 0.22 loggerheads 1000 hooks^{-1} on squid bait and 0.21 ± 0.06 loggerheads 1000 hooks^{-1} on mackerel bait), while in the eastern Mediterranean one loggerhead turtle was caught on squid bait and the other on mackerel, but both were hooked on J-hooks. There was no such pattern in catch rates of leatherback turtles in the Atlantic and no clear patterns in the variation in catch rates among hook types (Figure 26) for either species.

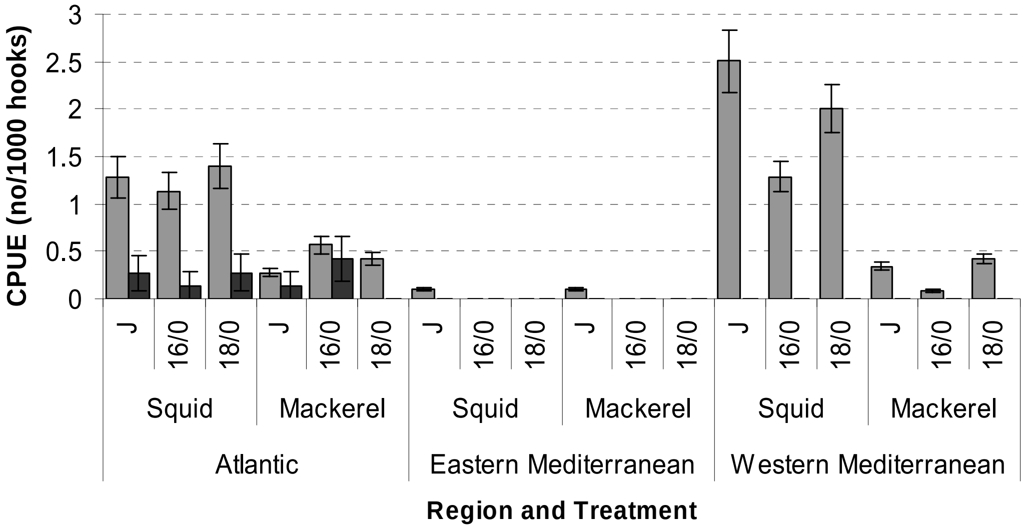

Figure 26 Catch per unit effort (CPUE, numbers per thousand hooks) of loggerhead (grey bars) and leatherback (black bars) turtles in the three regional trials. Error bars represent ± standard error.

As only nine leatherbacks were caught in the trials and all of these were in the Atlantic, they were removed from the main analyses. There is evidence that this species behave differently to loggerhead turtles when interacting with fishing gear (Gilman et al., 2005; Watson et al., 2005). Descriptive results for this species will be provided in the following sections.

With all regional data included, both region and bait had a significant effect (p<0.001, Table 10) on the probability of catching a loggerhead turtle, with the probability of turtle capture being greater in the Atlantic and western Mediterranean and greater with squid (Figure 27). For more details of GLM effects see Appendix 3 (Sections 11.1, 11.2, 11.3, and 11.4). Although the highest catch rates were recorded with J-hooks, and lowest with 16/0 hooks, the probability of catching a turtle was not significantly different among hook types. Table 10 sets out the odds ratios for each of the bait and hook effects, illustrating the greater odds of capturing turtles in the western Mediterranean and the Atlantic than in the eastern Mediterranean.

Since capture rates were so low in the eastern Mediterranean (2 turtles), this region was omitted from further analysis of treatment effects on turtle catch rates.

When analysed separately from other regions, the bait effect on the probability of catching a turtle remained significant in the Atlantic (p=0.002, Table 10) and although the probability of capture again varied by hook type, patterns were different to all regions combined, being lowest for J-hooks and highest for 18/0 hooks, but this variation was not significant (*p*>0.01, Figure 28 and Table 11).

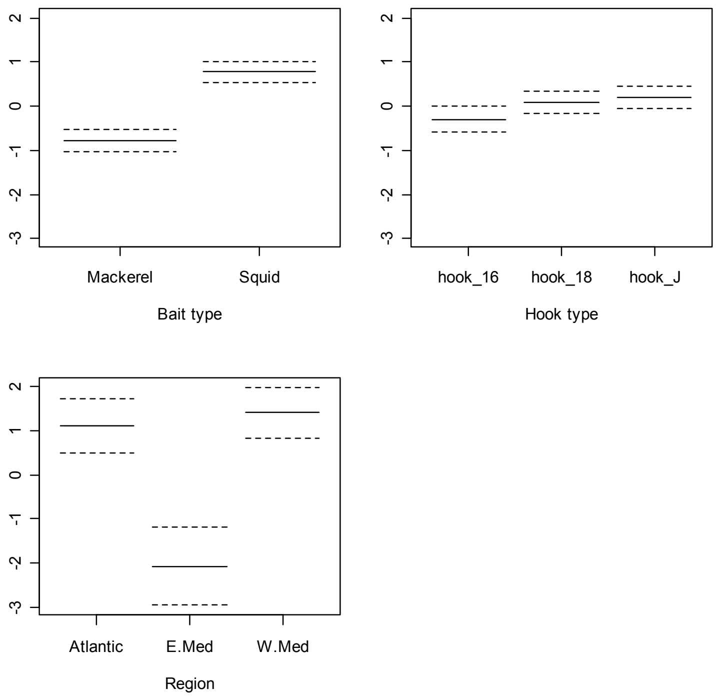

Figure 27 Marginal effects of bait type, hook type and region on probability of catching a turtle. Error bars represent ± the standard error.

Table 10 Significance levels (*p*) of ANOVA (Chi-squared statistic) for binomial GLM (logit link) on turtle catch data.

	***P* (Chi)**		
Factor	**Regions Combined**	**Atlantic**	**Western Mediterranean**
Bait	$3.694\ e^{-13}$	0.002	$8.472\ e^{-12}$
Hook type	0.10	0.927	0.04
Region	$3.222\ e^{-18}$		

Table 11 Odds ratios for binomial GLM on turtle catch data.

Effects		**Odds Ratios**		
		Regions Combined	**Atlantic**	**Western Mediterranean**
Intercept		0.00	0.00	0.00
Bait	**Squid**	2.17	1.73	2.58
	mackerel	0.46	0.58	0.39
Hook type	**J**	1.22	0.92	1.35
	16/0	0.75	1.01	0.65
	18/0	1.09	1.08	1.14
Region	**Atlantic**	2.62	-	-
	E. Med	0.11	-	-
	W. Med	3.52	-	-

Odds ratios to 2 decimal places.

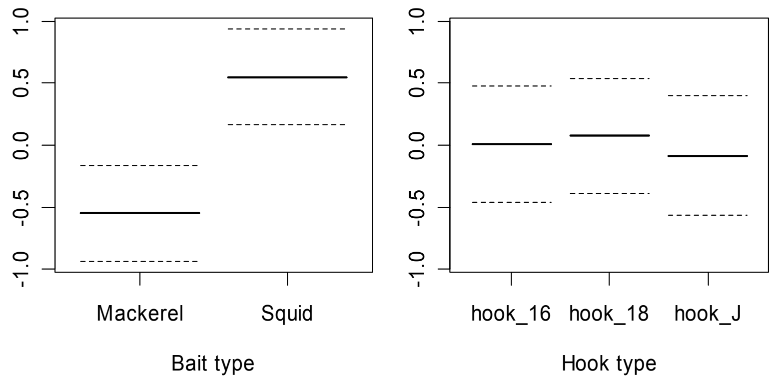

Figure 28 **Marginal effects of bait type and hook type on the probability of catching a turtle in the Atlantic. Error bars represent ± the standard error.**

In the western Mediterranean, bait had a similarly significant effect on the probability of catching a turtle to the Atlantic (Table 10, Figure 29). Patterns in hook effects in the western Mediterranean illustrated a similar pattern to when all regional data were analysed together, with the probability of catching a turtle being highest on J hooks and lowest on 16/0 hooks, but again this variation was not significant (p>0.01, Table 10).

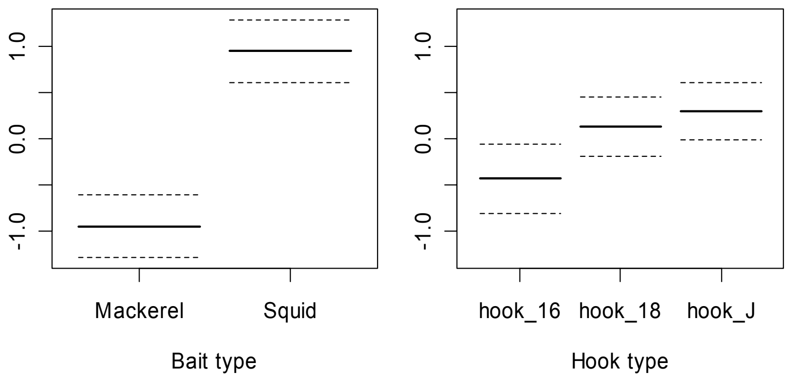

Figure 29 **Marginal effects of bait type and hook type on the probability of catching a turtle in the western Mediterranean. Error bars represent ± standard error.**

4.3.2.1 Effects of additional factors on turtle catch

When including sea surface temperature, soak time and depth into a generalised additive model as continuous predictors, there is some observational evidence for a negative relationship between sea surface temperature (in the range of 21 to 28 degrees Celsius) and probability of capture (for more detailed results see Appendix 3, Section 11.5 for details). The depth of the fishing gear and soak time exhibited little consistent pattern or correlation with the probability of capturing a turtle.

On the disaggregation of the analysis by region, the situation did not improve. Any correlation between turtle capture rate and sea temperature observed in the aggregated analysis dissolved. The temperatures observed in the Western Mediterranean and Atlantic did not overlap strongly. The noisy, largely flat trends produced, reveal that the apparent aggregated trend is largely the product of differing water temperatures among regions with different relative abundance of turtles.

When the hook position within a magazine on which a loggerhead turtle was caught (hook position 1 is equivalent to hooks 1 and 5; position 2 equivalent to hooks 2 and 4; and position 3 equivalent to hook 3 in each magazine) was included into the binomial GLM as a discrete linear predictor, it did not have a significant effect on the probability of turtle capture (see Appendix 3, section 11.6 for details).

4.3.2.2 Power analysis of binomial GLM of treatment effects on turtle catch

The power analysis (Figure 30 and Figure 31) indicates that there was a higher power to detect smaller effect sizes in the analysis of the Western Mediterranean. This is predominantly due to the higher number of hooks deployed in the Western Mediterranean region (the power surface is similar in the case of both regions). The power analyses were based on the least certain marginal effects. Consequently they demonstrate that per treatment effect, there was over an 80% chance of correctly identifying a positive result (defined as a treatment leading with odds ratio more extreme than 0.5 or 2) for all levels of each factor in this analysis. Figure 30 and Figure 31 also illustrate the trade-off in terms of statistical power, between effect size and number of samples. For both regions this analysis suggests that over 100,000 hooks would have to be deployed to detect an odds ratio of 2/3 or 1.5 (50% increase or decrease in the probability of catching a turtle).

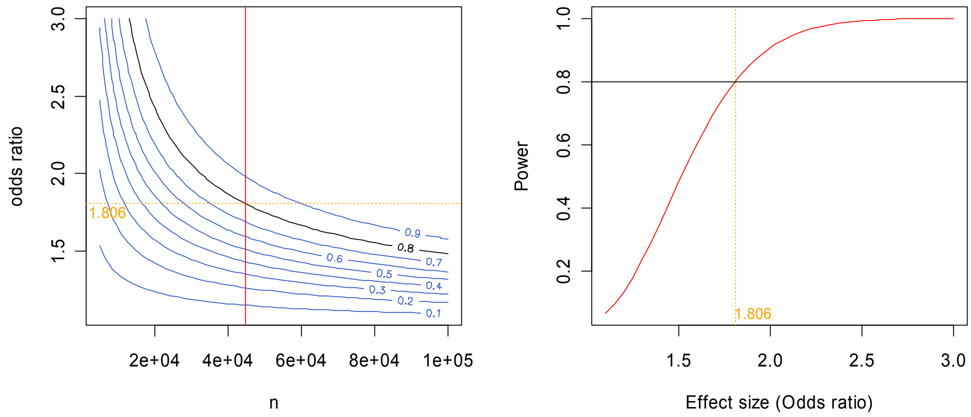

Figure 30 Power analysis results for Atlantic

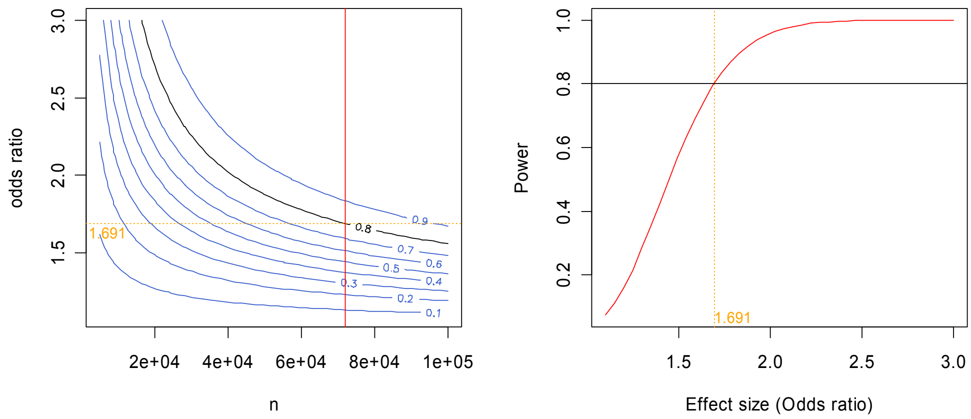

Figure 31 Power analysis results for western Mediterranean.

4.3.2.3 Predicted turtle catch rates by treatment effects

Predicted catch rates from the binomial GLM illustrate clearly the difference in catch rates between the two bait types and the varying pattern in hook effects between the Atlantic and the western Mediterranean (Figure 32). The lowest catch rates for loggerhead turtles were predicted for J hooks with mackerel bait in the Atlantic and for 16/0 hooks with mackerel bait in the western Mediterranean. Highest catch rates were predicted for 18/0 hook and squid bait in the Atlantic and for J hooks with squid bait in the western Mediterranean. Significantly lower catch rates were predicted for all hook types combined with mackerel bait than on squid combined with either 18/0 or J hooks in the western Mediterranean.

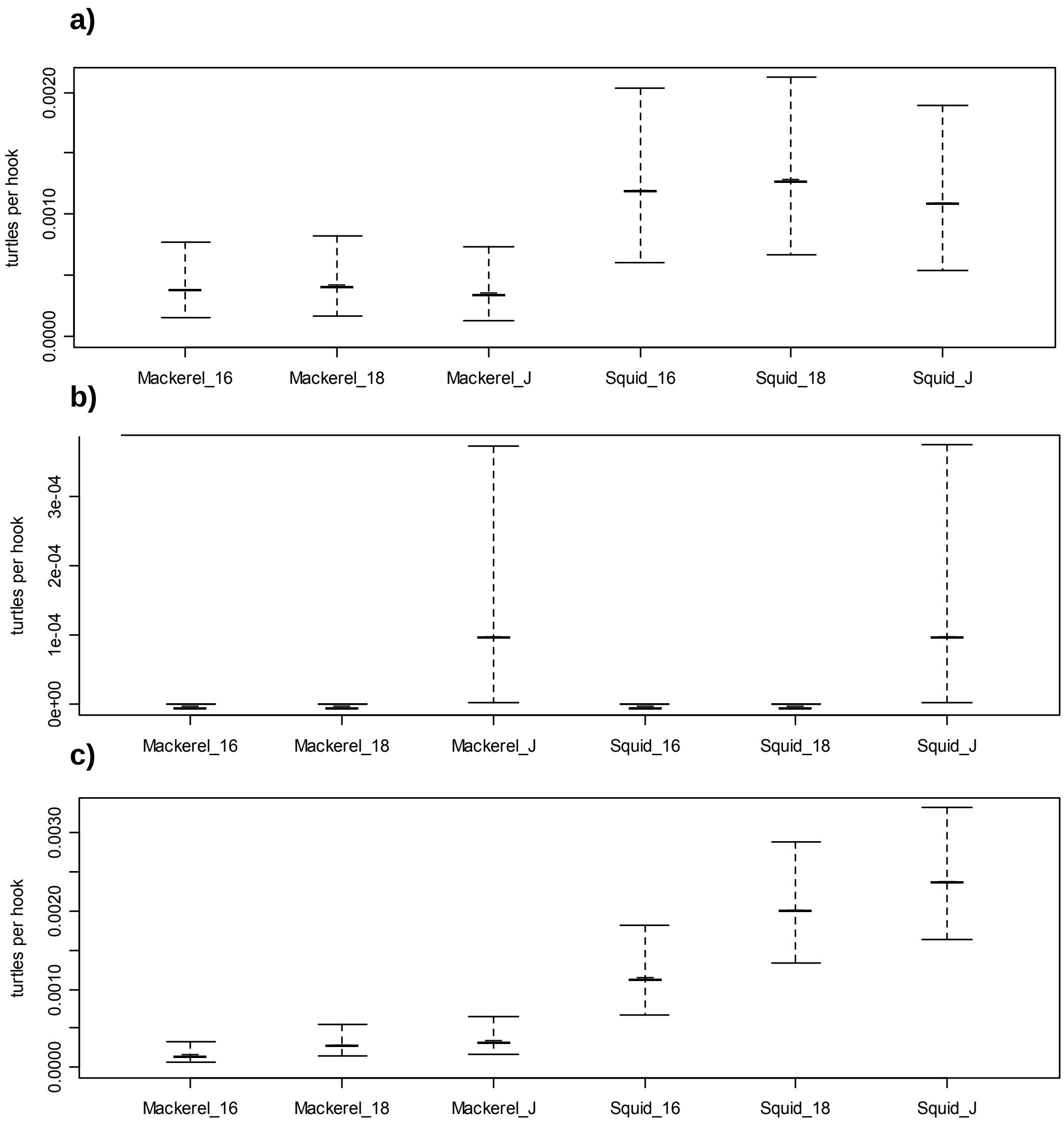

Figure 32 Predicted turtle catch (numbers hook^{-1}) for the a) Atlantic b) eastern Mediterranean and c) western Mediterranean. Error bars represent 95% confidence limits.

4.3.2.4 *Treatment effects on anatomical hooking location of turtles caught*

Out of a total of 22 hooking location categories, 17 of these were recorded among the 3 regional trials. Figure 33 and Figure 34 detail these fine scale hooking locations for leatherbacks and loggerheads pooled over all regions, and for loggerheads split between the Atlantic and Mediterranean (eastern and western trials pooled) respectively. For analysis and to simplify summaries, the fine scale hooking location categories were pooled into the following three categories 'Swallowed' –which included turtles recorded under the categories: Unk internal (deep) and Ingested oesophagus; 'Mouth' which included turtles recorded under the categories: 'beak', 'tongue', 'mouth', 'upper jaw', 'side jaw', 'lower jaw', 'glottis'; and 'External' included turtles recorded under the categories: 'shoulder', 'plastron', 'neck', 'front flipper', 'carapace', 'armpit', 'Unk, possibly entangled'. No turtles were recorded as hooked by the 'groin', 'rear flipper', 'head', 'tail' or 'other jaw location'. Table 12 details the number of each species caught by bait and hook type in each of the regional trials by these pooled hooking location categories.

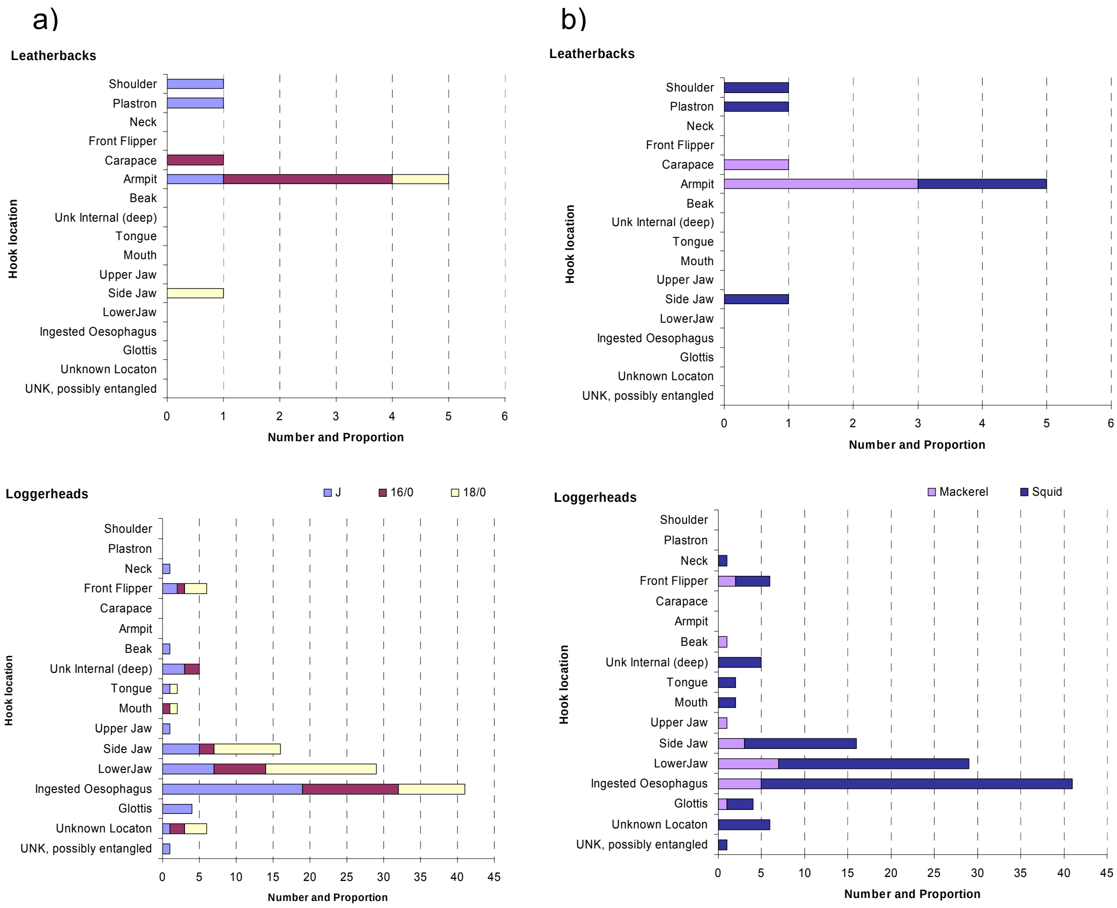

Figure 33 Detailed hooking location for loggerhead and leatherback turtles caught during the trials by a) hook type and b) bait type.

None of the leatherback turtles caught during the trials in the Atlantic were hooked internally (Figure 33). Leatherbacks were externally hooked by both bait types and by all of three hook types, however the smallest proportion of externally hooked leatherbacks were caught on 18/0 circle hooks (Figure 34). The 'armpit' was the most frequent external hooking location for leatherbacks, with the largest proportion of turtles hooked in this way caught on 16/0 circle hooks (Figure 33). The only leatherback hooked in the mouth (side of the jaw) was caught on squid bait and with an 18/0 circle hook.

Table 12 Number of each species of turtle caught in each regional trial by hook type, bait type and hooking location

Regional Trial	Species	Bait	Hook	Hooking location				
				Externally hooked	Hooked in mouth	Swallowed hook	Unknown hooking location	Total
Atlantic	***D. coraciea***	**Squid**	**J**	2	0	0	0	2
			16/0	1	0	0	0	1
			18/0	1	1	0	0	2
		Mackerel	**J**	1	0	0	0	1
			16/0	3	0	0	0	3
	C. caretta	**Squid**	**J**	0	2	7	0	9
			16/0	0	4	4	0	8
			18/0	0	5	4	1	10
		Mackerel	**J**	0	2	0	0	2
			16/0	0	1	3	0	4
			18/0	0	3	0	0	3
Eastern Mediterranean	***C. caretta***	**Squid**	**J**	0	0	1	0	1
		Mackerel	**J**	0	1	0	0	1
Western Mediterranean	***C. caretta***	**Squid**	**J**	2	12	13	2	29
			16/0	1	5	7	2	15
			18/0	2	14	5	2	23
		Mackerel	**J**	1	2	1	0	4
			16/0	0	0	1	0	1
			18/0	1	4	0	0	5
			Total	15	56	46	7	124

Eighty-two percent of all loggerheads caught during the trials were hooked with squid bait, and of these approximately equal numbers were either hooked in some part of the mouth or had swallowed the hook (Figure 34). Forty percent of all loggerheads caught were hooked on J hooks, 36% on 18/0 circle hooks and 24% on 16/0 circle hooks.

A larger proportion of loggerhead turtles hooked in the mouth were caught on 18/0 circle hooks than the other two hook types, with the least number of turtles hooked in this way being caught on the 16/0 circle hooks (Figure 34). The largest proportion of loggerheads which had swallowed the hooks were caught on J hooks, and the smallest proportion of these turtles were caught on 18/0 hooks (Figure 34). A similar pattern was observed when data for hooking location were split between geographical region (pooling Mediterranean trial captures) (Figure 36), although a slightly greater proportion of loggerheads which had swallowed the hook were caught on J hooks in the Mediterranean when compared with the Atlantic (54% compared with 42% respectively). Across all hook types a larger proportion of all loggerheads caught in the Atlantic had swallowed the hook compared with the Mediterranean (53% compared with 38% respectively.

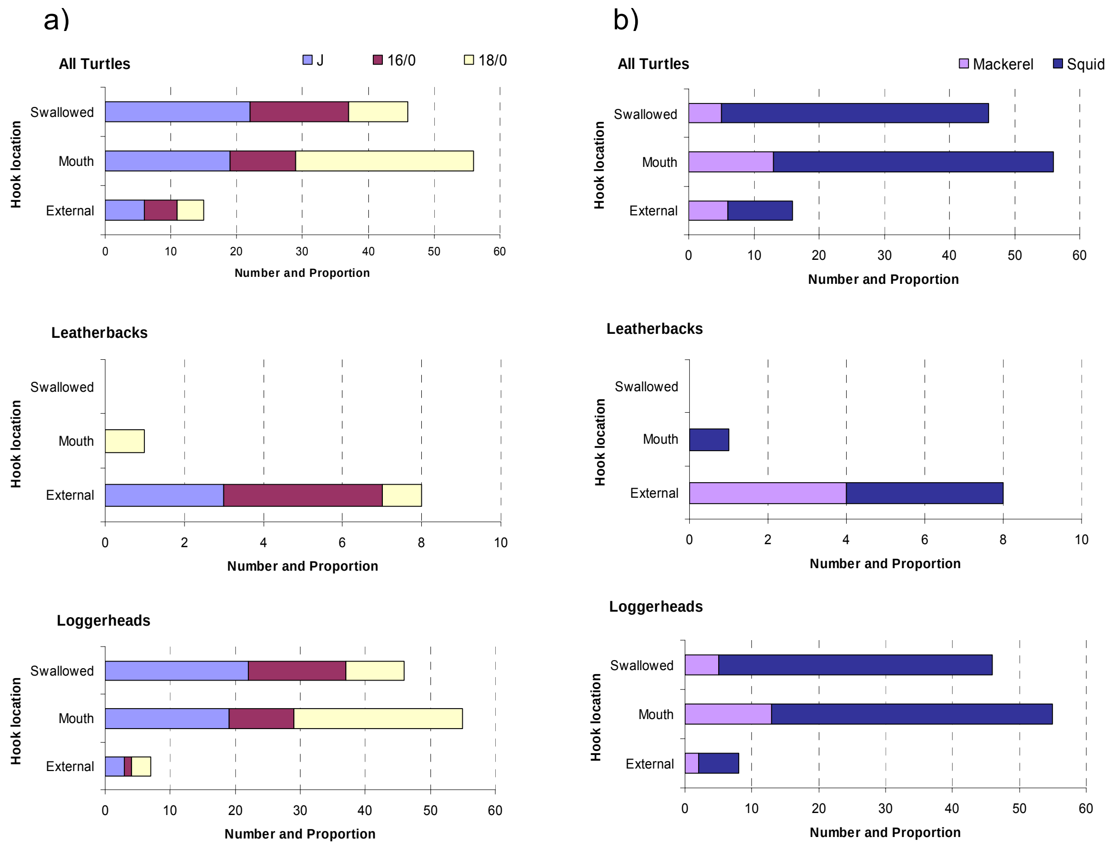

Figure 34 Hook location for loggerhead and leatherback turtles under simplified categories used in analyses by a) hook type and b) bait type.

Only 8 of the loggerheads caught during the trials were hooked externally, and all of these interactions occurred in the Mediterranean trials (Figure 33 and Figure 34). 6 of these had been hooked in the front flipper, by both bait types and all three hook types (Figure 33). On capture, the hooking location was unknown for 6 loggerheads and these individuals were removed from the statistical analyses.

Five out of the six turtles removed from the analysis due to an unknown hooking location, were caught on magazines set with circle hooks (3 on 18/0 and 2 on 16/0 hooks). These turtles came free of the hooks in the process of boating, and were would either have been hooked externally somewhere, entangled or hooked lightly in the mouth.

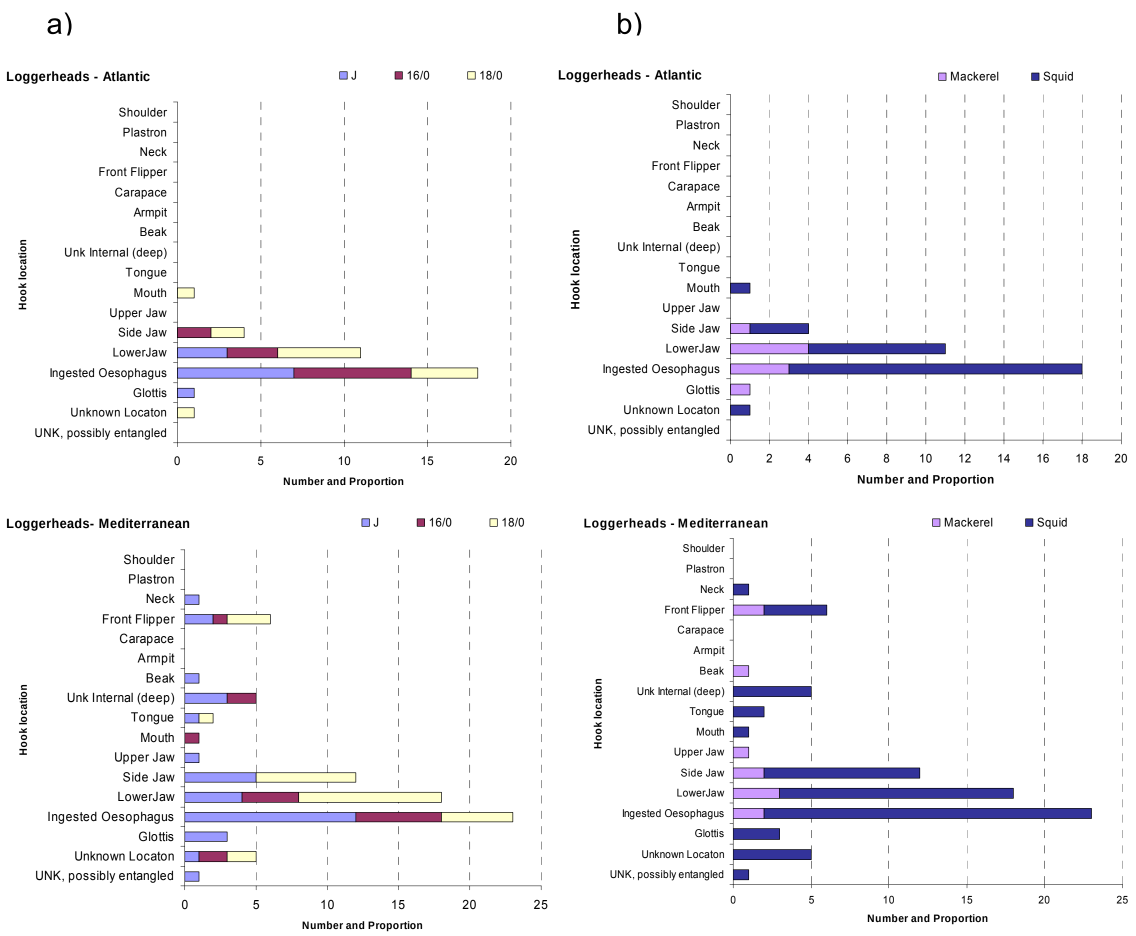

Figure 35 Hooking location of turtles caught by a) hook and b) bait type by region (Mediterranean trial captures pooled).

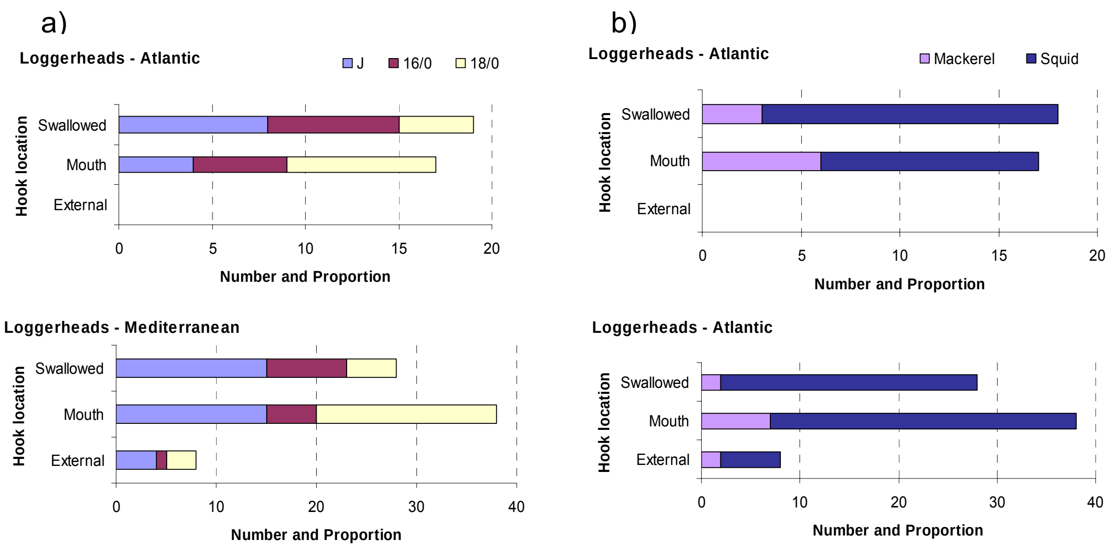

Figure 36 Hooking location of loggerhead turtles by a) hook type and b) bait type by region (Mediterranean trial captures pooled) under simplified categories used in analyses.

While at an observational level, hook type and bait type effects showed some influence on hooking location of loggerhead turtles, there were no statistically significant treatment effects (see Appendix 3, section 11.7 for Wald Statistics). Figure 37 summarises the marginal effects of hook and bait types alone, illustrating the slightly higher probability of a turtle swallowing the hook if caught on squid bait, mackerel bait slightly decreased the probability of swallowing the hook. 16/0 circle hooks increased the probability of the hook being swallowed, while 18/0 circle hooks decreased the probability and J hooks had no effect. The figure also illustrates the higher probability of a loggerhead turtle being hooked externally on an 18/0 circle hook compared with the non-offset 16/0 circle hooks which decreased the probability of being hooked in this way and compared with J hooks which had no effect.

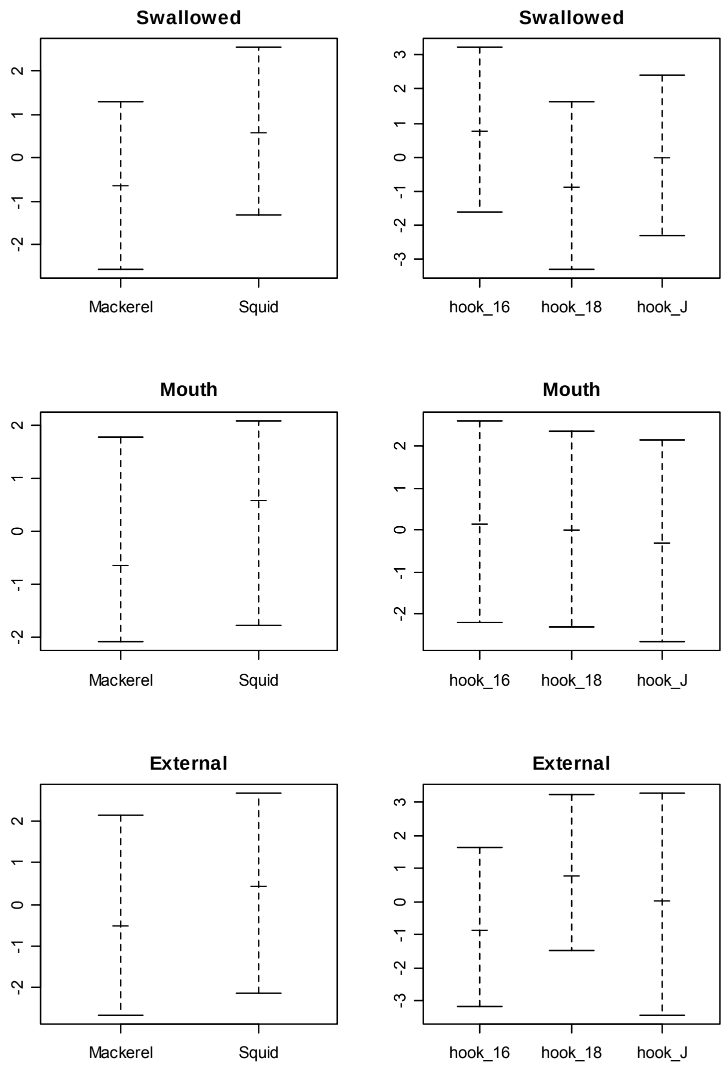

Figure 37 **Marginal effect of hook and bait type by hooking location of loggerhead turtles caught across all regional trials. Error bars represent ± standard error.**

4.3.2.5 Treatment effects on size of turtles caught

The lengths of all leatherbacks caught in the Atlantic were estimated, as all of these turtles were too large to bring on board the vessel. The leatherback turtles caught averaged 146.7 ±22.9 cm estimated carapace length, and those caught on squid were on average larger than those caught on mackerel bait (Table 13).

Table 13 Numbers and mean carapace lengths of leatherback turtles caught during the Atlantic trials by hook and bait type.

Bait Code	Hook Type	Number of turtles	Mean Carapace Length, cm	Standard Deviation, cm
Squid	J	2	160	56.6
	16/0	1	140	-
	18/0	2	150	14.1
Mackerel	J	1	140	-
	16/0	3	140	10
	18/0	-	-	-

Loggerhead turtles caught in the Atlantic were slightly larger than those caught in the western Mediterranean trials, averaging 58.9 cm ± 1.3 s.e. (range 46-76 cm) and 54.8 cm ± 0.7 (range 40-69cm) straight carapace lengths respectively. The two turtles caught in the eastern Mediterranean had straight carapace lengths of 60 and 80 cm (Figure 38).

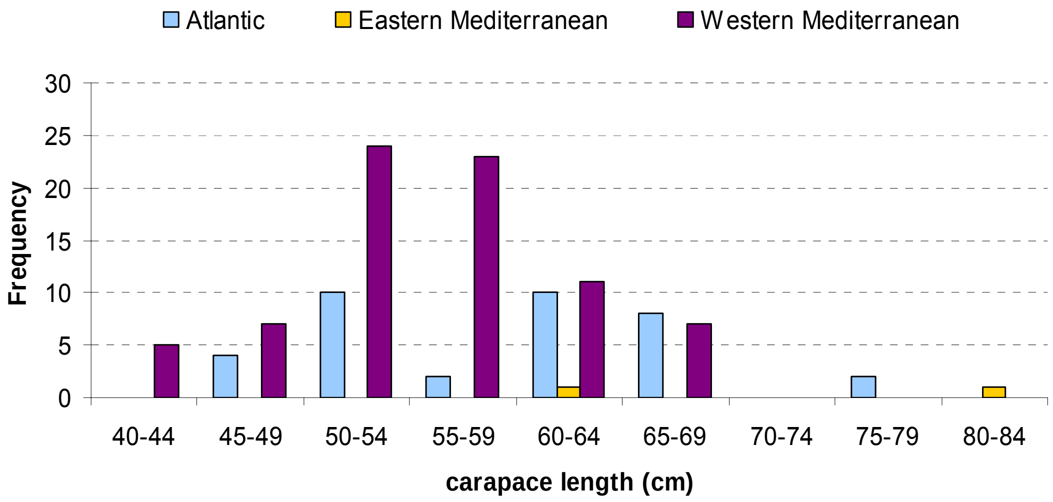

Figure 38 Straight carapace length (cm) and frequency of loggerhead capture in each of the regional trials.

The variation in the straight carapace lengths of loggerheads caught in the Atlantic and western Mediterranean was significantly different (p<0.009, see Appendix 3, section 11.8), but the type of hook or bait did not have a significant effect on the size of loggerhead turtles caught (Figure 39).

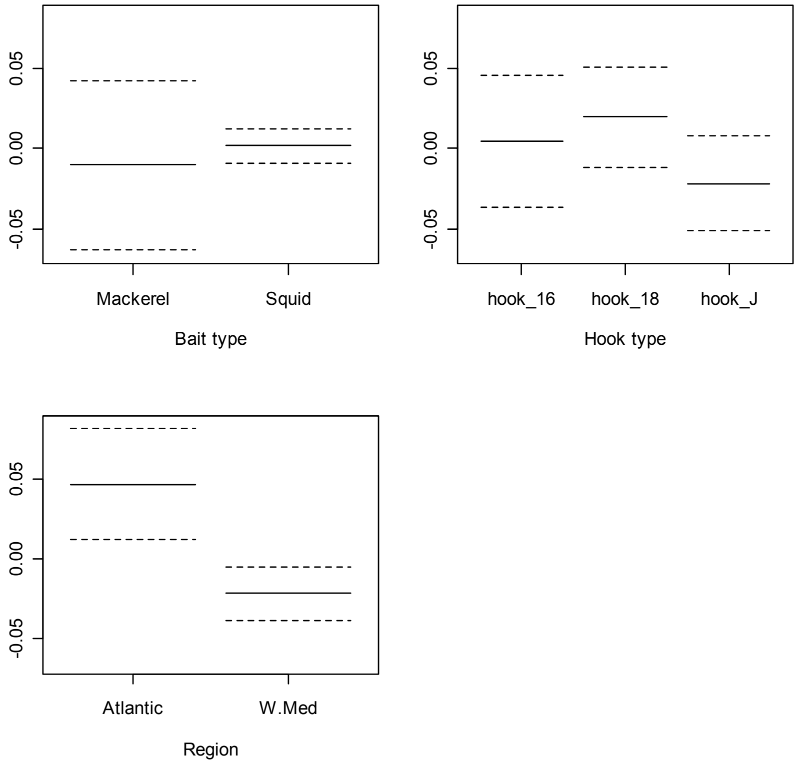

Figure 39 Marginal effects of bait type and hook type on the size (straight carapace length) of loggerhead turtles caught in the Atlantic and western Mediterranean. Error bars represent ± standard error.

Figure 40 illustrates the size of turtles caught by each hook type and also by hooking location for each hook type. Sample sizes were not large enough to analyse this data statistically, but they do provide some descriptive information on the secondary effects of hook type on potential post-hooking survival.

The modal class of loggerhead turtles caught on J hooks was the same for each hooking location, but for 16/0 circle hooks the modal size class was larger for those which had swallowed hooks (60-64cm) than those which were hooked in the mouth (50-54cm). 18/0 hooks were swallowed by turtles of a similar size to those which were hooked in the mouth, but loggerhead turtles caught on 18/0 hooks in general were slightly larger, modal class of 55-59 cm straight carapace length, than those caught on J hooks and 16/0 hooks (50-54cm straight carapace length).

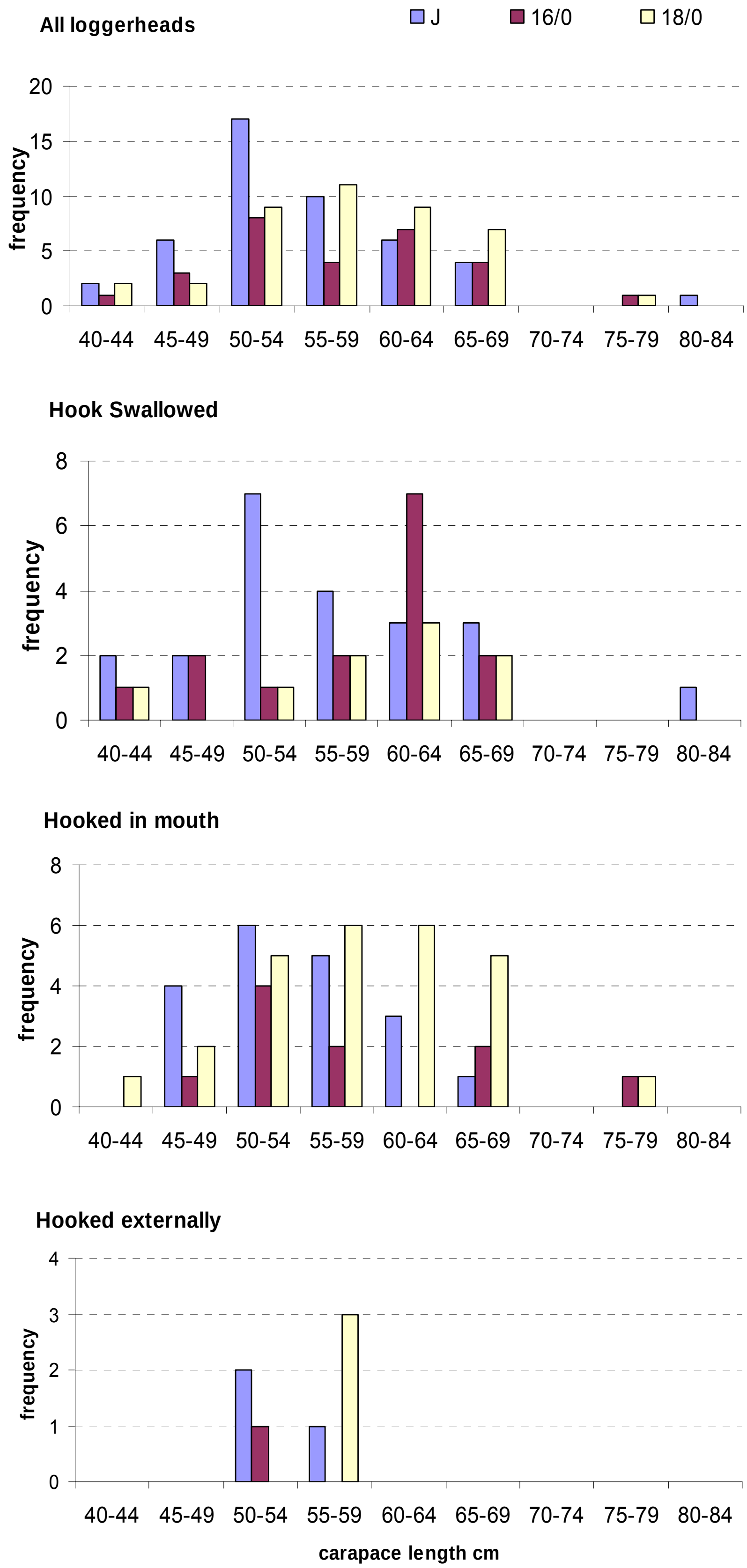

Figure 40 **Loggerhead straight carapace length (cm) and frequency of capture by hook type, and by hooking location and hook type.**

4.3.2.6 *Release condition by hook and bait type.*

Turtles which died during the trials as a result of the interaction with fishing gear were not caught on a particular type of hook or bait type. Table 14 details the numbers of turtles caught and their fate by hook and bait type in each of the regional trials as well as the respective percentage of all turtles caught.

Table 14 Details of the numbers and fate of turtles caught during regional trials.

Regional trial	Bait	Hook	Turtle died		Total Released Alive	
			Number	%	Number	%
Atlantic	Squid	J			11	8.9
		16/0			9	7.3
		18/0			12	9.7
	Mackerel	J			3	2.4
		16/0	1	0.8	6	4.8
		18/0	1	0.8	2	1.6
Eastern Mediterranean	Squid	J		0.0	1	0.8
	Mackerel	J		0.0	1	0.8
Western Mediterranean	Squid	J	3	2.4	26	21.0
		16/0	2	1.6	13	10.5
		18/0		0.0	23	18.5
	Mackerel	J		0.0	4	3.2
		16/0		0.0	1	0.8
		18/0	1	0.8	4	3.2
Grand Total			8	6.5	116	93.5

4.3.2.7 *Non-independence among turtle capture events.*

Generally, the frequency of number of turtles caught per treatment set (~215 hooks of a certain type and bait) closely follows that predicted by a binomial function. However, in 10,000 binomial simulations of the experiment (each including 930 replicate treatment sets of ~215 hooks), less than 5% of simulations included one or more capture event of three turtles. This is not reflected in the experiment, which observed several much larger capture events including two of six turtle captures. It is important to note that this provides some evidence of the violation of the assumption of independence among hooks which is necessary for the logical implementation of the binomial model. There are many reasons why such an assumption may not be consistent in this analysis; the most important of which is that distribution of turtles is not spatially homogeneous and instead they preferentially aggregate in superior foraging areas. Having stated this, the model offers a better fit than any other pdf (population density function) and offers an excellent approximation of over 90% of the observed data that consists of zero, one and two turtle captures.

Figure 41 details the frequency of turtles caught by set and illustrates that a small number of sets caught large numbers of turtles compared to others, demonstrating the patchy and aggregated distribution of turtles which is often referred to by other studies (Gilman et al., 2007). However, it is worth noting that all sets which caught more than 4 turtles were baited with squid.

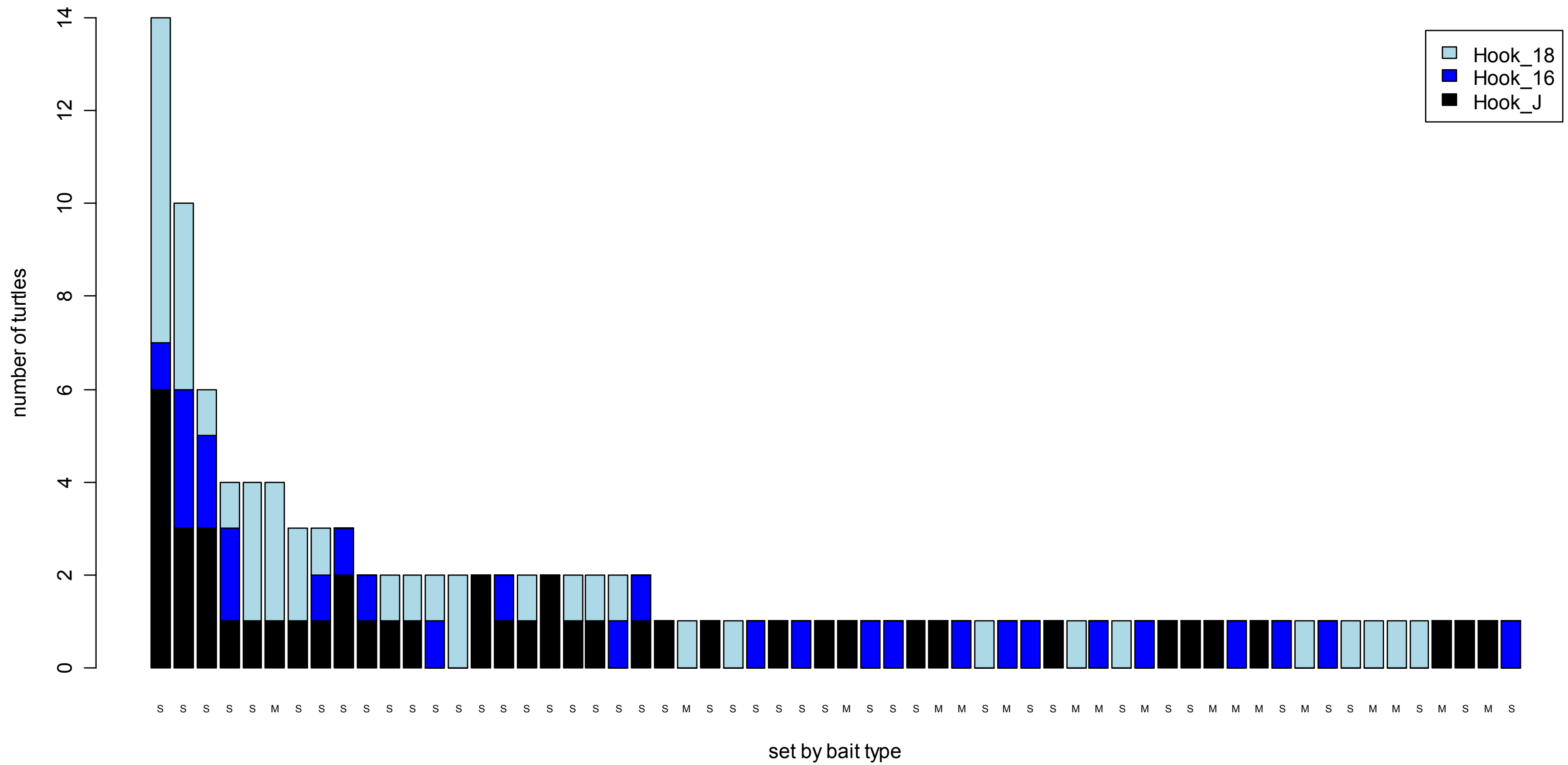

Figure 41 **Frequency of turtle capture by set, bait type and hook type.**

4.3.3 Treatment effects on swordfish catch

Swordfish catch rates were greatest by number in the western Mediterranean for J hooks baited with mackerel (22.14 swordfish 1000 hooks^{-1} ± 2.36 s.e.) and lowest for 16/0 hooks with mackerel bait in the eastern Mediterranean (0.10 swordfish 1000 hooks^{-1} ± 0.10 s.e.)

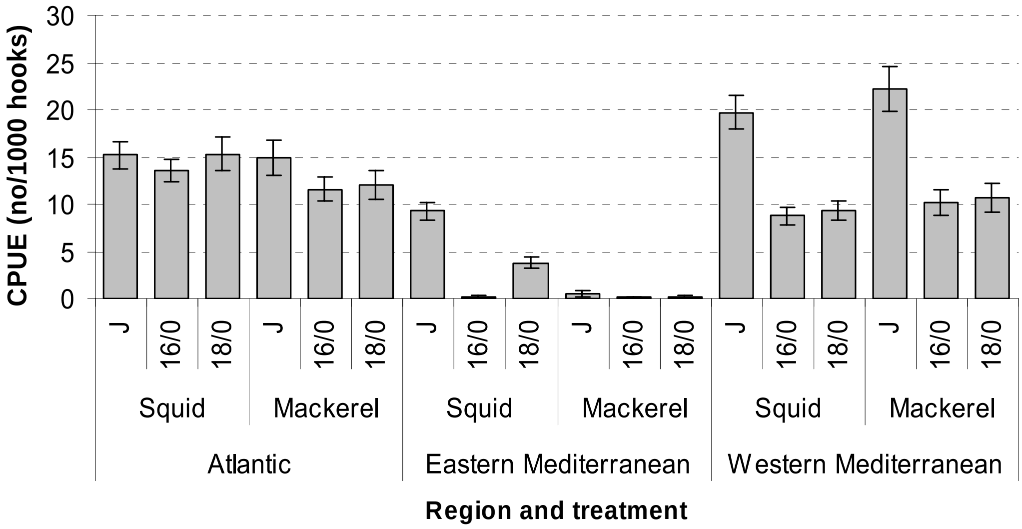

Figure 42 Catch per unit effort (CPUE, numbers 1000 hooks^{-1}) of swordfish in the three regional trials. Error bars represent ± standard error.

Binomial GLM (logit link) indicated that region, bait and hook type all had significant effects on the numbers of swordfish caught (see Table 15), with higher catch by number in the Atlantic and western Mediterranean, and on squid bait and on J hooks (Figure 43, Appendix 3,section 11.9).

Table 15 Significance levels (*p*) of ANOVA (Chi-squared statistic) for binomial GLM (logit link) on numbers of swordfish.

	***p* (Chi)**			
Factor	**Regions Combined**	**Atlantic**	**Eastern Mediterranean**	**Western Mediterranean**
Bait	0.01	0.93	1.71 e^{-30}	0.05
Hook type	2.66 e^{-34}	0.176	3.74 e^{-25}	1.27 e^{-29}
Region	7.66 e^{-135}	-	-	-

When regional data were analysed separately, there were significant bait and hook effects on the probability of catching swordfish in the eastern Mediterranean (Table 15 and Figure 43, Appendix 3, section 11.11), only significant hook effects in the western Mediterranean (Table 15 and Figure 44, Appendix 3, section 11.12) but no significant treatment effects in the Atlantic (Table 15 and Figure 45, see Appendix 3, Section 11.10). Patterns in effects differed between regions, particularly by bait type with the probability of catching a swordfish being greater for mackerel in the western Mediterranean, and greater for squid bait in the eastern Mediterranean and Atlantic (Figure 45, Figure 44 and Figure 46 respectively).

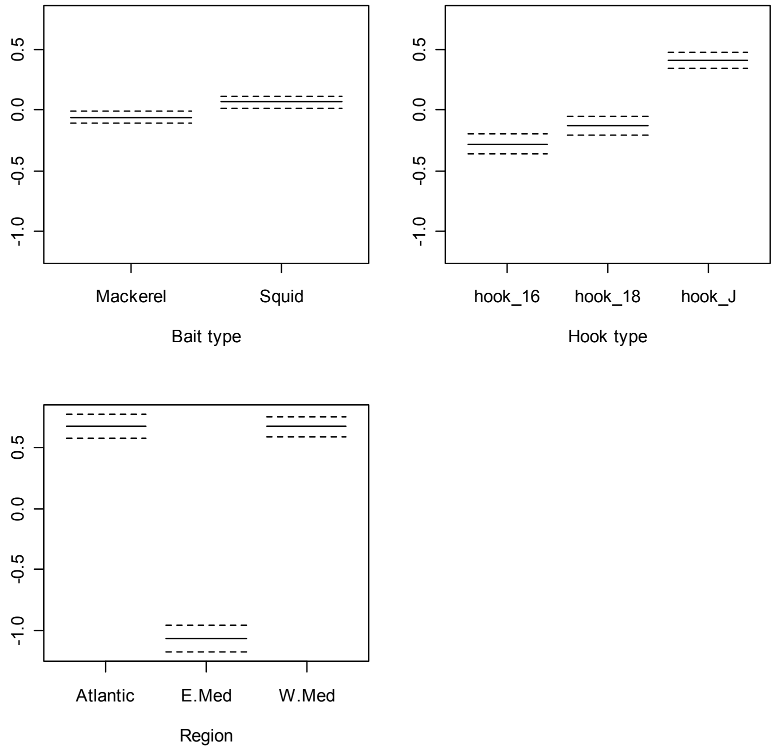

Figure 43 **Marginal effects of region, bait type, hook type on probability of catching a swordfish. Error bars represent ± the standard error.**

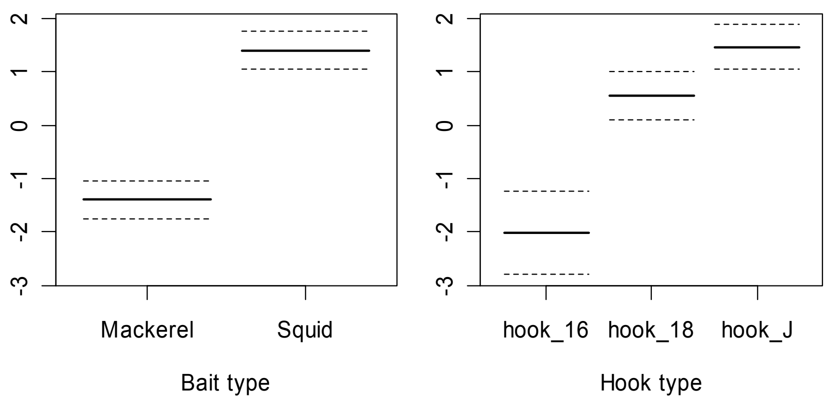

Figure 44 **Marginal effects of bait type, hook type on probability of catching a swordfish in the eastern Mediterranean. Error bars represent ± standard error.**

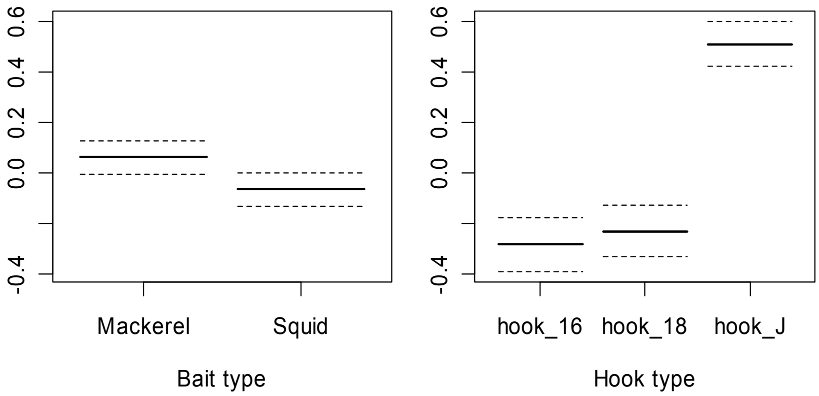

Figure 45 **Marginal effects of bait type, hook type on probability of catching a swordfish in the western Mediterranean. Error bars represent ± standard error.**

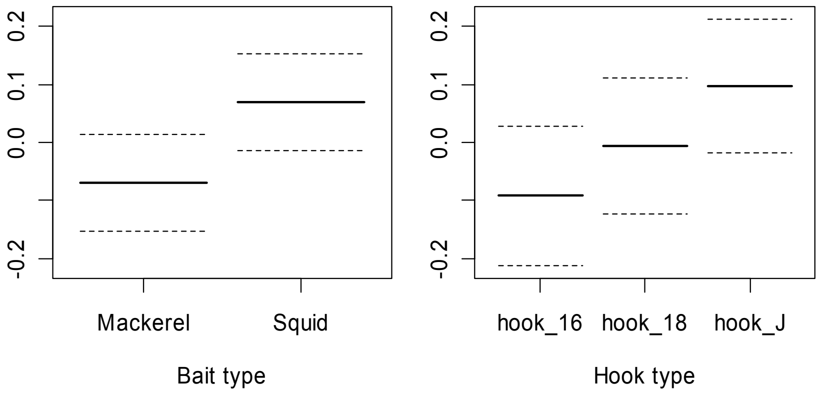

Figure 46 **Marginal effects of bait type, hook type on probability of catching a swordfish in the Atlantic. Error bars represent ± standard error.**

The size of swordfish caught varied among trial regions; the largest mean size of fish was caught in the Atlantic (51.8 kg ± 1.5 s.e.), the next greatest was in the eastern Mediterranean (25.6 kg ± 1.0 s.e.) and the smallest was in the western Mediterranean (18.3 kg ± 0.5 s.e.) (Figure 47).

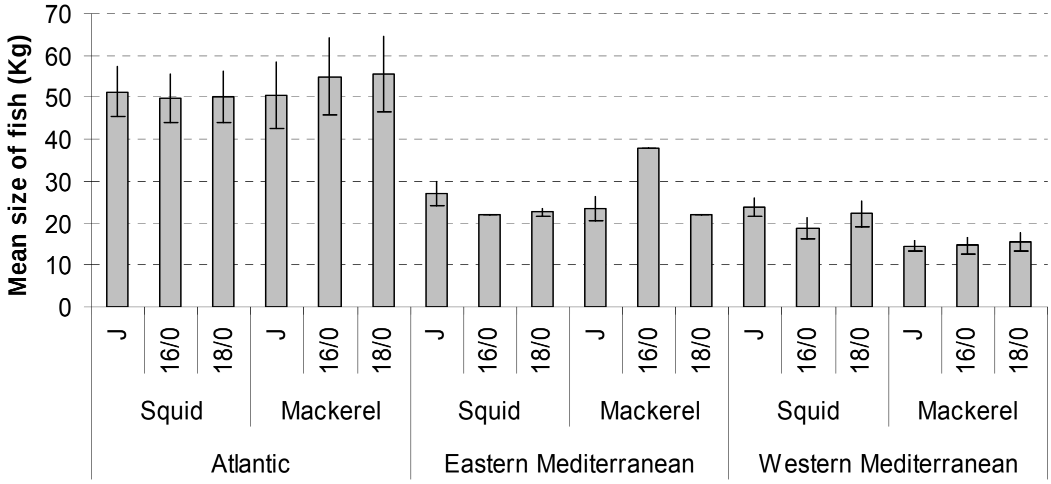

Figure 47 **Mean size of swordfish caught by region, bait and hook type. Error bars represent ± one standard error.**

When all data were analysed together with a lognormal GLM, there were significant effects of region, bait and hook type on the size of swordfish caught (Table 16, with larger fish being caught in the Atlantic, on squid and on J-hooks (Figure 48, Appendix 3, Section 11.13).

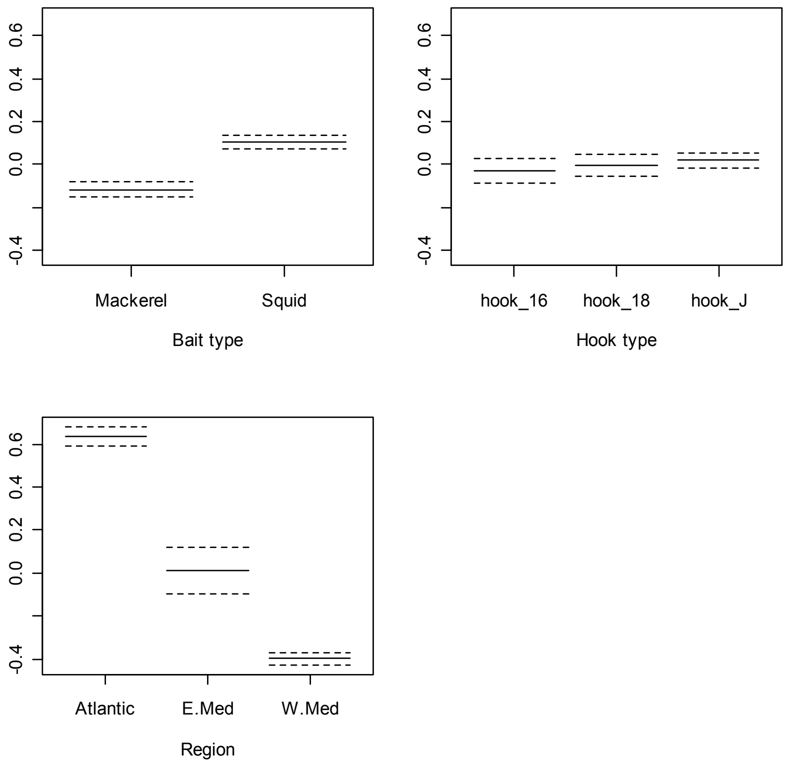

Figure 48 **Marginal effects of region, bait type and hook type on the size (kg) of swordfish caught during the trials. Error bars represent ± standard error.**

Table 16 **Significance levels (*p*) of ANOVA (F-test statistic) for lognormal GLM (Gaussian) on size (kg) of swordfish.**

	***P* (F)**			
Factor	**Regions Combined**	**Atlantic**	**Eastern Mediterranean**	**Western Mediterranean**
Bait	2.2 e^{-16}	0.74	0.94	2.0 e^{-16}
Hook type	0.007	0.96	0.03	0.222
Region	2.2 e^{-16}	-	-	-

When regional data were analysed separately, patterns in bait effects on size of swordfish caught remained consistent among regions with larger fish being caught on squid bait Figure 49, Figure 50 and Figure 51, but the effect was only significant in the western Mediterranean (Table 16). Patterns in hook effects on swordfish size differed among regions and were not significant (p>0.01, Table 16, see Appendix 3, sections 11.14-11.16).

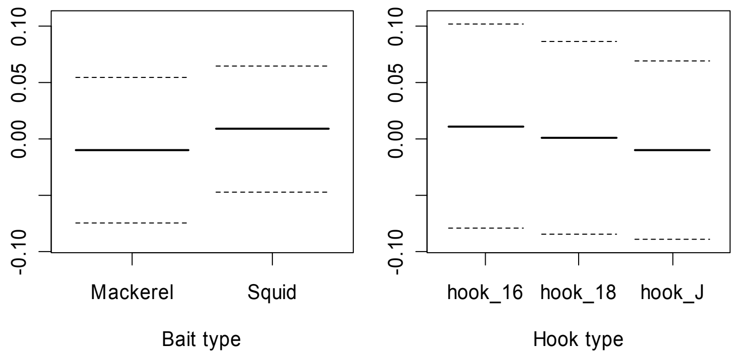

Figure 49 **Marginal effects bait type and hook type on the size (kg) of swordfish caught in the Atlantic. Error bars represent ± standard error.**

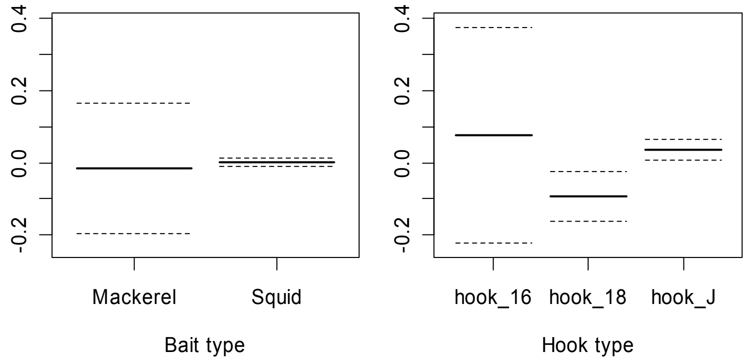

Figure 50 **Marginal effects bait type and hook type on the size (kg) of swordfish caught in the eastern Mediterranean. Error bars represent ± standard error.**

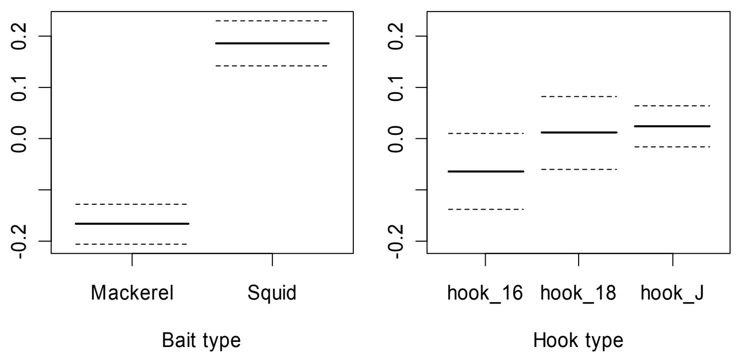

Figure 51 **Marginal effects bait type and hook type on the size (kg) of swordfish caught in the western Mediterranean. Error bars represent ± standard error.**

By weight the greatest catch rate was in the Atlantic for squid bait combined with 18/0 hooks (0.733 kg hook $^{-1}$ ± 0.09 s.e.) and again lowest for 16/0 hooks with mackerel bait in the eastern Mediterranean (0.0038 kg hook^{-1} ± 0.0038 s.e.).

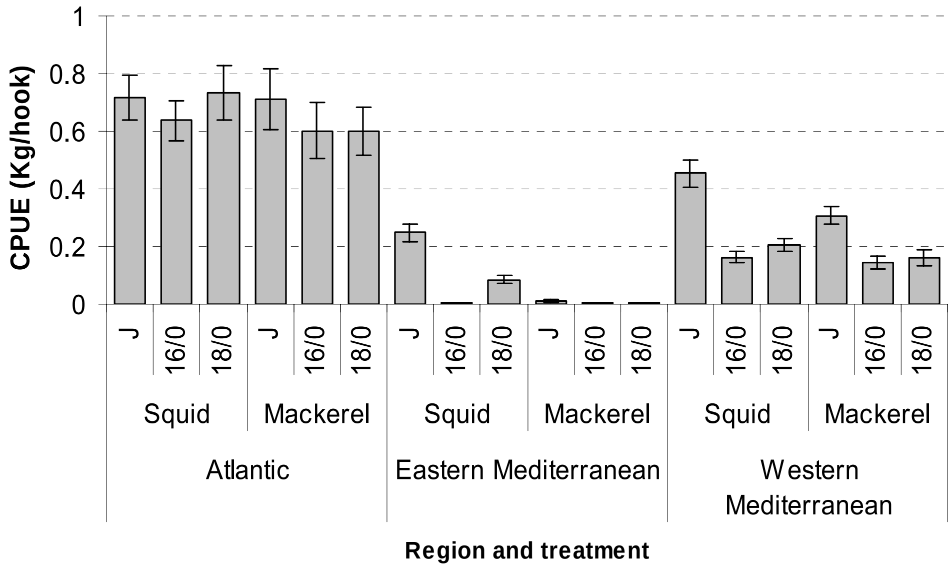

Figure 52 Catch per unit effort (CPUE, kg hook^{-1}) of swordfish in the three regional trials. Error bars represent ± standard error.

Results of the delta-lognormal GLM for all regional data combined indicated significant region, bait and hook effects on the probability of catching a swordfish, but the significance levels are difficult to interpret (see Appendix 3, section 11.17 for full tables and diagnostic plots) due to more than one underlying probability distribution.

However, patterns in bait and hook effects were consistent when data were analysed for each region independently and these patterns are illustrated in the predicted catch rate plots below in 4.3.3.2 (Appendix 3, sections 11.18-11.20).

4.3.3.1 Effects of additional factors on catch of swordfish

Temperature had relatively little consistent effect on swordfish catch rates among regions. This may be attributed to the limited overlap in temperature range among regions of different relative abundances of swordfish. Similarly, mean set depth did not appear to follow any relationship with swordfish catch rate. Soak time, on the other hand, exhibited a relatively strong positive, linear correlation with swordfish recapture rates (see Appendix 3, section 11.21).

When the hook position within a magazine on which a swordfish was caught (hook position 1 is equivalent to hooks 1 and 5; position 2 equivalent to hooks 2 and 4; and position 3 equivalent to hook 3 in each magazine) was included into the binomial GLM as a discrete linear predictor, it did not have a significant effect on the probability of catching a swordfish (Appendix 3, section 11.22).

4.3.3.2 Predicted swordfish catch rates by treatment effects

Predictions from the GLM clearly illustrate the correspondence among regions in treatment effects upon swordfish catch rates (Figure 53). In all three regions, the lowest swordfish catch was predicted for 16/0 hooks combined with mackerel bait and the highest catch rate was predicted for J hooks with squid bait (see Appendix 3, Section 11.23.

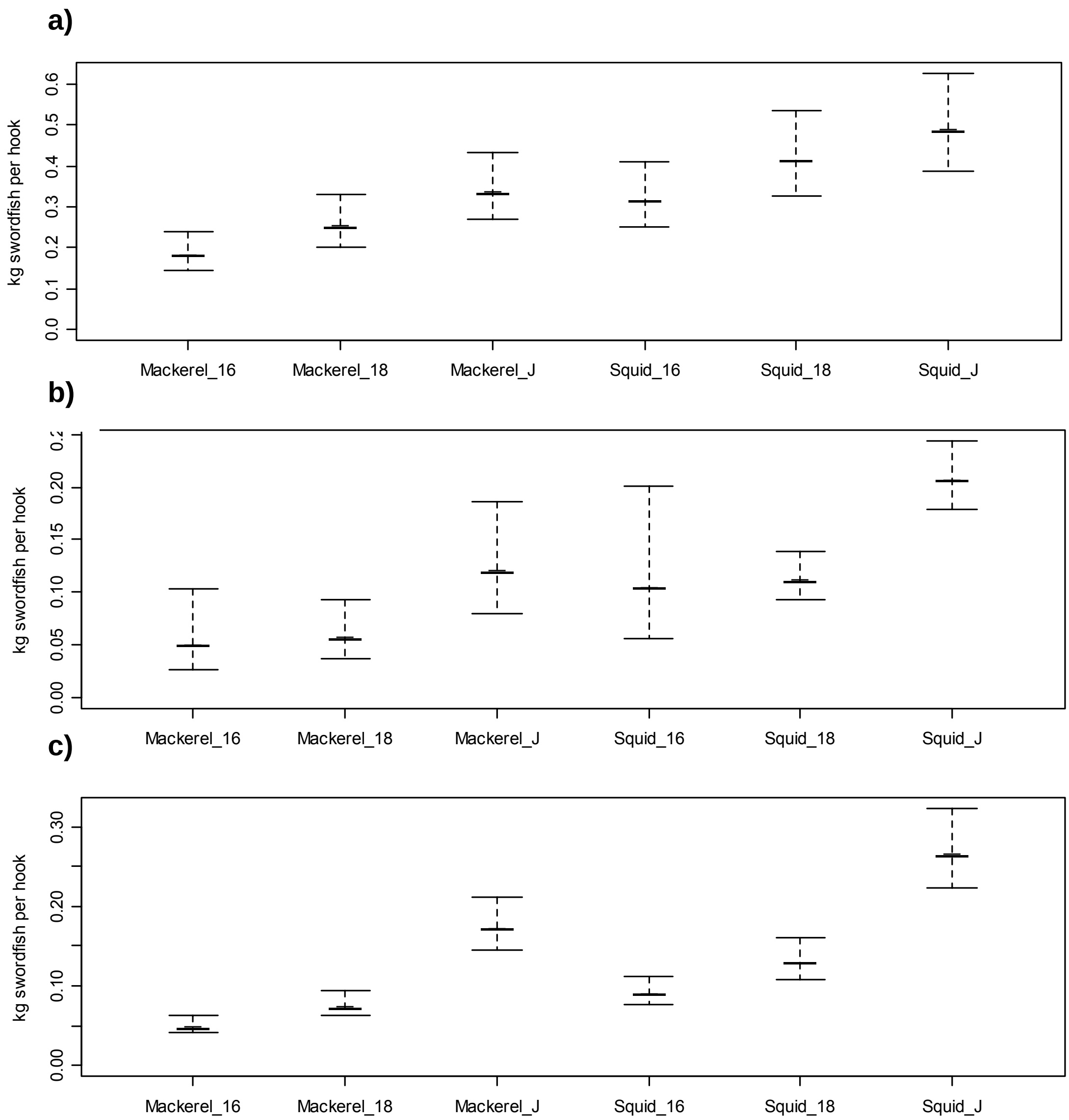

Figure 53 Predicted swordfish catch (kg/hook) for the a) Atlantic b) eastern Mediterranean and c) western Mediterranean. Error bars represent 95% confidence limits.

4.3.4 Predicted number of turtles per kg of swordfish catch for each treatment combination

Combined predictions from both the binomial model for the probability of turtle capture and the delta-lognormal model on the probability of swordfish capture, gives the predictions illustrated in Figure 54. The lowest number of turtles caught per kg of swordfish was predicted for mackerel bait combined with J-hooks in both the Atlantic and western Mediterranean regions. Predicted turtles/per kg swordfish with this combination of bait and hook, were significantly lower than squid bait combined with either 18/0 circle hooks or J-hooks in the western Mediterranean (see Appendix 3, Section 11.23).

a)

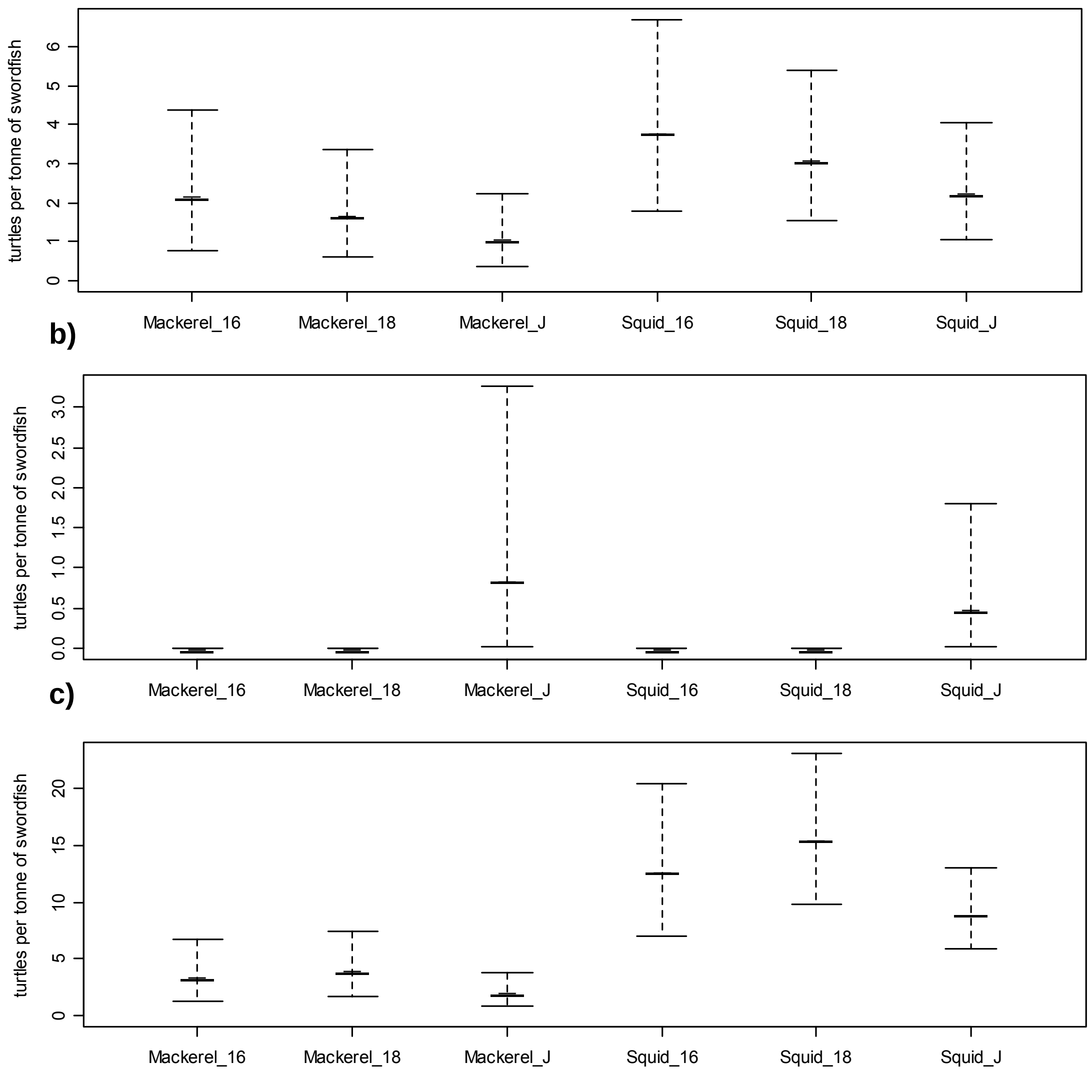

Figure 54 **Predicted numbers of turtle caught per kg of swordfish for each combination of hook and bait type the a) Atlantic b) eastern Mediterranean and c) western Mediterranean. Error bars represent 95% confidence limits.**

4.3.5 Treatment effects on catch of secondary target species

4.3.5.1 Region, hook and bait effects on tuna species combined

Out of the secondary target species of fish caught in the trials, tuna species combined was the only group which could be analysed across all regions.

Binomial GLM (logit link) indicated that region, bait and hook type all had significant effects on the numbers of tuna species caught during the trials (ANOVA (chi test) p<0.01, See Appendix 3, 11.24 for full results tables). The probability of catching tuna species was greatest in the western Mediterranean, and lowest in the Eastern Mediterranean, greatest on 18/0 circle hooks and lowest on J hooks and greater on sets baited with squid than those baited with mackerel (Figure 55).

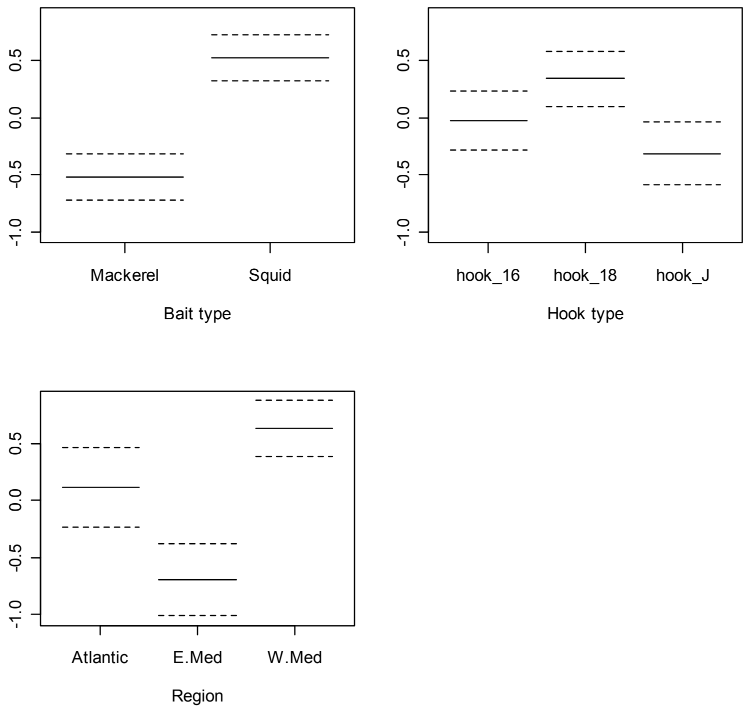

Figure 55 Marginal effects of region, bait type, and hook type on probability of catching tuna spp. Error bars represent ± standard error.

4.3.5.2 Hook and bait effects on bluefin tuna catch in the western Mediterranean

Bluefin tuna were only caught during the western Mediterranean trials. A separate analysis was carried out for this species due to its high market value and the current problems associated with management of the stock. Bait had a significant effect on the probability of catching a bluefin tuna in the western Mediterranean (ANOVA (chi-test), p<0.01, see Appendix 3, section 11.25 for full analysis). There was a significantly greater probability of catching a blue fin tuna on squid bait than on mackerel bait (Figure 56). Probability of catch varied among hook types (18/0 > 16/0 > J hooks) but this variation was not significant (p>0.01).

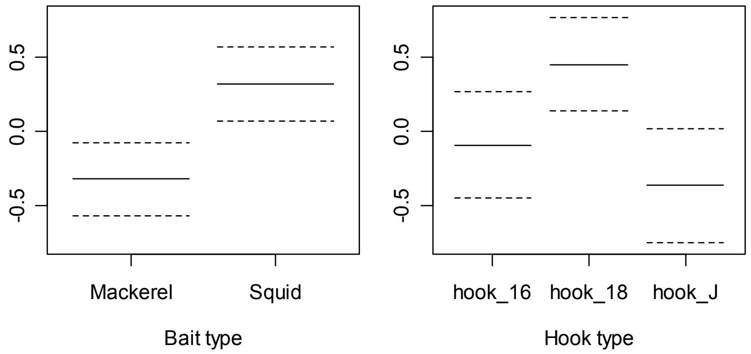

Figure 56 Marginal effects of bait type, and hook type on probability of catching a blue fin tuna in the western Mediterranean. Error bars represent ± standard error.

4.3.5.3 Hook and bait effects on blue shark catch in the Atlantic

There were sufficient data for blue shark in the Atlantic to analyse the probabilities of capture by hook and bait type. Although there were variations in the probability of capture, with it being greater for mackerel bait and 18/0 circle hooks, this variation was not significant (ANOVA (chi-test), p>0,01, see Appendix 3, 11.26 for full results, Figure 57)

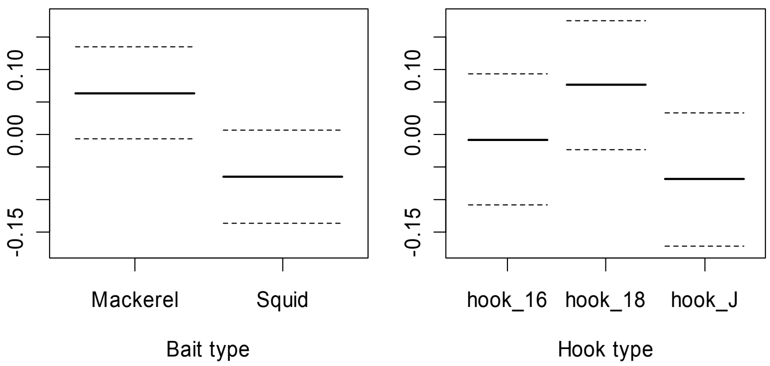

Figure 57 Marginal effects of bait type, and hook type on probability of catching a blue shark in the Atlantic. Error bars represent ± standard error.

4.3.5.4 Hook and bait effects on billfish species (except swordfish) in the Atlantic

The probability of catching a billfish species in the Atlantic was greater on mackerel bait than squid bait, greatest for J hooks and lowest for 16/0 circle hooks, but again this variation was not significant (ANOVA (Chi-test), p>0.01, see Appendix 3, 11.27 for details, Figure 58).

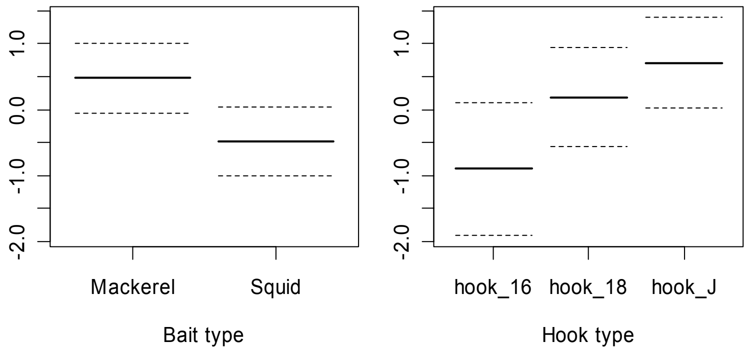

Figure 58 Marginal effects of bait type, and hook type on probability of catching billfish *spp.* in the Atlantic. Error bars represent ± standard error.

5 Website and Fisher questionnaire

5.1 Website

The aim of the website is to provide a means of communication about the progress and results of the project, and to provide materials concerning avoiding turtle bycatch and releasing turtles that have been caught in longlines. Initial content and design for the project website was drafted on an internal website (www.turtles.mrag.net). The content and design was revised during the experimental trials to include photographs taken from the trials as a brief summary of how to handle turtles if they are caught on a longline.

The website is currently hosted at http://www.mrag.co.uk/turtle. Materials regarding how to handle turtles are available on the site in English, Spanish and Greek.

Screen shots of the website are provided in Appendix 4 and site statistics in Appendix 5.

5.2 Questionnaire development and implementation

5.2.1 Questionnaire development

The objectives of the questionnaire, as specified in the proposal, were:

- to raise awareness in the fishing industry of the issues of turtle bycatch and potential mitigation measures;
- to confirm the commonly used gear and bait configurations in the different fleets;
- to determine what problems they foresee with the gear and bait configurations to be tested in the experimental fishing and if the gear modifications would be acceptable to fishers;
- to investigate fishers' perceptions of the problem of turtle bycatch and assess their estimations of turtle catch rates
- to provide an opportunity for fishers to offer their own ideas of how bycatch of turtles might be reduced; and
- to involve fishing fleets outside of the countries that will be carrying out the experimental fishing, such as Italy, Malta and Cyprus.

The fisher questionnaire was developed with the following structure:

- General Information
- Gear and bait details for swordfish surface longlining
- Fishery interactions with turtles

Questions were designed to explore details of the issues. The draft questionnaire was then tested and revised before implementation, to ensure that the questions were as effective as possible at obtaining the desired information.

In order for fishers to indicate the areas they usually fish, and the areas in which they most frequently experience interactions with turtles, maps of the Eastern and Western Mediterranean, and Atlantic were developed, with a 1° by 1° grid overlaid for the Mediterranean, and a 5° by 5° grid overlaid for the Atlantic. Fishers could indicate where they usually fish, and on a separate map, where interactions with turtles are most common, by placing a cross in each square. The questionnaires provided information on the usual fishing areas, and the areas and time periods in which interactions with turtles are most common.

5.2.2 Questionnaire testing

The draft questionnaire was tested with vessel masters and skippers in Spain and Greece. These trials provided useful feedback on the best way to approach certain questions, and possible issues that might arise with some of the response options that had been defined. The questions and responses were subsequently revised to address these issues. Three trials were carried out in Greece (2 in Kyllini and 1 in Alexandroupoli) and six in Spain. Further details are given below.

The final version of the questionnaire is included in Appendix 6.

5.2.2.1 Atlantic

According to the official fishing vessel list in BOE #308 of 26 December 2006 the Spanish Atlantic fishing fleet targeting swordfish with pelagic longline is composed of 140 vessels. The fleet is split between 96 vessels fishing in the North Atlantic area (north of 5ºN), and 44 vessels whose fishing activity is carried out in the South Atlantic area (south of 5ºN).

The preliminary contacts with the Galician fishing industry have shown that most of the Atlantic vessels targeting swordfish carry out long fishing trips in distant fishing grounds staying little time at the landing port. Moreover, in the case of the fleet fishing in South Atlantic areas, those landing ports are frequently spread around the Atlantic (South Atlantic African coast, South American coast, etc.). Some of the vessels, mostly fishing in the north Atlantic, operate in Galician ports (mainly Vigo); landings of the vessels usually takes place sequentially over time in order to maximize prices of the catches in the market. This gradual landing pattern, with low availability of fishing skippers represents a practical difficulty in implementation of the survey by means of personal interview. An alternative is to distribute the questionnaire to the skippers through the fishing associations, as suggested by some of their representatives. This was done, but no responses were received, therefore all questionnaires for this fleet were implemented through personal interview in Galicia and South Africa.

5.2.2.2 Western Mediterranean

According to the official fishing vessel list in BOE #308 of 26 December 2006, the Spanish Mediterranean fishing fleet targeting swordfish with longline is composed of 101 vessels spread along 22 fishing ports; four of those ports account for around 60 % of the vessels (Carboneras, Garrucha, Aguilas and Cartagena).

The preliminary version of the questionnaire was tested during the period 22nd to 27th November 2006 through personal interviews with six skippers/owners of the Spanish Western Mediterranean fleet in three different ports (Carboneras, Cartagena and Motril). The results of these trials were used to refine the questionnaire to establish the final version.

5.2.2.3 Eastern Mediterranean

The pilot trials of the initial questionnaire took place between the 28th of November and the 6th of December for vessels from the ports of Kyllini and Alexandroupolis.

The aim was to align questions to both the requirements of the project and also to the common practice of the fishing fleet.

The questionnaire was tested by experienced staff from Lamans who interviewed three different skippers / owners. Based on the input provided by these trials, a number of comments and suggested revisions were recorded and were elaborated in the preparation of the final version of the questionnaire.

Additionally, these preliminary trials provided some initial information on the methods and characteristics of swordfish fishing in Eastern Mediterranean, which were used to plan the experimental trials.

In order to acquire information on usual fishing practices of other fleets active in the eastern Mediterranean swordfish fisheries, and to disseminate the project among fishermen from these fleets, the questionnaire was carried out in Greece including Crete, as well as with fishermen from Cyprus and Malta.

Cyprus:
Contacts were made with 2 individual fishermen. The number of licenses is limited to 60 but yearly the requests are 35-40. Swordfish catches in Cyprus range between 50-100 t per year.

Italy:
In Italy the questionnaire was sent to Mr. Massimiliano Valastro (fisheries expert) who contacted 20 fishermen of the Italian fleet who use longline fishing gear. Swordfish catches in Italy range between 7 000 – 8 000 t per year.

Malta
Mr. Shane Hunter (fisheries expert) from AquaBiotech Group implemented the questionnaire with 10 Maltese fishermen. Swordfish catches in Malta range between 140-200 t per year but there was a sharp increase to 362 tons in 2005.

5.2.3 Sampling strategy

To ensure that a representative sample of vessels was included in the questionnaire, an estimate of the number of vessels involved in surface longline swordfish fisheries in Spain and Greece was obtained. This helped determine how many questionnaires needed to be carried out, as well as defining the sampling frame, i.e. how many vessel masters to interview from different ports.

Sampling theory demonstrates that sample sizes depend, among other things, on the population being sampled. The higher the proportion of vessel masters being interviewed, the more representative the sample will become of the population. However, there are diminishing returns as the proportion sampled increases. Sampling needs to be random (representative of the population), and the sample size needs to be at least equal to the square root of the population size. Hence, if there are 1000 vessels, at least 32 should be interviewed.

According to the Fisheries Department of the Hellenic Ministry of Rural Development and Food, 995 fishing vessels have been issued a license for swordfish fishing during 2006 in Greece. From these vessels, 388 vessels renewed their swordfish licence, and the rest have been granted a licence after special request to the Fisheries Administration of the Prefectures in Greece. Also 321 vessels have as a first choice bluefin tuna and as a second option swordfish and other tunas. The reported swordfish catches in Greece have been rather stable during the last three years ranging from 1 120 to 1 311tons.

It was therefore estimated that between 300 and 700 vessels might target swordfish for all or at least some of the annual fishing season. If there were 500 vessels, a sample size of 22 would be adequate, and a sample of size of 32 would be sufficient up to a population of 1000. It was therefore proposed to interview approximately 30 vessel masters in Greece, from a variety of ports, which would be sufficient for the maximum possible number of vessels, 995.

In Spain, there were 101 vessels fishing for swordfish in the Western Mediterranean, and therefore a sample size of 10 would be sufficient. However, we proposed to interview at least 15–20 vessel masters in order to ensure adequate representation from different ports and of different vessel sizes and gear types.

5.2.4 Database construction for fisher questionnaire

Data from the questionnaire were centrally collated using a web-based application. Using a customised PHP survey application, the entire questionnaire was made available online, so the consortium members were able to input their questionnaire results using via the internet. The data were thus centrally available for all the partners to interrogate by either online using a web interface to the mysql database that stores the responses or by exporting the data into text, excel or SAS files for further analysis.

5.2.5 Questionnaire implementation

Questionnaires were conducted by AZTI for the Atlantic and Western Mediterranean fleets, and by Lamans for the Eastern Mediterranean fleets, including Greece, Cyprus and Malta.

For the Atlantic fishery, where contact with the vessel owners and skippers was difficult as a result of the length of time the vessels spend at sea, 11 interviews were carried out (8 interviews for the North Atlantic fleet and 3 for the South Atlantic). This included interviews in Cape Town, South Africa, a port that the fleet uses, as well as San Ciprian in Galicia. For the fleet of 140 vessels, a sample size of 11.8 was required to be representative.

For the Western Mediterranean fishery, where 10 interviews needed to be carried out as a sample of the 101 vessels, 19 questionnaires were successfully implemented.

For the Eastern Mediterranean fishery, where a sample size of 32 would have been sufficient for up to 1,000 vessels, 62 interviews were successfully carried out. This comprised 30 in Greece, 20 in Italy, 10 in Malta and 2 in Cyprus.

5.3 Analysis

Analysis of the questionnaire results was carried out for each fishery (Atlantic, Western Mediterranean, Eastern Mediterranean) separately in order to compare characteristics between the different fisheries, and because trial interviews had indicated that different gear types and configurations were used in each area.

Summary statistics were used to present the following indicators:

- Principle, secondary and tertiary fishing activities;
- Fishing patterns (average number of days per month targeting swordfish);
- Vessel characteristics: average length, average power (hp);
- Gear characteristics: percentage using traditional or American longline; percentage using J-hooks or Circle hooks; average gear configurations (line length, numbers of hooks, depth of setting, soak time etc); use of light sticks;
- Percentage of fishers that would consider using a different hook type;
- Percentage using different bait types;
- Percentage of fishers that would consider using a different bait type;
- Percentage of fishers that indicated turtles disrupt their fishing activity;
- The ways in which turtles disrupt their fishing activity;
- Average numbers of turtles caught per month;
- Ways in which turtles were caught in the gear;
- Percentage of fishers that think something needs to be done to reduce turtle by-catch.

In addition, respondents opinions on, for example, why they would or would not be willing to use a different hook or bait type, were also discussed and are presented in the Results section below.

Maps were prepared to indicate the fishers usual fishing grounds, and the areas where the respondents indicated that interactions with turtles are most frequent. These were overlaid with maps of the locations of our experimental fishing trials and locations where turtles were caught, to explore whether our trials were representative of the general patterns of fishing effort and areas where fishermen reported most frequent interactions with turtles.

5.4 Results

5.4.1 Number of respondents

The number of questionnaires carried out in each fishery were large enough to provide a representative sample, based on the total number of vessels in each fishery (Table 17).

Table 17 Number of vessels and sample sizes in each fishery

Fishery	Estimated number of vessels in the fishery	Minimum sample size required	Number of respondents to questionnaire	Number of respondents as a % of number of vessels
Atlantic	140	11.8	11	7.9 %
W. Mediterranean	101	10	19	18.9 %
E. Mediterranean	~ 1000[4]	32	62	6.2 %
Total	1240	35	92	7.4 %

[4] This is the number of vessels with licences to fish for swordfish but swordfish may not always be the prime target species of these vessels.

5.4.2 Fishing activities and patterns

Figure 59 shows that the main activity of the majority of respondents is swordfish fishing. Tuna and albacore are the most commonly targeted species after swordfish. In the Western Mediterranean, the vessels alternate swordfish fishing with other drifting longline gears targeting bluefin tuna (mainly in springtime, from April to June-July) and albacore (summertime). Some vessels shift to semi-pelagic longline (piedra-bola) during short periods of time to target demersal species. In the Eastern Mediterranean, the drifting longline fishery targets mainly swordfish. Other pelagic species such as tuna and albacore are targeted as a secondary activity, and some fishermen also use nets and bottom longlines to target bottomfish such as hake and seabream.

Fishing activities are more varied in the Mediterranean fisheries, and fishers were more likely to have secondary and tertiary fishing activities, whereas very few (2 out of 11) respondents from the Atlantic fishery had tertiary fishing activities.

Fishing patterns throughout the year, in terms of the average number of days fishing for swordfish each month, are different in the three fisheries (Figure 60).

5.4.2.1 Atlantic:

In the Atlantic fishery, the peak fishing season is from November to May (average 20.8 days' fishing each month), with the low season June to October (average 11.0 days' fishing each month). During the low season, some vessels (the "non freezer fleet") do not target swordfish at all, and instead change their fishing effort to targeting other species (mainly albacore). Other vessels maintain roughly constant fishing effort throughout the year (the "freezer fleet").

5.4.2.2 Western Mediterranean:

In the Western Mediterranean, swordfish fishing takes place all year round, although the peak season is from July to December (average 15.8 fishing days per month) and the low season is from January to June (average 3.9 fishing days per month). Almost all vessels have a period of at least three months in the year when they do not target swordfish at all — only one respondent to the questionnaire indicated that their vessel fished for swordfish throughout the whole year.

5.4.2.3 Eastern Mediterranean:

The peak swordfish season in the Eastern Mediterranean is earlier than in the Western Mediterranean — from May to September. In accordance with current Greek legislation, the drifting long line fishery is allowed from first day of February to the last day of September. However, at other times of the year, they move outside the 6 n.m. limit to continue fishing. Average number of days fishing swordfish in the peak season is 9.0 days per month, and in the low season is 3.2 days per month. Some vessels only fish a few days a month for a few months in the year; these vessels had indicated that swordfish was not their principal fishing activity. In general, the fishers in the Eastern Mediterranean tend to have more diverse fishing activities, targeting swordfish for fewer days per month and fewer months per year than in the Western Mediterranean.

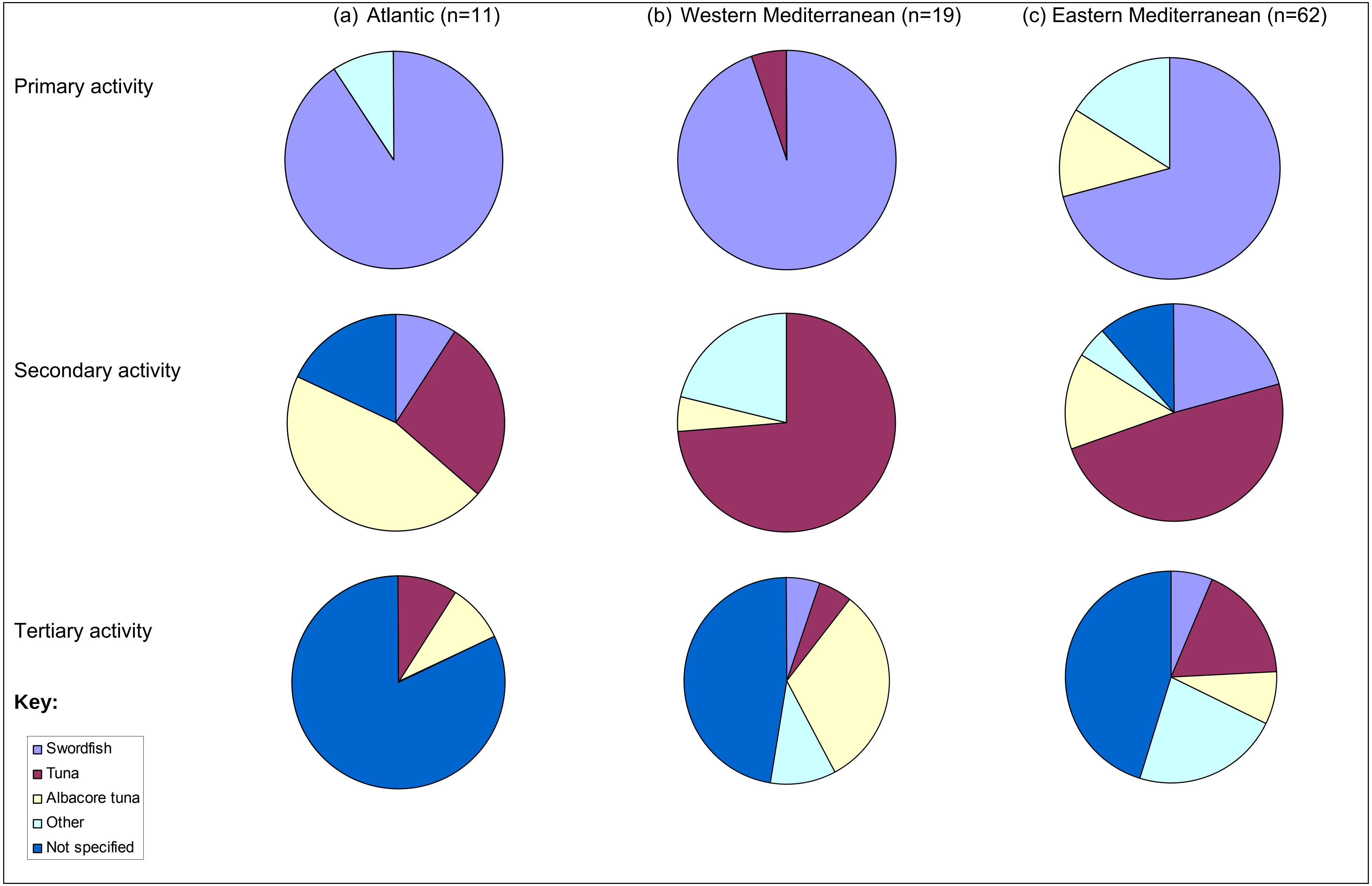

Figure 59 Principle fishery activity of respondents, and secondary and tertiary activities

There are different fishing patterns in different parts of the Eastern Mediterranean (Figure 61). The Greek, Cypriot and Maltese fleets concentrate their effort more over the summer months (May – September), whilst the Italian fleet fishes more over the winter months, with a second peak around June - July (average 4.5 days fishing per month from May – September, and 6.4 days per month from October – April).

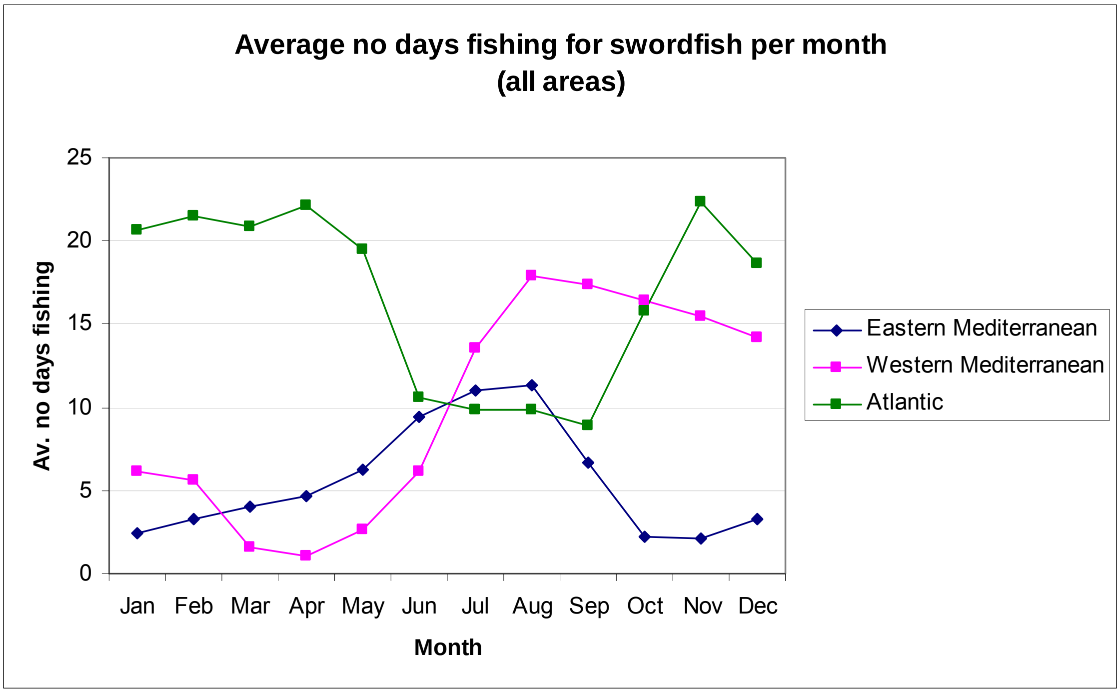

Figure 60 **Average number of days fishing for swordfish each month, by fishery**

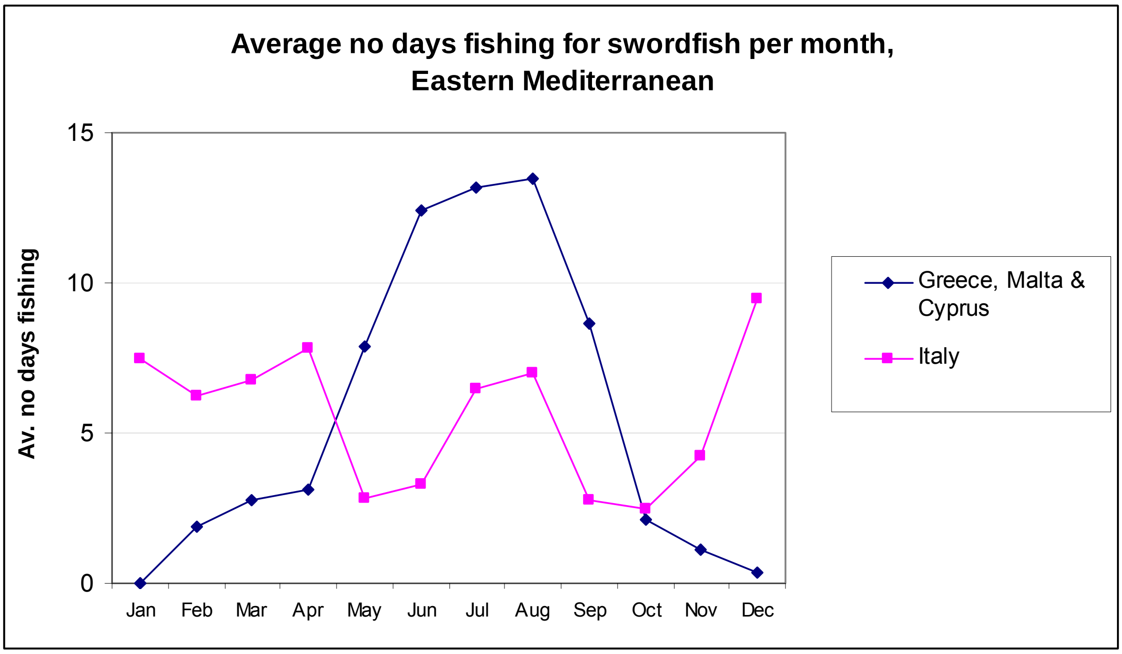

Figure 61 **Average number of days fishing for swordfish per month, Eastern Mediterranean**

5.4.3 Vessel and gear characteristics

5.4.3.1 Vessel length, power and longline type and hook type

Average vessel and gear characteristics for each fishery are shown in Table 18

Table 18 Average vessel and gear characteristics

	Atlantic	Western Mediterranean	Eastern Mediterranean
Vessel characteristics			
Average vessel length (m)	30.4 ± 1.6 s.e.	19.4 ± 0.8 s.e.	13.9 ± 0.6 s.e.
Average vessel power (hp)	423.4 ± 54.3 s.e.	245.5 ± 27.6 s.e.	235.2 ± 26.5 s.e.
Percentage using different longline types			
American	100	26.3	3.2
Traditional	0	57.9	96.8
Both	0	15.8	0
Percentage using different hook types			
J-hook	100	100	98.4
Circle hook	0	0	0
Both	0	0	1.6

5.4.3.2 Type of longline

The type of longline used in each fishery varies (Figure 62). 100 % of respondents in the Atlantic fishery use the 'American/florian type' longline, where the branchlines are longer and the distance between branchlines is longer, than with the 'traditional' longline gears used in the Mediterranean fisheries, so that they can cover larger distances and hauling speeds are faster (Table 19). Almost all respondents in the Eastern Mediterranean use the traditional type of longline, with very few respondents using the American type (one respondent from Crete and one from Cyprus). In the Western Mediterranean, a larger proportion of fishers have begun to adopt the American longline, either instead of, or in addition to, the traditional longline gear.

5.4.3.3 Hook types

100 % of respondents in all three regions use J-hooks to target swordfish, as they believe this to be the best hook type for catching swordfish. Only one respondent from the Italian fishery indicated that he used both J-hooks and circle hooks. However, it should be noted that within the 'J hook' family, there is no standardisation of hook shape and size. There are several types of hook with slightly different shapes (hence the producers use different references and different ways of expressing the size).

5.4.3.4 Line length and numbers of hooks

All except two respondents use the same type of hooks on the line (the exceptions were one respondent from Western Mediterranean and one respondent from Eastern Mediterranean (Italy), who includes some tuna-type hooks on the same line). The longest lines are used in the Atlantic fishery (50 nautical miles), and the shortest lines are used in the Eastern Mediterranean fishery with the traditional longline (21.5 nm). The largest numbers of hooks, both in total and per mile, are used in the Western Mediterranean fishery, both with the American and traditional longline types.

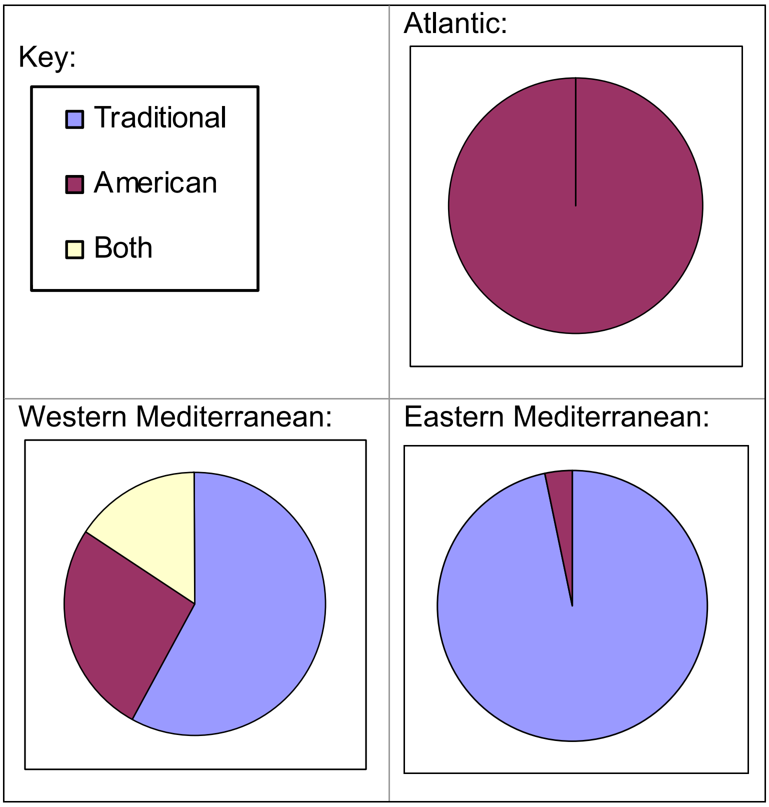

Figure 62 Type of longline used in each fishery

Table 19 Line length, total number of hooks and number of hooks per mile

	Atlantic	Western Mediterranean	Eastern Mediterranean*
Average length of line (miles)			
American		40.4 ± 3.8 s.e. (n=7)	-
Traditional	50.2 ± 2.4 s.e. (n=9)	29.3 ± 1.5 s.e. (n=13)	21.5 ± 2.1 s.e. (n=62)
Average number of hooks in total			
American	1,080 ± 41.3 s.e.	1315 ± 168 s.e.	-
Traditional	-	2279 ± 167 s.e.	659 ± 51.4 s.e.
Average number of hooks per mile			
American	21.9 ± 1.2 s.e.	38.1 ± 10.1 s.e.	-
Traditional	-	79.3 ± 5.3 s.e.	57.8 ± 12.9 s.e.

* Distance units used in the Eastern Mediterranean were nautical miles

5.4.3.5 Average gear configurations

Average gear configurations — in terms of branchline length, distance between branchlines, distance between floats, distance between the float and first branchline, number of hooks between floats and the depth of setting — are provided in Figure 63 – Figure 66.

5.4.3.6 Atlantic

Average gear configuration for the Atlantic fishery is given in Figure 63, with line diameters and soak time given in Table 20.

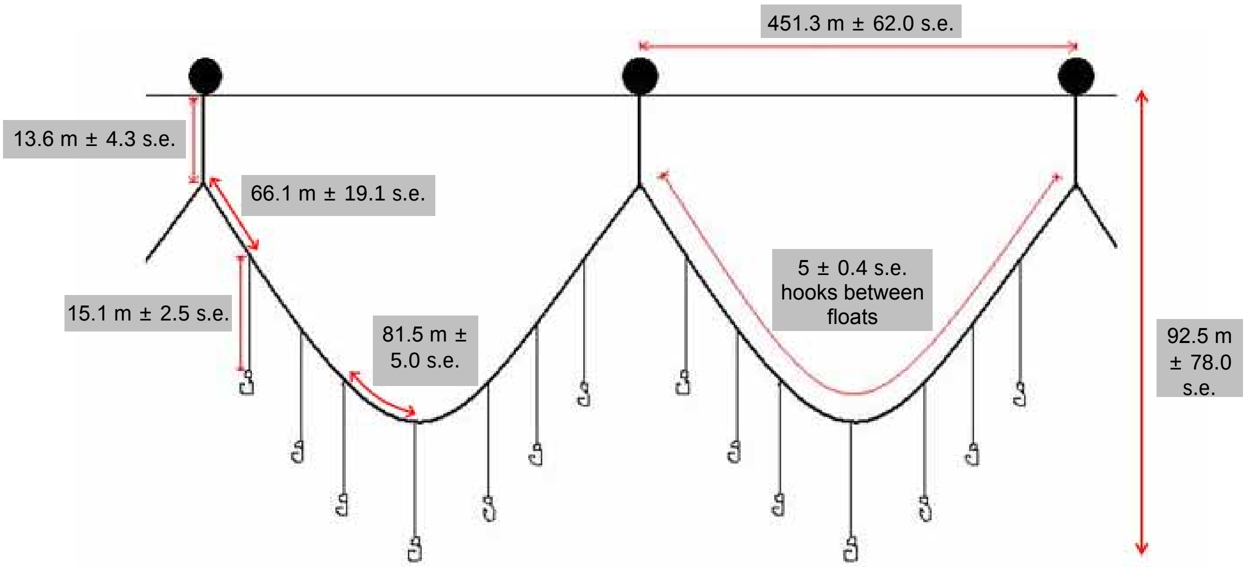

Figure 63 Average gear configuration in the Atlantic fishery

Table 20 Mainline and branchline diameters and average soak time, Atlantic

Detail	Average
Diameter of mainline (mm)	3.7 ± 0.1 s.e.
Diameter of branchline (mm)	2.5 ± 0.3 s.e.
Av. soak time (hours)	14.8 ± 1.0 s.e.

5.4.3.7 Western Mediterranean

Average gear configuration for the Western Mediterranean fishery (traditional longline) is given in Figure 64, with line diameters and soak time given in Table 21. Details for the Western Mediterranean (American longline) fishery, are given in Figure 65 and Table 22.

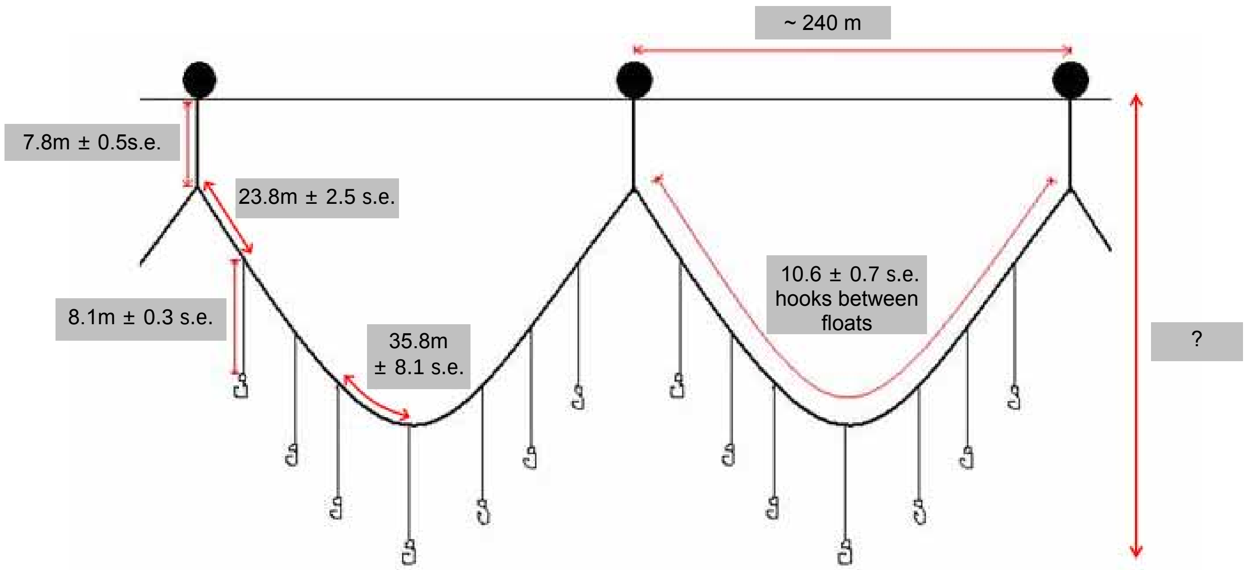

Figure 64 Average gear configuration (traditional longline), Western Mediterranean

Table 21 Mainline and branchline diameters and average soak time (traditional longline), Western Mediterranean

Detail	Average
Diameter of mainline (mm)	2.0 ± 0.0 s.e.
Diameter of branchline (mm)	1.4 ± 0.0 s.e.
Av. soak time (hours)	12.0 ± 0.5 s.e.

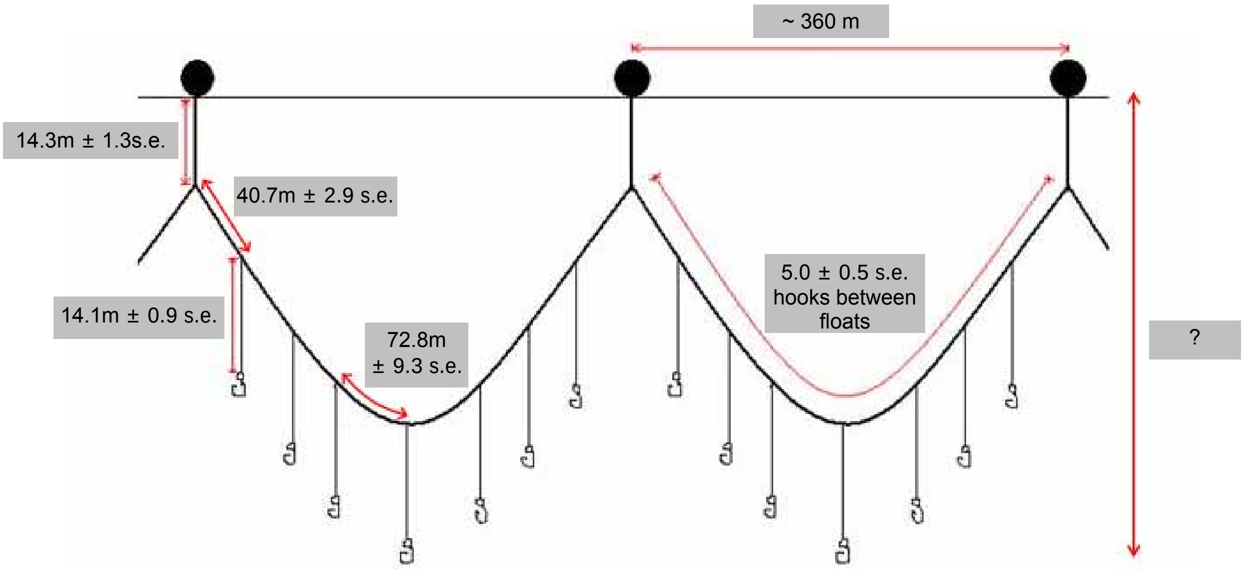

Figure 65 Average gear configuration (American longline), Western Mediterranean

Table 22 Mainline and branchline diameters and average soak time (American longline), Western Mediterranean

Detail	Average
Diameter of mainline (mm)	3.0 ± 0.2 s.e.
Diameter of branchline (mm)	1.5 ± 0.0 s.e.
Av. soak time (hours)	12.4 ± 0.9 s.e.

5.4.3.8 Eastern Mediterranean

Average gear configuration for the Atlantic fishery is given in Figure 66, with line diameters and soak time given in Table 23.

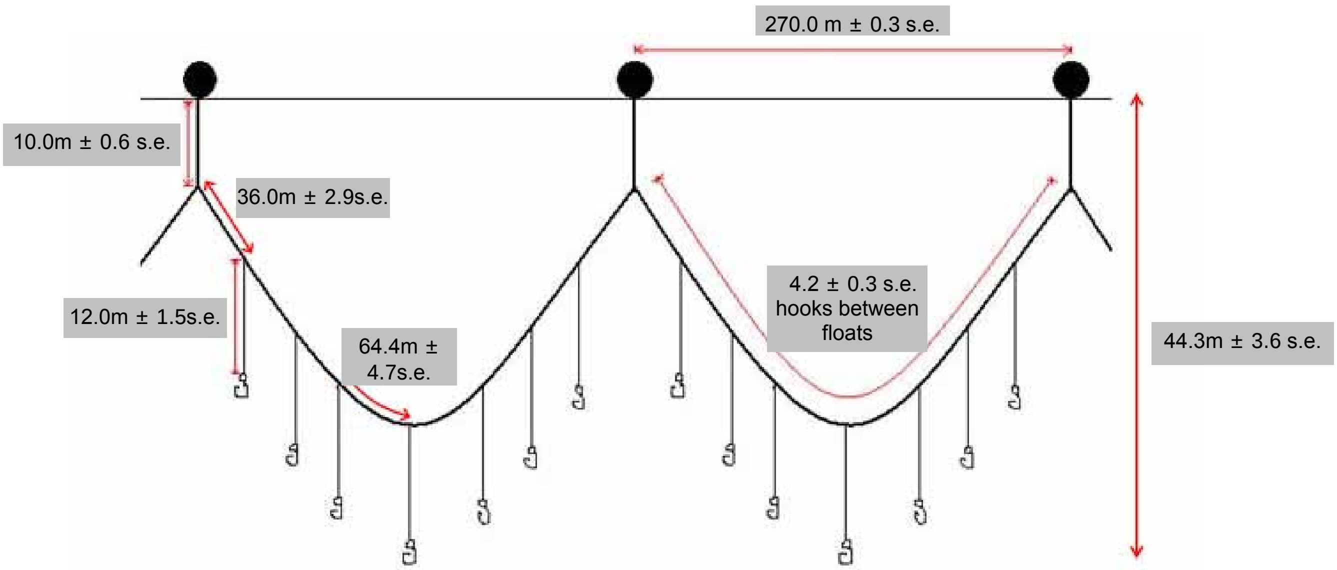

Figure 66 Average gear configuration, Eastern Mediterranean

Table 23 Mainline and branchline diameters and average soak time, Eastern Mediterranean

Detail	Average
Diameter of mainline (mm)	2.0 ± 0.0 s.e.
Diameter of branchline	1.5 ± 0.0 s.e.
Av. soak time (hours)	10.5 ± 0.3 s.e.

5.4.3.9 Number of lines set at once:

In the Atlantic and Western Mediterranean fisheries, only one line is set at once. However, some fishers in the Eastern Mediterranean set more than one line at once (Table 24).

Table 24 Number of lines set at one time, Eastern Mediterranean

Number of lines set at once	Percentage of respondents
1	82.3
2	1.6
3	1.6
4	3.2
5	4.8
6	4.8
Not specified	1.6

5.4.3.10 Use of light sticks

Most fishers use light sticks as an attractant device when fishing for swordfish (Table 25). In the Atlantic and Western Mediterranean fisheries, most use electrical light sticks, whereas in the Eastern Mediterranean, half use electrical and half use chemical light sticks. In the Atlantic, the light sticks are located on every branchline, whereas in the Mediterranean fisheries, they are more widely spaced.

Table 25 Use of attractant devices, by fishery

	Atlantic (n=11)	**Western Mediterranean** (n=12)[a]	**Eastern Mediterranean** (n=62)
Percentage that use light sticks			
Always	100.0	100.0	48.4
Sometimes	0.0	0.0	6.5
Do not use	0.0	0.0	27.4
No response	0.0	0.0	17.7
Type of light sticks used (% of respondents)			
Chemical	27.3	8.3	48.5
Electrical	72.7	91.7	51.5
Spacing of light sticks (% of respondents)			
1 every branchline	100.0	41.7	53.3
1 with 1 without	0.0	8.3	6.7
1 with, 2 or 3 without	0.0	16.7	6.7
1 with, 4 or more without	0.0	33.3	10.0
Random	0.0	0.0	23.3

a. The question concerning attractant devices was added in to the questionnaire after a number of questionnaires had already been conducted in the Western Mediterranean. These results therefore reflect those interviews that were conducted after the question had been added.

5.4.3.11 Colours of light sticks used

The most popular colour light sticks used are blue and green (Figure 67).

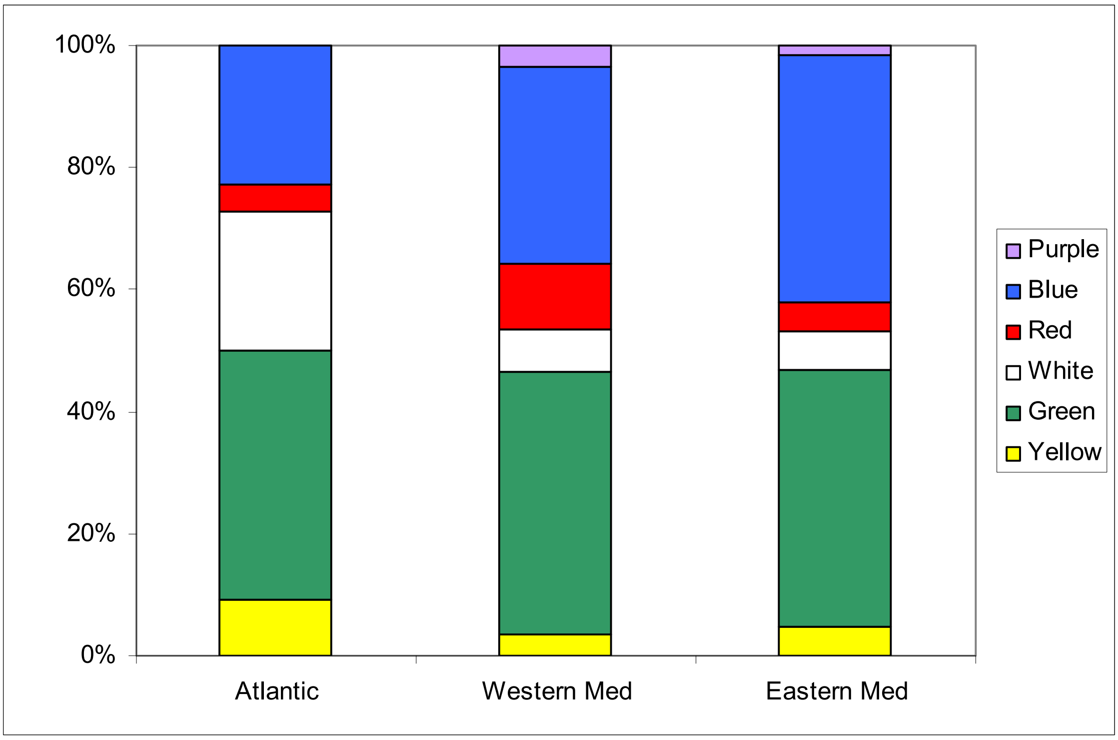

Figure 67 Colour of light sticks used, by fishery

5.4.3.12 Acceptance of different hook types

To gauge their acceptance of a possible change in hook type, fishers were asked, 'leaving aside the issue of cost, do you think it would be possible to use a different type of hook (e.g. circle hook instead of J-hook) to fish for swordfish?' (Table 26).

Table 26 Possibility of using different hooks types, % of respondents

	Atlantic	Western Mediterranean	Eastern Mediterranean
Possible	0.0 %	5.3 %	21.0 %
May be possible	45.5 %	5.3 %	24.2 %
Not possible	54.5 %	89.5 %	51.6 %
No response	0.0 %	0.0 %	3.2 %

In the Atlantic, over half the respondents said circle hooks would not be possible because they are less effective or catch different types of fish. However, almost half were willing to consider the possibility of using circle hooks, but said they would have to be tested to prove their effectiveness for catching swordfish and for reducing turtle bycatch.

Respondents in the Western Mediterranean were by far the most sceptical about a possible change in hook type. Some of the fishermen had participated in (and many had heard about) experimental trials run previously, and said that the tests had shown circle hooks had a very low effectiveness in terms of catching swordfish.

Respondents from the Eastern Mediterranean were most open to trying a different hook type (21.0 %), because they thought it would be worthwhile to try. However, the majority (51.6 %) thought it would not be possible to use a different type of hook, and justified this saying they were 'very satisfied' with their current (J) hooks, and that J-hooks are the best.

5.4.3.13 Bait types

In the Atlantic, all respondents use both fish (mackerel, *Scomber scombrus*) and squid (Table 27). Respondents that indicated they also used 'other' bait types use pieces of the abdomen of blue shark. In the Western Mediterranean, they also use both fish and squid. For the fish, most use mainly mackerel and, less frequently, sardines. Fish and squid are mixed in different proportions that vary according to availability of the bait in the market, price and skipper's experience of the fishing efficiency of the bait. The cheaper mackerel is used in a higher proportion than the more expensive squid. Other species used as bait are round sardinella (*Sardinella aurita*) and chub mackerel (*Scomber japonicus*).

In the Eastern Mediterranean, fish is more commonly used as bait than squid, only about half of respondents indicating that they used the latter. Whilst nearly half (48.4 %) use **only** fish in the winter, this goes down to 29.0 % in the summer, and a higher proportion use squid only, or fish and squid in the summer than in the winter. Most use the same bait on the whole line (Table 28). Of the eleven respondents who said the bait they use 'depends', 68 % indicated that it depended on price and availability in the market, 18 % indicated that it depended on the season, and 14 % said they used more squid in summer in order to target tuna as well as swordfish.. For the type of fish used, most use mackerel, some indicated they used chub mackerel, European pilchard or Mediterranean horse mackerel.

For fish and squid bait, all respondents use them whole rather than in pieces. The only bait type used in pieces was the abdomen of the blue shark in the Atlantic fishery.

Table 27 Bait types used, in summer (April-September) and winter (October-March), by fishery (% of respondents)

	Atlantic		Western Med		Eastern Med	
	Summer	Winter	Summer	Winter	Summer	Winter
Fish only	0.0 %	0.0 %	0.0 %	0.0 %	29.0 %	48.4 %
Squid only	0.0 %	0.0 %	0.0 %	0.0 %	19.4 %	3.2 %
Fish & squid	81.8 %	81.8 %	100.0 %	100.0 %	48.4 %	40.3 %
Fish, squid & other	18.2 %	18.2 %	0.0 %	0.0 %	0 %	0 %
None	0.0 %	0.0 %	0.0 %	0.0 %	3.2 %	8.1 %

Table 28 Use of same bait type or mixed bait types on one line (% of respondents)

Bait arrangement	Atlantic	Western Med	Eastern Med
Same bait on whole line	0.0 %	0.0 %	59.7 %
Mixed bait on whole line	100.0 %	100.0 %	19.4 %
Depends	0.0 %	0.0 %	17.7 %
No response	0.0 %	0.0 %	3.2 %

In the Atlantic and Western Mediterranean, all respondents indicated that they mix the bait they use on the same line (Table 28). In the Atlantic, most use 2 or 3 mackerel to 1 squid. Some vessels use more squid than mackerel if possible. However, bait choice can also depend on the previous day's catches in terms of what the skipper thinks is most effective bait that day.

In the Western Mediterranean, there are various combinations of mackerel, sardines and squid that are used. Most use more fish (mainly mackerel) than squid, although 26 % of respondents indicated that the proportions of mackerel and squid they use depended on the season or water temperature. 60 % of these respondents indicated that they use a higher proportion of squid in the summer months. One respondent indicated that this was because he believed the fish is more easily removed from the hook when the water is warmer.

In all fisheries, all respondents use almost all thawed bait, with a small proportion of fresh bait in some cases (Table 29).

Table 29 Average proportion of fresh and thawed bait used

Bait type	Atlantic	Western Med	Eastern Med
Fresh bait (%)	0 %	3.1 %	1.6 %
Thawed bait (%)	100 %	96.9 %	98.4 %

5.4.3.14 Acceptance of other bait types

To gauge their acceptance of a possible change in bait type, fishers were asked, 'leaving aside the issue of cost, do you think it would be possible to change the type of bait you use for swordfish?' (Table 30).

Table 30 Possibility of using different bait types (% of respondents)

	Atlantic (n=9)	Western Mediterranean (n=19)	Eastern Mediterranean (n=62)
Possible	0%	15.8 %	8.1 %
May be possible	18.2%	15.8 %	24.2 %
Not possible	63.6%	52.6 %	67.7 %
No response	18.2%	15.8 %	0.0 %

In all fisheries there was a low acceptance of using other bait types. In the Atlantic, there was a low acceptance of other bait options, as they claim that mackerel and squid are the only options on the market. Some respondents had tried other bait types (horse mackerel or artificial baits) but results had not been good.

The majority (53 %) of respondents from the Western Mediterranean did not find other bait types would be acceptable, the best options being mackerel and squid (and in some cases sardine). The main reasons cited included (in order of frequency of citations) lack of availability of other species on the market, the fact that current bait types are most effective, the cost of alternative bait types (also indicating that if alternatives were the same price or cheaper than current bait types, then there would be a possibility of using them), alternatives such as sardine are too easily removed from the hook, and for mackerel, the added benefit that the same fish can be reused two or three times if it is not taken as bait. Other bait options mentioned include sardine (although it is too easily removed from the hook) and sable (although there is a lack of availability on the market).

In the Eastern Mediterranean, there was greater reluctance to accept alternative bait types (68 % of respondents). Most indicated that this was because the current bait types (mackerel and to a lesser extent, squid) were the most effective. Some also indicated that they were the cheapest baits. If alternative cheap baits were available, it might be possible to change. Those that thought it may be possible to change baits, said it would be possible in order to try out different bait types, or that sardines can also be good.

Although there was a seemingly low acceptance of the possibility of using different bait types, because the question asked whether they would be able to change their bait type from what they currently use, the results must be compared with their currently practices. Therefore, the results are encouraging because they suggest the fishermen would be open to using mackerel bait, since it is a bait type they already use and consider to be effective.

5.4.4 Interactions with turtles

5.4.4.1 Whether turtles disrupt their fishing activity

The proportion of fishermen who feel that turtles disrupt their fishing activity was in the Western Mediterranean (63 %, compared to 55 % in the Atlantic and 40 % in the Eastern Mediterranean) (Figure 68(a)). In the Atlantic and Western Mediterranean, the main problems that the turtles caused fishermen were slowing hauling procedures and damaging the gear (Figure 68(b)). In the Eastern Mediterranean, stealing bait from the lines was the main concern of the fishermen.

However, of the turtles that do get caught on the lines, most respondents reported that 76-100% of turtles that were caught, survived.

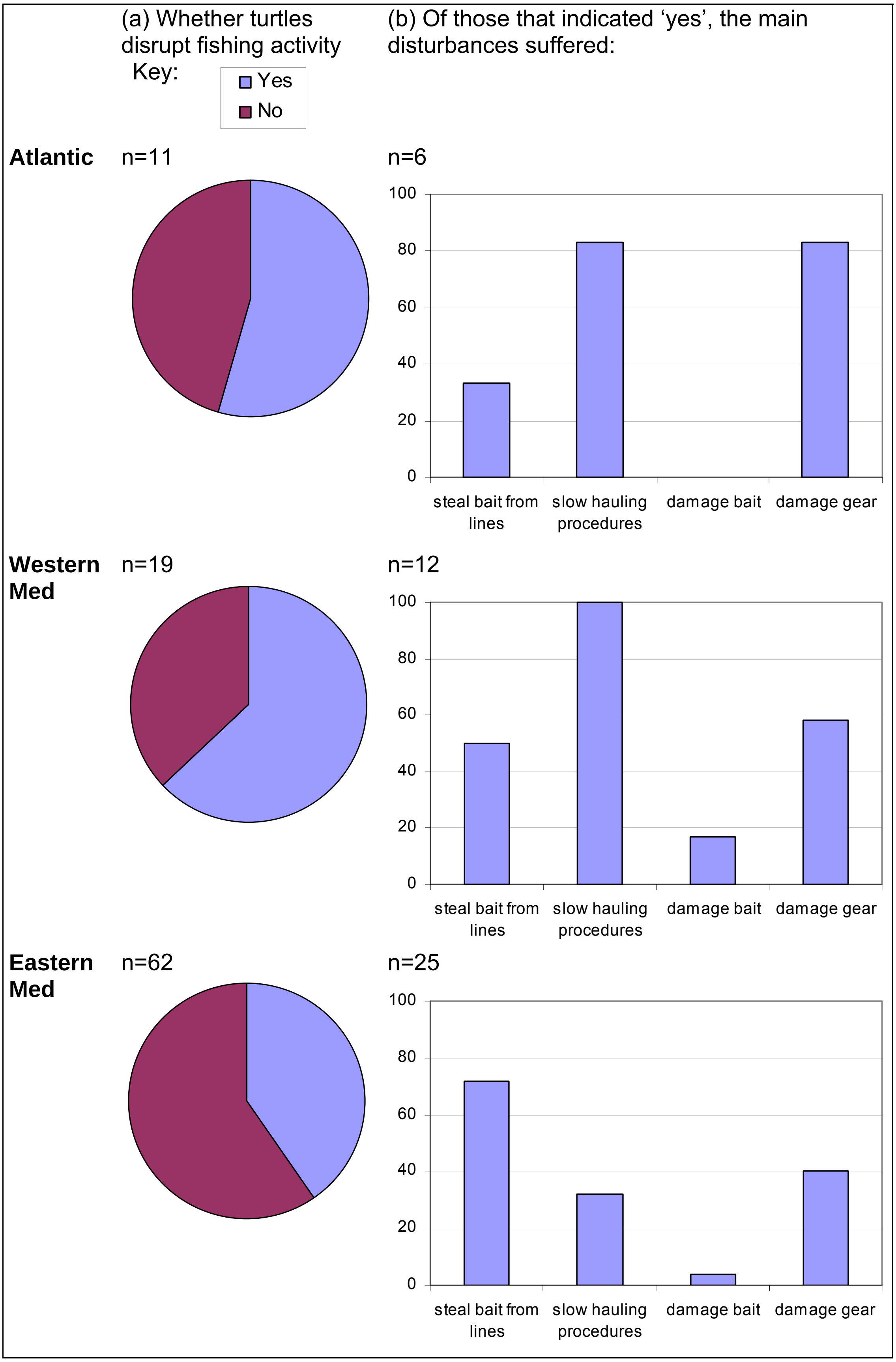

Figure 68 **Disruption of fishing activities by turtles, and the types of disruption caused**

5.4.4.2 Numbers of turtles caught

The highest catch rates of turtles reported by the fishermen are in the Western Mediterranean (Figure 69), in terms of numbers of turtles caught per month (per fisherman), and also controlling for the numbers of days fishing, and numbers of hooks set.

The data from one fisherman using a traditional longline in the Western Mediterranean, who indicated he catches 650 turtles per month from May to September, were removed from this analysis. Whilst this may well be true, this value was an outlier for the data, relating to the use of longline for species other than swordfish.

Data for Western Mediterranean were analysed as a whole and also separated according to gear type (traditional longline or American longline). Turtle catch rates indicated by the American longline respondents were higher than those for the traditional longline, although these data were influenced by one respondent who indicated high catch rates of 300 turtles per month. In addition, if the data from one traditional longline fisherman had not been removed (see above), the traditional longline would have had a higher turtle bycatch rate. Comments from the fishermen indicated that since they had switched from the traditional gear to the American longline, catch rates of turtles were much lower than they had been previously. These data for individual gear types are not conclusive and are based on relatively small sample sizes. This study set out to test the specific gear configurations indicated in the Terms of Reference against the most common gear type, and not to investigate the influence of different gear types such as traditional and American longlines on turtle bycatch. To investigate this, a separate study would have to be conducted with this specific aim.

Overall, comparing the different regions, the average catch rates for the Western Mediterranean per respondent per month, per day's fishing and per 1,000 hooks are around twice as high in the western Mediterranean as in the eastern Mediterranean over the summer months. The average turtle catch rate over the whole year in the Western Mediterranean is 0.26 per 1,000 hooks, compared to 0.12 per 1,000 hooks in the Atlantic and 0.12 per 1,000 hooks in the Eastern Mediterranean (Table 31).

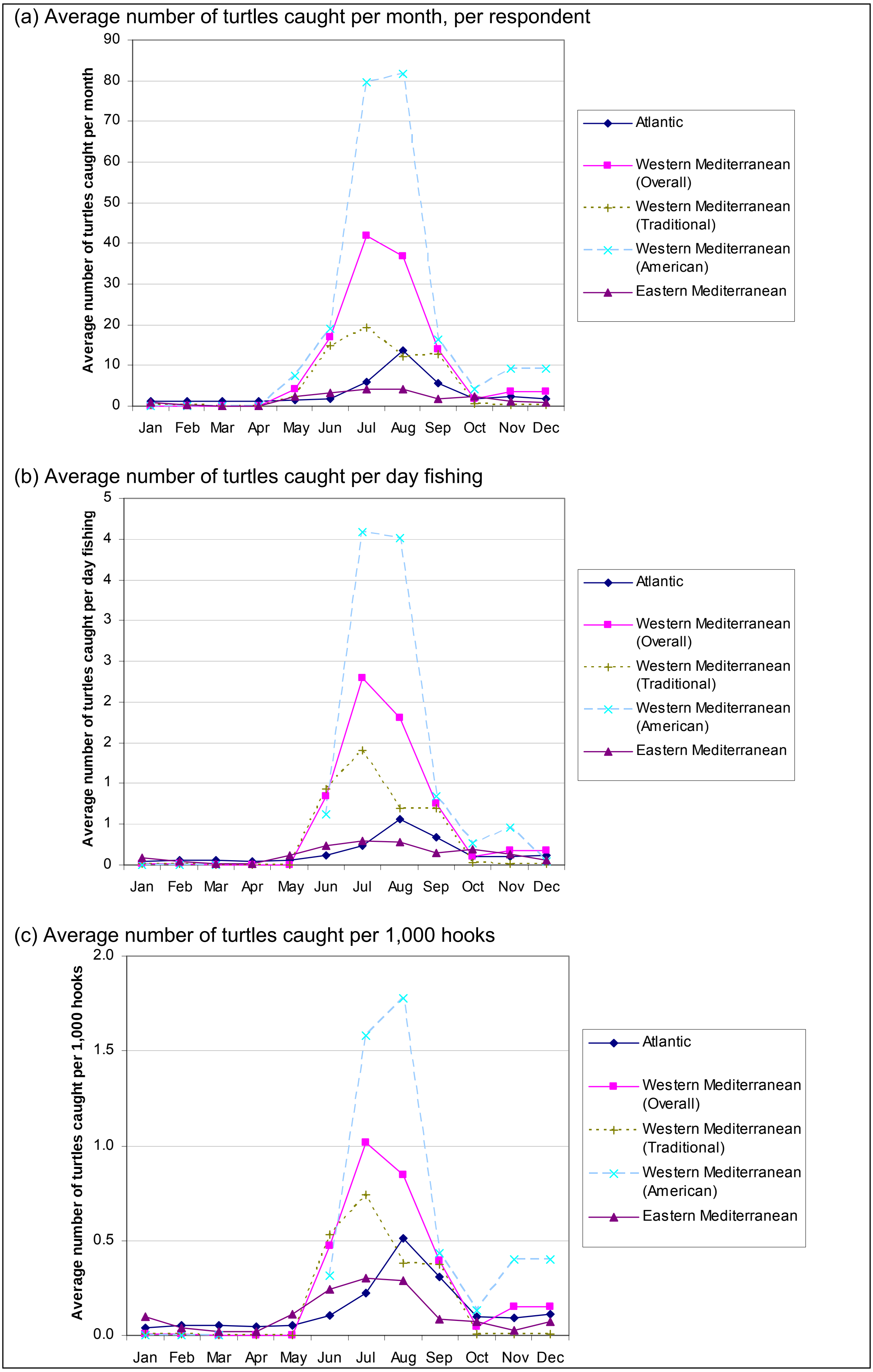

Figure 69 **Average numbers of turtles caught in each fishery: (a) per respondent per month; (b) per day fishing; and (c) catch rate per 1,000 hooks.**

Table 31 Average turtle catch rates from the questionnaire, by fishery

	Average number of turtles per month (per respondent)			Average number of turtles per day fishing			Average number of turtles per 1,000 hooks		
	Winter	Summer	Annual	Winter	Summer	Annual	Winter	Summer	Annual
Atlantic	1.54	4.92	3.23	0.08	0.23	0.15	0.08	0.21	0.14
W Med (overall)	1.50	18.93	10.22	0.08	0.95	0.52	0.06	0.46	0.26
W Med (Traditional)	0.21	10.30	5.25	0.02	0.62	0.32	0.01	0.34	0.17
W Med (American)	3.79	33.99	18.89	0.13	2.39	1.03	0.16	1.03	0.50
E Med	0.95	2.64	1.79	0.09	0.18	0.14	0.05	0.18	0.12

5.4.4.3 Gear interactions with turtles

In the Eastern and Western Mediterranean, turtles were reportedly most commonly caught by being hooked in the mouth (Figure 70). In the Atlantic, leatherbacks were reported to be the most frequently caught species, and usually caught through becoming entangled in the gear. The Western Mediterranean had a higher proportion of respondents who reported that turtles are caught by swallowing the hook.

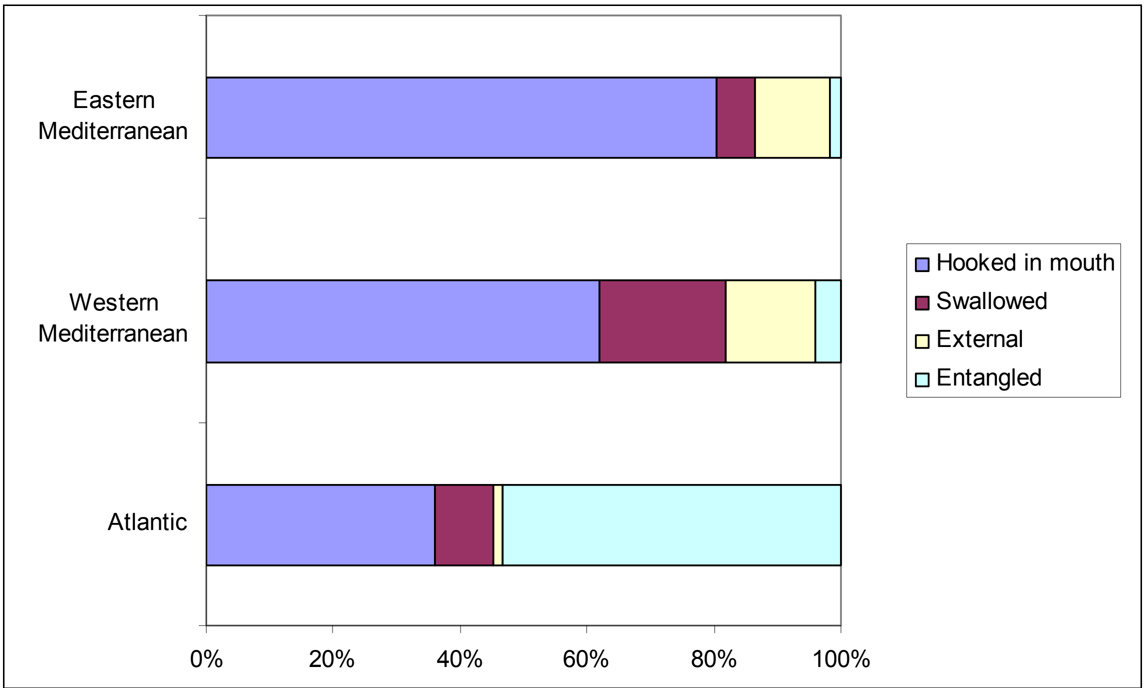

Figure 70 Hooking location of turtles caught on longlines (% of turtles caught)

5.4.4.4 Fishermen's opinions

A greater proportion of fishermen in the Western Mediterranean thought that something needs to be done to reduce the number of turtles caught, than in the other two fisheries (Figure 71). This corresponds with their indication that more turtles are caught in fishing activities in the Western Mediterranean than in the Eastern Mediterranean or Atlantic.

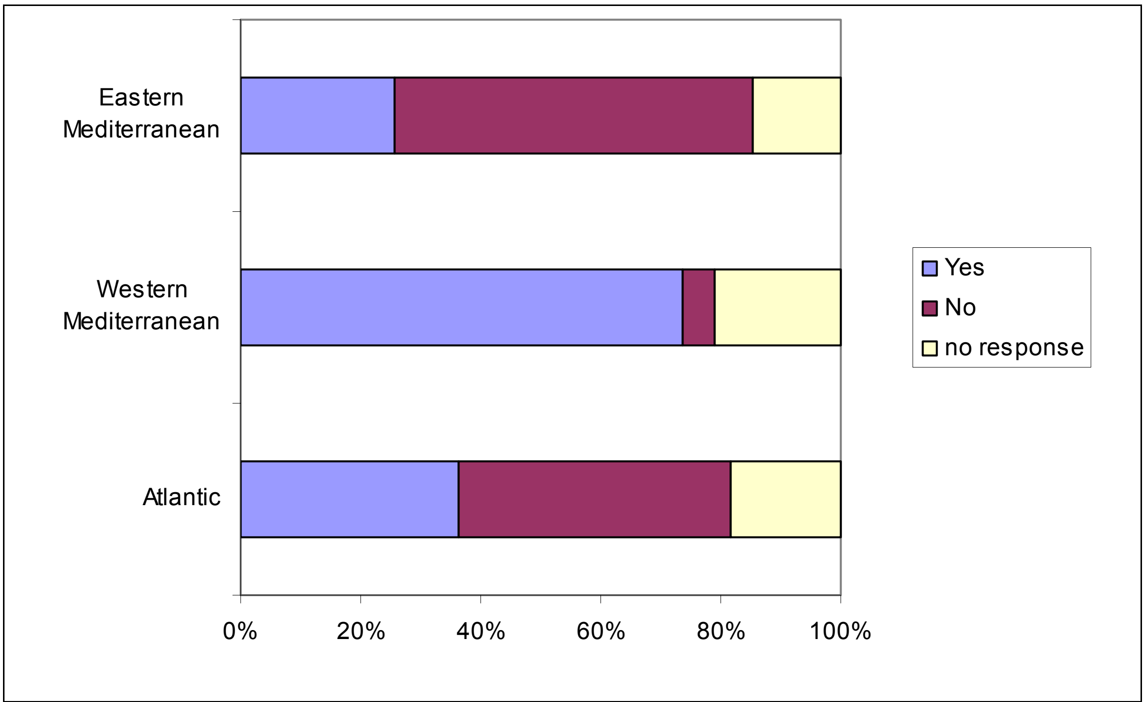

Figure 71 Respondents' opinion on whether anything needs to be done to reduce the number of turtles caught

Respondents had different opinions about what could be done to tackle the problem. Most thought it was a problematic issue and had difficulty in coming up with suggestions of what could be done to reduce numbers of turtles caught. However, this was an open-ended question that did not require a response, and so not all fishers attempted to give a suggestion as to how the problem could be addressed.

Whilst there was no consensus amongst the fishermen, some of the respondents in the Western Mediterranean suggested the most pragmatic options. 47% of the 19 respondents made a suggestion of how to tackle the problem, including:

- setting the gear deeper (21% of the 19 respondents) (although they warned this would still catch turtles, but fewer, bigger ones; it would also result in a reduction of the numbers of swordfish caught, although larger fish are caught at greater depths; furthermore, although fewer turtles would be caught at greater depths, there would be greater mortality of those that were caught as the risk for the turtles would be higher; and finally setting gear deeper is only appropriate during the summer when sea surface temperatures are higher);
- changing from squid bait to mackerel bait in the summer (16% of the 19 respondents);
- stop fishing during months with high turtle catch rates (5%).

11% of respondents from the western Mediterranean were keen to point out that they did not agree with the use of circular hooks to reduce turtle bycatch. One respondent also indicated that the problems with turtles were greater for driftnet gears than for longlines.

26% of the 62 respondents from the eastern Mediterranean made suggestions about how to reduce turtle bycatch. 8% thought the gear should be set deeper and 6% thought fishermen should be reimbursed for damages caused by turtles in order for them to be more sensitive towards the turtles. 6% thought a change in hook size could help, although there was no consensus on whether the hooks should be larger or smaller (half of these thought larger hooks should be used and half thought smaller hooks should be used). 3% also suggested stopping fishing activity for certain periods, either the summer, or the reproductive period, and that this should be compensated from the government or EU funds.

5.4.5 Normal fishing locations and interactions with turtles, compared with trials

The location of fishers' normal swordfish fishing activity (indicated by questionnaire respondents) and the locations of experimental trial sets are illustrated in Figure 72 a), Figure 73 a), and Figure 74 a) for the Atlantic region, eastern Mediterranean region and western Mediterranean region respectively. Figure 72 b), Figure 73 b), and Figure 74 b) illustrate the areas where fishers reported interactions with turtles to be most common and the location of turtles captures during the trials for the three regions. The shaded areas on the maps for usual fishing activities and areas of interactions with turtles are based on the number of respondents that indicated each area, and not the actual amount of fishing effort, or the actual turtle bycatch rates in each area, as the responses are not scaled to total fishing effort or fleet size.

The fishing trials were designed to maximise both turtle and swordfish catches in a relatively limited number of days to produced meaningful statistical results, and as a result did not necessarily correspond closely in all regions with areas highlighted by questionnaire respondents.

The usual fishing areas of the Atlantic fleet cover a huge area, with vessels licensed to fish either above or below 5° north of the Equator. The vessel selected for the trials had a licence to fish in the southern swordfish stock area, and in this sense the trials were not representative of the entire Atlantic EU fleet. However, the usual fishing grounds and locality of turtle bycatch reported by respondents active in the southern Atlantic overlapped slightly with both the trial location and where turtles were caught during this study.

In the eastern Mediterranean, due to the number of countries involved (Greece, Italy, Cyprus, Malta), the location of the experimental trials was also not fully representative of the entire fishing area of the swordfish fleet in this region. However, comparing the map of usual fishing activity in the eastern Mediterranean with the areas of interactions with turtles, gives an indication of the areas where turtle bycatch is most likely.

The fishing trial locations in the western Mediterranean do however correspond broadly with the areas where fishermen indicated they usually target swordfish. Furthermore, the locations where turtles were captured during the trials also correspond with the areas that fishermen indicated interactions with turtles are most common.

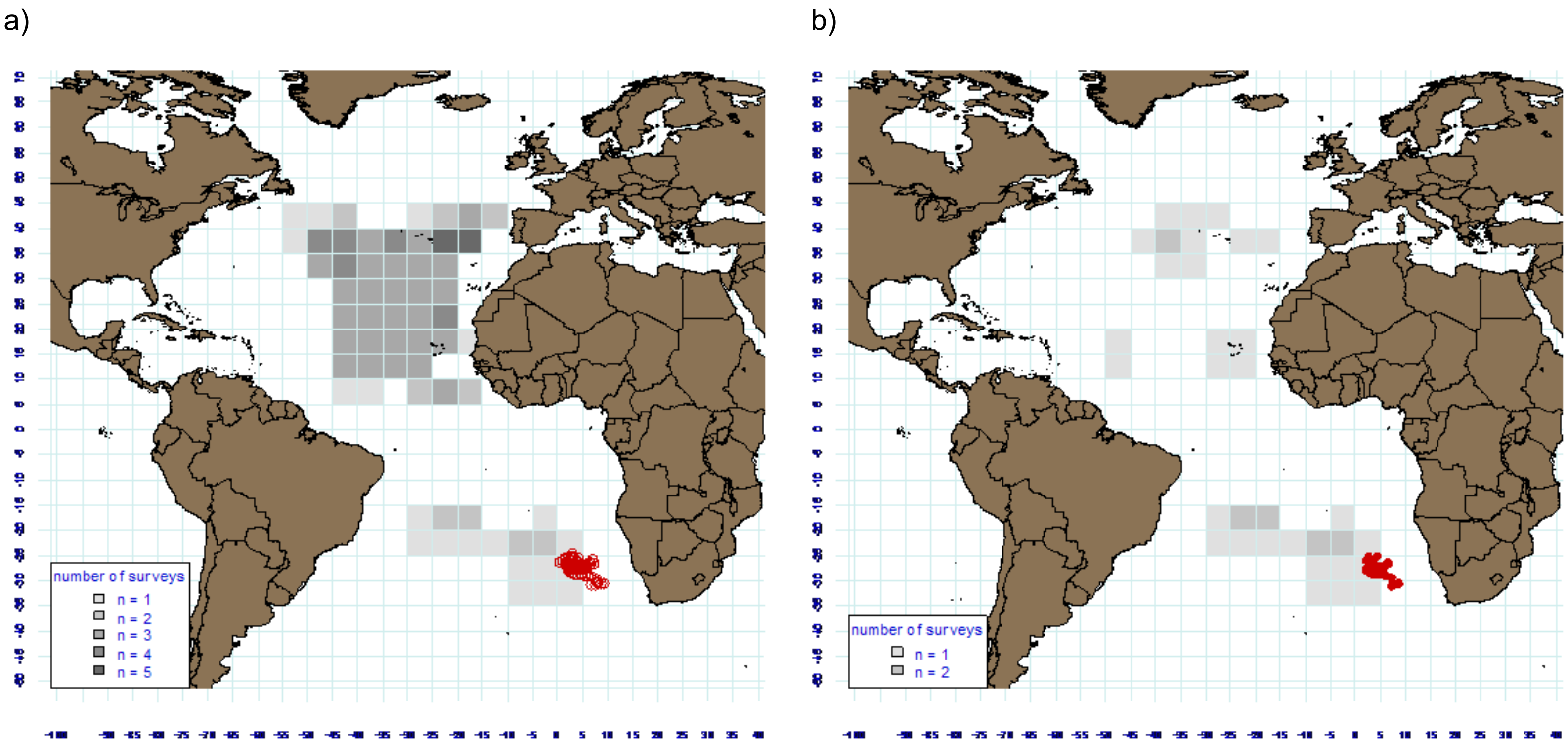

Figure 72 Maps illustrating a) the location of the Atlantic experimental trial sets, (red open circles) and location of usual fishing activities as reported by fisher questionnaire respondents (grey shaded cells) and b) the locality of turtle captures during the experimental trials in the Atlantic (closed red circles) and the location of interactions with turtles during usual fishing activities in the Atlantic as reported by fisher questionnaire respondents (grey shaded cells) (number of respondents that indicated each area, not scaled to total fishing effort).

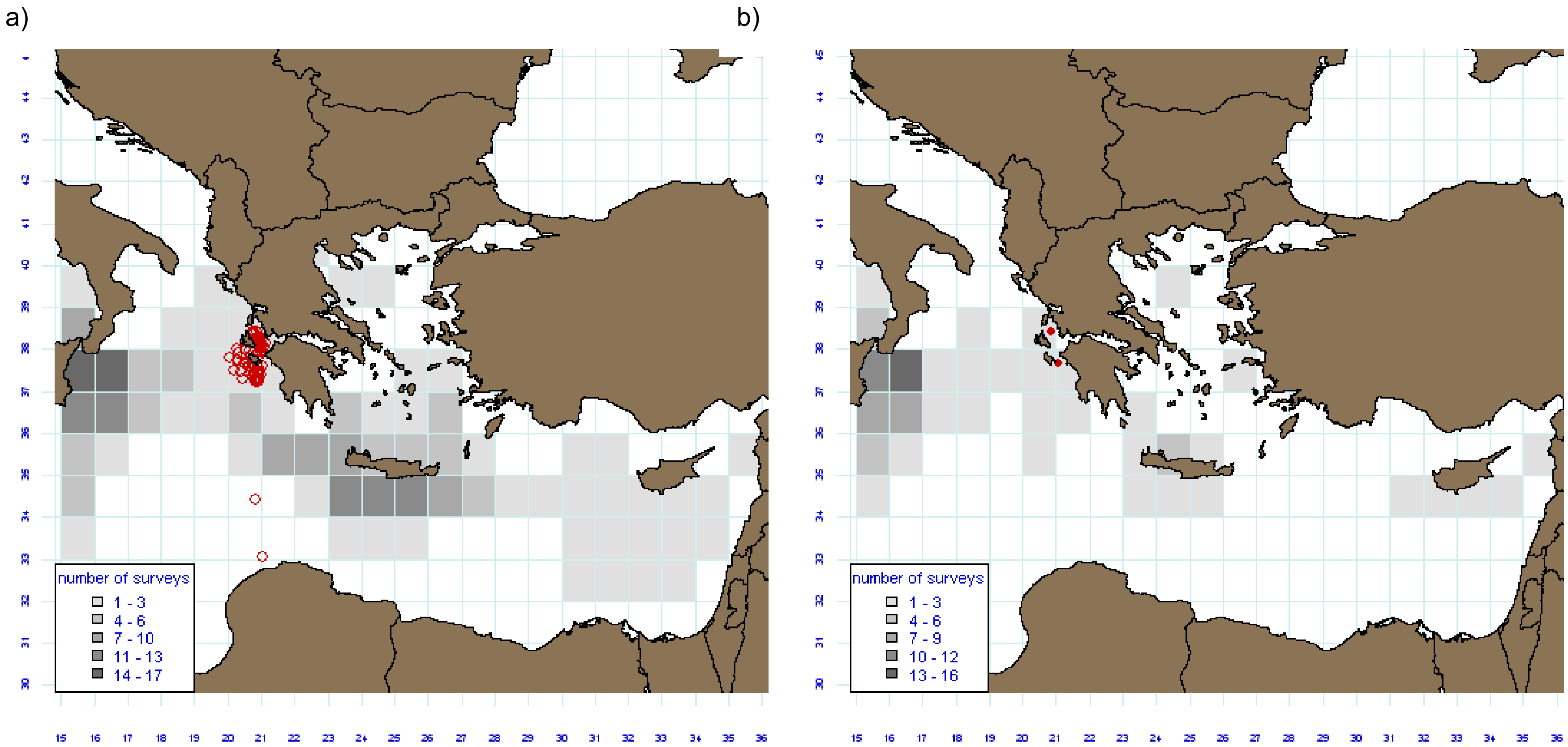

Figure 73 Maps illustrating a) the location of the eastern Mediterranean experimental trial sets, (red open circles) and location of usual fishing activities as reported by fisher questionnaire respondents (grey shaded cells) and b) the locality of turtle captures during the experimental trials in the eastern Mediterranean (closed red circles) and the location of interactions with turtles during usual fishing activities in the eastern Mediterranean as reported by fisher questionnaire respondents(grey shaded cells) (number of respondents that indicated each area, not scaled to total fishing effort).

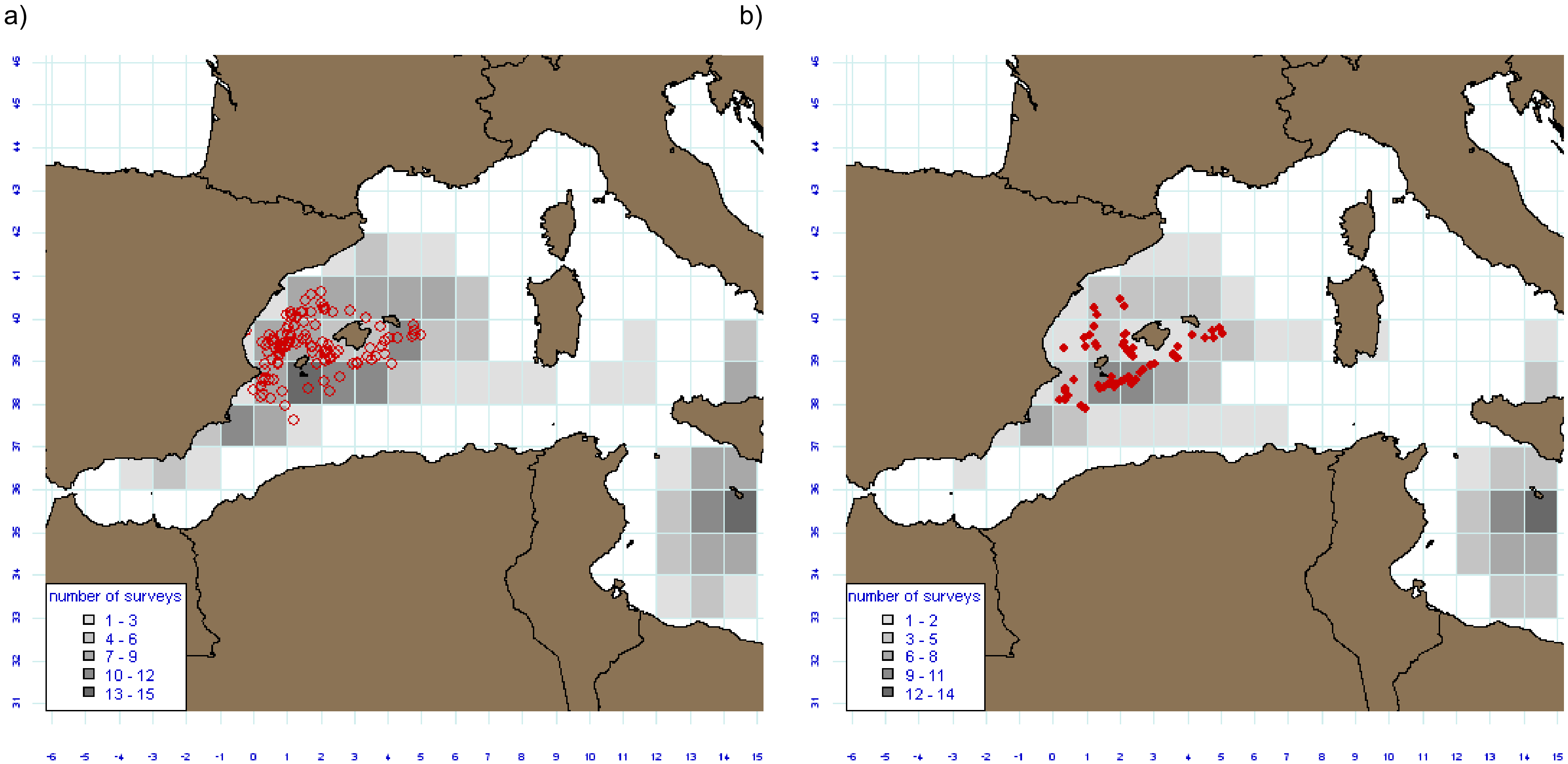

Figure 74 Maps illustrating a) the location of the western Mediterranean experimental trial sets, (red open circles) and location of usual fishing activities as reported by fisher questionnaire respondents (grey shaded cells) and b) the locality of turtle captures during the experimental trials in the western Mediterranean (closed red circles) and the location of interactions with turtles during usual fishing activities in the western Mediterranean as reported by fisher questionnaire respondents (grey shaded cells) (number of respondents that indicated each area, not scaled to total fishing effort).

6 Discussion

6.1 Effects of hooks and baits on turtle catch

Out of the mitigation measures under evaluation in these trials, bait type had the greatest influence on loggerhead turtle bycatch. In the Atlantic and western Mediterranean, mackerel bait lead to significantly lower probabilities of catching loggerhead turtles than squid bait. This result corresponds with findings in studies carried out by the United States National Marine Fisheries Service (NMFS) in the pelagic longline fishery targeting swordfish in the North East Distant (NED) statistical reporting area of the Western North Atlantic (Watson et al., 2005), where loggerhead catch rates were 3.4-10 times lower on mackerel than squid bait. In the NED studies, mackerel bait also had a significant effect on the catch rates of leatherback turtles, but due to the small number of leatherback turtles caught during our trials it is not possible to make logical comparisons between studies on bait effects of leatherback catch rates. Interaction rates of both turtle species have also been documented in observer data from Canadian Atlantic waters to be lower for mackerel than squid baits (Javitech Ltd, 2002).

In this study, the bait effect was particularly evident when data from the Atlantic and western Mediterranean were explored at the set level at times when loggerhead densities in the vicinity of the trials were high. Only sets baited with squid caught more than four turtles during these high loggerhead density periods and mackerel lines set consecutively on these dates consistently caught fewer turtles (see Figure 41).

Due to very low turtle catch rates in the eastern Mediterranean (two loggerhead turtles caught in 70 days of fishing), nothing conclusive could be drawn from these data and were not included in statistical analyses on the probability of capture by bait or hook type.

Hook effects on probability of turtle capture were not as conclusive as bait effects, differing between the Atlantic and the western Mediterranean. In addition, while turtle catch rates on test circle hooks differed from those on J hooks, their effect on the capture probability was not deemed statistically significant. Probability of capture by hook type was slightly increased for 18/0 circle hooks and decreased for J hooks in the Atlantic. Although both of these hook types were tested in the trials carried out by Watson et al (2005) in the north western Atlantic, results contrast with those from this study, with 18/0 circle hooks significantly reducing loggerhead catch rates compared with offset 9/0 J hooks regardless of which bait type they were combined with. In the NED trials, 18/0 offset hooks combined with mackerel bait led to the greatest reduction in loggerhead turtle catch rates, but these circle hooks also significantly reduced catch rates when combined with squid bait, indicating that hook effects were comparable to bait effects (Watson et al., 2005).

Other research with considerable relevance to this study was that carried out between 2000 and 2004 on industrial vessels operating in the swordfish and blue shark directed fisheries in the Atlantic around the Azores (Bolten et al., 2005 and related papers). The trials in the Azores fisheries, tested a variety of circle hooks but only on squid bait with slightly different combinations in each year of the following non-offset and offset versions of 9/0 J hooks, 16/0 and 18/0 circle hooks (see Table 32). The results from these trials are quite difficult to interpret, but in general were similar to our findings, particularly in the Atlantic, in that the circle hooks tested, did not generally reduce capture rates of loggerhead turtles when compared to the 9/0 J hooks.

Only in one year of the trials, 2003, did 18/0 non-offset circle hooks (not tested in this study) catch significantly fewer turtles than 16/0 non-offset circle hooks which caught fewer than the Japan tuna hook, which is more similar in shape to J hooks (Bolten and Bjorndal, 2005). Results from the western Mediterranean, correspond with these results, but only with respect to 16/0 circle hooks which decreased the probability of turtle capture compared with 18/0 and J hooks, which illustrated the highest probability.

The variation in the hook effects on loggerhead catch rates illustrated by our results, highlights the fishery- or regional-specific manner in which hook effects (or other mitigation measure effects) can be manifested, and support suggestions that wherever possible, trialling measures within different fisheries prior to implementation is advisable (Read, 2007).

Table 32 Summarised results from key comparative studies testing hook and bait types in Atlantic swordfish fisheries.

Gear		Trial results			NED Atlantic results				Azores
		Atlantic	E.Med	W.Med		2000	2001	2002	2003
Bait	Squid vs Mackerel	**M<S**	na	**M<S**	**M<S**				
Hook	J vs 16/0 circle vs 18/0 circle	J < 16/0 < 18/0	na	16/0 < 18/0 < J	**18/0 < J**				
	J vs 16/0					J<16/0			
	J vs 16/0 vs 18/0						18/0 < J< 16/0		
	18/0 vs 16/0							18/0 < 16/0	
	18/0 vs 16/0 vs tuna								**18/0 < 16/0 < tuna**

6.2 Effects of hooks and bait type on swordfish catch

Bait did not have as dramatic an effect on the probability of catching the target species, swordfish as it did on the probability of catching turtles. Only in the eastern Mediterranean did bait have a significant effect on probability of swordfish capture, with significantly increased probability of capture on sets baited with squid. When considering the data across regions and those of the Atlantic in isolation, patterns were similar to those in the eastern Mediterranean but were not significant. When it came to the effect of hook type on the probability of catching swordfish, general patterns in hook type were consistent among the regional trials with capture being more likely on J hooks than 18/0 hooks, which were more likely to hook swordfish than 16/0 hooks. However, the extent and direction of marginal effects of hook type on the probability of capture was not consistent among regions making it difficult to make conclusions on their effects on catch rate by numbers across the board.

While little information is provided on the effects of hook type on swordfish catch for the studies carried out in the Azores, a preliminary report indicated that use of circle hooks (possibly 16/0 non-offset) reduced swordfish CPUE by number when compared with J hooks (possibly 9/0 non-offset J hooks) (Read, 2007) which broadly corresponds with our results across all regions. However, these patterns contrast with analysis of observer data in the Hawaii-based longline fishery for swordfish (Gilman et al., 2007), which experienced an increase in CPUE (numbers per thousand hooks) of the target species during the two years after regulations were brought in specifying the use of fish bait instead of squid combined with 10º offset 18/0 circle hooks instead of J hooks. Only in the western Mediterranean, did sets baited with mackerel illustrate a higher swordfish catch rate than squid, but this could not be attributed to a statistically significant bait effect.

The influence of hook and bait types on swordfish numbers caught is an important consideration with respect to species conservation. However, the size of fish caught and the overall change in catch weight resulting from a gear modification must also be considered, in order to determine the viability of a mitigation measure to the fishing industry. For this reason, the effects of bait and hook types on the size of the fish caught were explored.

Over all oceans combined, sets baited with squid hooked significantly larger swordfish than mackerel, and J hooks caught significantly larger swordfish than 18/0 circle hooks, which caught larger fish than 16/0 circle hooks. However, when data were analysed separately by region, patterns only followed through for bait effects; hook type effects on size varied among regions. The size of swordfish caught varied between the Atlantic and Mediterranean trials. Atlantic fish were significantly larger than those caught in the eastern Mediterranean that, in turn were larger than fish caught in the western Mediterranean. It is possible that differences in size of target fish among regions, influenced effects of hook type within regions both on size and the number of fish caught.

To take into account any interaction between swordfish size and trial region, an analysis was carried out combining the effects of bait, hook and ocean on both the probability of capture and the size of swordfish caught (delta-lognormal Generalised Linear Model). Although calculation of statistical significance for individual levels of predictors in this model is problematic, model predictions could be made for each combination of categorical predictors accounting for both important response variables. The model predicted the highest swordfish catch (by weight) for J hooks baited with squid, and the lowest catch rates for 16/0 circle hooks baited with mackerel for each region. Although there were slight variations among other combinations of hook and bait type, in general squid predicted higher catch rates than for mackerel regardless of hook type (except when combined with J hooks in the western Mediterranean), and J hooks consistently predicted higher catch rates than for circle hooks.

These results differ from those in the Atlantic NED water studies, where comparisons between the same hooks (either J hooks or 18/0 circle hooks) always illustrated higher CPUE by weight (Kg per thousand hooks) when baited with mackerel rather than squid (Watson et al.. 2005). Watson et al. (2005) found that mackerel bait combined with circle hooks increased swordfish catch rates by 30% in the NED Atlantic trials. The Atlantic trials in this study caught similar sized fish (mean weight 51.8kg ±1.5 s.e., ranging in length from 67 – 281 cm fork length) to those caught during the NMFS trials in the NED, which ranged from 57-283cm in length and averaged 50.1 kg in weight, but there was no increase in catch rates associated with the use of either of the circle hooks combined with mackerel.

The combined results of decreased turtle catch rates and increased swordfish catches on mackerel bait combined with 18/0 circle hooks, led Watson et al. (2005) to recommend the use of these circle hooks and fish bait to reduce bycatch of both loggerheads and leatherbacks in longline fisheries targeting swordfish. Although, predictions from our model indicated in general decreased catch rates of swordfish on mackerel bait, when combined with J hooks variation in catch rates between squid and mackerel baits (for which low turtle catch rates were predicted) were not significantly different from each other (with respect to 95% confidence intervals). Use of mackerel bait should therefore not be overlooked as a potential mitigation measure for reducing turtle bycatch, based on the grounds of lower target catch rates indicated here.

6.3 Effects of hook and bait on turtle hooking location and survival potential

Catch rate may be considered the most important factor when considering gear modification as a mitigation measure to reduce the impact of fishing on turtle populations. However, of secondary importance is how these modifications affect turtle physiology and post-release survival rate. Previous studies with particular relevance to these trials (Bolten and Bjorndal, 2005; Watson et al., 2005), have supported the use of circle hooks due to the lower numbers of turtles which swallow these hooks compared with smaller J hooks. This is based on the assumption that turtles which swallow hooks are likely to have poorer post-release survival either due to internal damage caused during the process of removing these hooks, or because deeply ingested hooks cannot be or are not removed at all (Gilman, 2005).

Studies carried out in the North East Distant (NED) swordfish US longline fishery by Watson et al. (2005) testing 18/0 circle hooks with both mackerel and squid bait found that they had a significant effect on hooking location of the loggerheads caught during the four months of trials carried out in 2002 (Watson et al., 2005). The turtles caught during these trials were most often hooked internally; 80% of turtles caught on J hooks had swallowed them, whilst only 27% of those caught on circle hooks had swallowed them, and the commonest hooking location for turtles caught on circle hooks was the mouth. Loggerhead turtles caught during experimental trials carried out between 2000-2004 in the Azores swordfish fishery (Bolten and Bjorndal, 2005), also found significant effects of hook type on hooking location with greater percentages of turtles being hooked in the throat by J hooks than circle hooks (16/0 and 18/0 offset and non-offset hook types pooled).

The results from this study indicated similar patterns in hooking location by hook type, with fewer loggerheads swallowing 18/0 circle hooks than J hooks among all trials. Predictions from the multinomial analysis illustrated that 18/0 circle hooks decreased the probability of turtles swallowing the hook, 16/0 circle hooks increased the probability and J hooks had no effect. Similarly, J hooks had no effect on whether a turtle was hooked externally, while 18/0 circle hooks increased the probability of being hooked in this way and 16/0 circle hooks reduced the chances of a turtle being hooked externally. Hook type had little effect on whether a turtle was hooked in the mouth. Despite these apparent effects on hooking location by hook type, none of these effects were found to be significant. Similar size frequencies of turtles were caught during these trials (mean 56.85cm, range 40-80cm straight carapace length) to the size frequencies of turtles caught in the NED (mean 56.8 cm, range 32.4-68 cm straight carapace length) and Azores studies (mean ~57cm, range ~28-89cm straight carapace length (calculated from curved carapace length) (Watson et al., 2005, Bolten and Bjorndal, 2005). It follows that other factors such as statistical power lead to a lack of significance rather than the size distribution of sampled turtles.

Squid bait increased the probability of a loggerhead turtle swallowing the hook, while mackerel bait reduced the probability of loggerheads being hooked in this manner. This effect was not significant statistically, and bait did not determine whether loggerhead turtles were caught by hooks in the mouth or externally. Similarly, bait did not have significant effects on the hooking location of loggerhead turtles caught in the NED trials during the Watson et al. (2005) study and this effect was not tested during the Bolten and Bjorndal (2005) trials in the Azores.

Loggerhead turtles caught during our Atlantic trials were significantly larger than those caught in the Mediterranean, but there was no significant effect of hook type or bait type on the size of turtles caught. Some patterns in the data reflected possible interactions between hook type and size, size of turtle hooked and the manner in which turtles were hooked. For example, J hooks caught a greater proportion of smaller turtles than both of the circle hooks across all regions and a larger proportion of (generally larger) Atlantic loggerheads (53%) had swallowed hooks than those in the Mediterranean (42%). A slightly greater percentage of hooks swallowed by loggerheads in the Atlantic (21%) than in the Mediterranean (17%) were the largest 18/0 circle hooks. Additionally, 16/0 circle hooks were swallowed by larger loggerhead turtles (in all regions) than loggerhead turtles hooked in the mouth by these hooks. Unfortunately insufficient data were available to analyse this hypothesis statistically and in addition a number of contradictory patterns existed. For example, J hooks and 18/0 circle hooks were also swallowed, hooked in the mouth and hooked externally by the same size ranges of turtles and even the smallest size range of the turtles caught were capable of swallowing the largest 18/0 circle hooks.

Observations made during the trials provide some evidence that squid might in fact ease the passage of hooks, as it was reported that even very small turtles could swallow 330g sized squid bait with 18/0 circle hooks enveloped entirely in the squids' mantle. Whether this anecdotal information is born out by the higher 'swallowing' probability of 16/0 circle hooks cannot be concluded here, but perhaps deserves further research as it corroborates observations of captive turtles feeding on squid in the same manner (Watson et al., 2003; 2004).

Kerstetter and Graves (2006) commented that when circle hooks are swallowed (by swordfish) they have less of a tendency to become snagged on internal tissue, often resulting in the hook slipping back into the mouth. The result is reduced internal injury to the hooked swordfish and better survival rate on the line which ultimately improved the condition of landed fish. However, anecdotal evidence from the Atlantic and western Mediterranean trials provided by an observer who worked on both of these regional trials contradicts this theory with respect to turtle catch on these hooks. Although turtles caught with the larger circular hooks were more often caught in the lower jaw or in the side of the mouth, circular hooks were much more difficult to remove than J-type hooks whether hooked in the mouth or internally. To remove ingested circle hooks they must be twisted to remove the barb and the turned point, causing a lot of traction in the oesophagus, tissue tears and haemorrhages. Even when turtles were hooked in the mouth, difficulty was experienced in removing circle hooks, especially 16/0 non-offset due to the smaller gap between shank and the point. The observer also commented that all catch was more 'tightly' hooked by circle hooks, with less catch being lost from these hooks during the hauling and boating procedure. Unfortunately, this effect was not recorded consistently during the trials. While these observations were made by a single observer, it would appear to be an issue worthy of further investigation across regional fleets more widely.

As only nine leatherback turtles were caught during these trials it is difficult to make conclusions about the effects of hook and bait types on hooking locations. However, the fact that none of these 9 leatherbacks had swallowed the hook corresponds with results from other studies in which larger numbers of this species were caught, which conclude that they are more likely to become hooked externally in longline fishing gear (Watson, et al., 2005). In the NED trials, although effects on hooking location by hook type were not as pronounced as for loggerhead turtles, significantly more of this species were hooked externally, but bait had no effect (Watson et al., 2005).

6.4 Effects of additional factors on turtle and swordfish catch

Previous research has highlighted marked effects of sea surface temperature (SST) on catch rates of both loggerhead and leatherback turtles (Javitech Ltd, 2003; Watson et al., 2005) as well as the influence of daylight hauling time and soak time on loggerhead catch rates (Bolten and Bjorndal, 2003; Watson et al., 2005). Evidence also exists for deeper setting of lines reducing turtle bycatch (Gilman et al., 2006). However, the effects of these additional factors (SST, set depth and soak time) did not have dramatic effects on the catch rates of loggerhead turtles in these trials. Similarly, SST and set depth did not appear to strongly influence the probability of swordfish capture. The lack of relationship between turtle and swordfish catch rates with SST temperature may be due to the lack of overlap among regional trials in this variable, combined with the relatively short timescales over which the trials were carried out. In contrast, soak time had a significant and positive effect on swordfish catch rates by number, but as in other studies may be confounded by increases in hauling times as a result of increased catches (Watson et al., 2005).

The effect of hook position within a magazine on probability of capture was also explored for both turtle and swordfish, but there were no clear patterns in the variable for either species. Bolten and Bjorndal (2005) found similar non-effects for loggerheads in the Azorean swordfish fishery, and the only published information on this is for leatherbacks in the NED waters of the Atlantic which were more often associated with the shallowest branch lines (Watson et al. 2005)

The lack of effects from these factors on turtle bycatch should be treated with caution as these trials were not specifically designed to test them.

When frequency of capture by set and date was explored (Fig.41), it became apparent that although turtle capture events are on the whole rare by nature, occasional peaks in capture occur irrespective to some degree of the bait or hook types being utilised. There was a general trend for sets baited with squid in these areas or times at which turtle incidence was elevated to catch more turtles than those with mackerel, but it highlights the highly variable nature of turtle distribution within any ocean area and associated limitations in studying factors influencing turtle bycatch. The peaks in bycatch recorded during our trials, corroborate analysis of observer data from the Hawaii-based swordfish longline fishery, which provided the first empirical evidence of higher probability of turtle capture on sets subsequent to sets which had already caught turtles (Gilman et al., 2007). The authors suggest that the phenomena might be utilised to coordinate in-fleet avoidance of such bycatch hotspots (Gilman et al., 2007).

Presence of turtles however, does not necessarily lead to interactions with longlines, as the low turtle catch rates experienced during the eastern Mediterranean trials illustrated. The observer commented in his report that although substantial numbers of loggerhead turtles were observed in the vicinity of the fishing vessel, they did not interact with the longline fishing gear. Communications with Archelon also confirmed that nesting frequency on Zakynthos Island was not lower than usual (Archelon, pers. comm.). Nesting turtles tend not to feed during the inter-nesting period, and this may explain the lower catch rates for loggerheads observed during these trials and reported by other studies (Tudela, 2004) in this part of the Mediterranean.

Swordfish catch were also considerably lower in the eastern Mediterranean than preceding years, and the fishermen involved in the trials commented on this. According to the fishermen, all the swordfish fishing vessels which operate in the wider area of Zakynthos suffered similarly low catch rates for swordfish this summer. Indicative of this was that some fishermen kept their vessels in port, unable to compensate the expenses of the fishing trips with such low catch rates. Industry representatives believe that poor catches this year were due to the presence of large fishing vessels fishing with nets in the international sea zones in the fishing grounds of South Ionian Sea.

6.5 Effects of hook and bait on secondary target species

Across all regions, significantly more tuna in general were caught on squid bait, and catch rates were significantly decreased for J hooks and increased for 18/0 circle hooks. There were similar patterns for blue fin tuna in the western Mediterranean, although only the bait effect was significant. In light of the current issues with the stock of this species in Mediterranean, this result supports any recommendation that might be made for a move to mackerel bait. Large numbers of blue shark were caught during the Atlantic regional trials, and although more were caught on mackerel and on 18/0 hooks, these differences were not significant and contrast with more extensive studies (with respect to effort) carried out in the Atlantic and Pacific which have indicated reduced shark catch on mackerel bait (Gilman et al., 2007; Watson et al., 2005). Effects on billfish species other than swordfish (greater catch rates on mackerel, J and 18/0 hooks) were not significant.

6.6 Fisher Questionnaire

54%, 63% and 45% of fishermen from the Atlantic, Western Mediterranean and Eastern Mediterranean fisheries, respectively, reported that turtles disrupted their fishing activity. The main disturbances reported (in order of importance) were that they slow hauling procedures, damage gear and steal bait from the lines. The fact that the highest proportion of fishermen reporting turtle-related disruption came from the Western Mediterranean, also ties in with the higher catch rates of turtles there reported by the fishermen (0.89 per 1000 hooks, compared with 0.14 in the Atlantic and 0.09 per 1000 hooks in the Eastern Mediterranean). These relative catch rates were also corroborated in our experimental trials. This is also reflected in the 74% of respondents in the Western Mediterranean who felt that something needs to be done to reduce the number of turtles caught as by-catch.

The higher catch rates of swordfish on J-hooks demonstrated during these trials are also backed up by the results of the questionnaire, in which 100% of respondents indicated that they fished using J-hooks when targeting swordfish, because they consider them to be the most effective hook type.

When questioned about the acceptability of a change in hook type, from J-hook to circle hook, this would not be acceptable to the majority of fishers, as they considered that the J-hook is the best and that circle hooks have a low effectiveness for catching swordfish. Fishermen from the Atlantic and Eastern Mediterranean fisheries were most accepting of trying different hook types (46% and 42% of respondents from each fishery respectively, answered ‘yes’ or ‘maybe’ possible to change hook type) although added that their effectiveness would have to be tested. Fishermen from the Western Mediterranean fishery were most opposed to the idea of changing their hook type. Some of the fishermen had participated in (and many had heard about) previous experimental trials, which had shown a low effectiveness for circle hooks in terms of catching swordfish. Catch rates by hook type observed during the western Mediterranean trials corroborate the previous trial's results, being lower for circle hooks than for J-hooks.

With respect to bait used, the questionnaires indicated that the fishermen in all three areas use both mackerel and squid bait, both of which they consider to be effective. Fishermen in the Atlantic and Western Mediterranean mix both bait types on the same line, and may alter the proportion of mackerel to squid depending on the season, water temperature, fishing area and previous day's catches. In general, they use a higher proportion of mackerel than squid bait (e.g. 2 or 3 mackerel to 1 squid), which may be due to cost[5]. However, some skippers prefer to use a higher proportion of squid when possible (Atlantic). In the western and eastern Mediterranean more squid tended to be used during the summer months. In contrast to the western Mediterranean where skippers mix bait on the whole line, in the Eastern Mediterranean, 67 % of respondents used the same bait type on the whole line. Those that did mix bait types tended to use a higher proportion of mackerel than fishermen in the Western Mediterranean, and in the Eastern Mediterranean a large proportion do not use any squid at all (only 57 % indicated they use squid).

Most fishermen (64% in the Atlantic, 53% in the Western Mediterranean and 76% in the Eastern Mediterranean) felt it would not be possible to change their bait type. However, this is based on the premise that they are already using both squid and mackerel as bait types, as the question explored whether they would be able to change from what they currently use. The main reasons for not wanting to change included: a lack of availability of other species on the market; the fact that current bait types are most effective; the cost of alternative bait types (also indicating that if alternatives were the same price or cheaper than current bait types, then there would be a possibility of using them); alternatives such as sardine are too easily removed from the hook; and for mackerel, the added benefit that the same fish can be reused if it is not taken as bait. However, the fact that the fishermen already use mackerel is an encouraging starting point, as they may be open to the possibility of using a higher proportion of mackerel bait on their lines. The possible drawback with this is that during the summer, the fishermen tend to use a higher proportion of squid bait , which they indicated stays on the hook better than mackerel when sea surface temperatures are higher.

The fishers questioned agreed that reducing turtle by-catch is a difficult issue. Although most did not know what could be done, in the western and eastern Mediterranean, of the 25 respondents that made suggestions, the most popular were:

- setting the gear deeper (36%); ;
- reimbursing fishermen for damages caused by turtles (16 %);
- changing from squid bait to mackerel bait in the summer (12 %);
- stopping fishing during periods of high turtle bycatch (e.g. summer, reproductive periods) with compensation for fishermen (12 %).

Setting the gear deeper may be a more natural transition for fishermen in the Western Mediterranean, where some fishermen have already adopted the 'American/Florian-type' longline in addition to the traditional longline. The American longline is set deeper than the traditional longline, and so may result in lower turtle by-catch rates. Several questionnaire respondents indicated that their average

[5] The skipper of the vessel chartered for trials in the Atlantic commented that squid is generally the more expensive bait, but is more readily available on the market.

monthly catches of turtles had already decreased dramatically as a result of using the American longline[6]. This deserves further exploration, particularly the mortality of turtles caught on these lines, which is often greater for deeper-set lines. A combination of reducing the proportion of squid used as bait during the summer months, setting the gear deeper and avoiding areas or seasons when turtle bycatch are highest, may be the most effective and acceptable way of reducing turtle bycatch in the Mediterranean. However, the acceptability of these specific options should be explored in greater depth with the fishermen across all fleets active in this region.

A number of respondents were keen to point out that they did not agree with the use of circular hooks to reduce turtle bycatch. Some fishermen also indicated that the problems with turtles were greater for driftnet gears than for longlines.

6.7 Lessons learned

When predictions from the statistical models (one for turtle capture rate and one for swordfish capture rate) are combined, the number of turtles per tonne of swordfish capture can be predicted (Figure 54). It was not possible to make predictions for the eastern Mediterranean, but for the Atlantic and the western Mediterranean, they predicted that the lowest ratios of turtles per tonne of swordfish were for mackerel combined with J hooks in both, with 1-5 turtles caught per tonne compared with 1- 10 turtles per tonne on squid bait with these hooks. The circle hooks combined with squid bait predicted the highest catch rates per tonne of swordfish (1-20 turtles per tonne swordfish).

Comparison of our regional trial set and turtle capture locations with the usual fishing and turtle capture locations reported by respondents of the fisher questionnaire, indicate that extrapolations from these catch rate predictions would not be valid for either the Atlantic or eastern Mediterranean trials. In the eastern Mediterranean this is a consequence of the low turtle capture rates during the trials as well as their locality not encompassing the entire fishing area covered by the different countries with swordfish fleets active in this region. In the Atlantic, our regional trials were focused in only a small area covered by EU vessels fishing in the Atlantic. In addition, catch rates experienced during the trials were higher than usual, due to efforts to locate trial sets where turtle incidence was likely to be higher, therefore biasing any scaling up of turtle to swordfish catch rates.

However, Figure 74, demonstrates that the trials carried out in the western Mediterranean correspond very closely with the usual fishing activity in this region and where turtles have usually been caught in the experience of those interviewed in the fisher questionnaire. Other reports have documented similar rates of turtle capture in this region and swordfish catch rates were not reportedly lower than usual.

Extrapolating up the numbers of turtles caught per tonne of swordfish by an estimate of swordfish catch from 2006 for this region (1350 tonnes, 2006 ICCAT data), provides predictions of the numbers of turtles potentially caught by each of the six hook and bait combinations for that year. These predictions are illustrated in Figure 75.

[6] This information contrasts with the results of the questionnaire, as responses were confounded by catch rates being given by fishers who had used both gear tyes.

The predictions of loggerhead numbers caught on squid bait for the western Mediterranean correspond with estimates made by other studies for the Spanish Mediterranean drifting longline fisheries region which ranged from 1,953-23,888 loggerheads between 1985 and 1995 (SEC, 2005). Considering most fishermen in this region already use both mackerel and squid bait, an estimate of the number of turtles caught on mixed bait (e.g. 50-50 squid to mackerel ratio assuming a linear relationship between turtle catch rate and each bait effect) is 7480 loggerheads. So if a shift from mixed squid and mackerel bait were to be made, this would result in a reduction in turtles caught of 4675 turtles in a year (based on 2006 swordfish catch rates and turtle: swordfish catch rates predicted from our trials). Using swordfish catch rates predicted for the different gear combinations used in these trials, this shift in bait type would require an increase in effort of 21% in order to catch the same total weight of swordfish for a year.

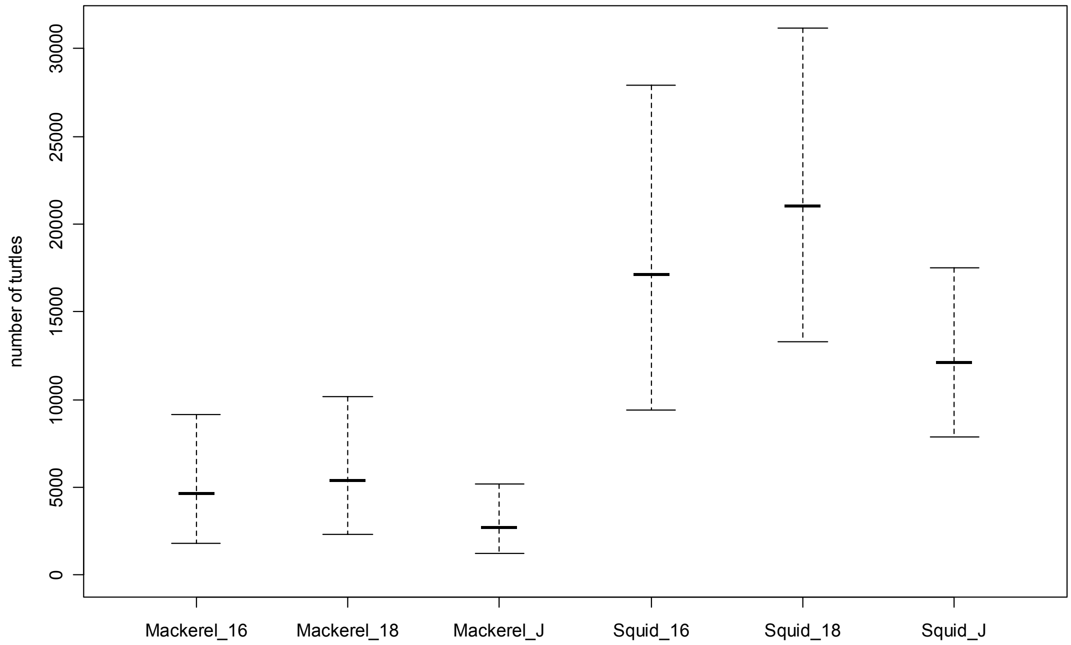

Figure 75 Estimated turtle bycatch corresponding with the total swordfish catch in 2006 in the western Mediterranean trials for each combination of bait and hook type tested.

This is clearly a simplified analysis on the effects bait has on turtle catch rates, when there may in fact be more complex relationships involved. The effect of squid bait on the probability of turtle catch might be represented by a curvilinear relationship, with catch rates increasing exponentially once a certain proportion of squid is present on a line, or there may be a threshold density of squid bait for a given area or distance which leads to an increase in turtle bycatch. Further research exploring the consequences of mixing different proportions of bait on lines is required in order to determine this. By exploring mixed bait effects further, an optimum proportion of squid and mackerel bait on a line might be determined which maximises swordfish catch whilst minimising turtle bycatch, thus providing an alternative to a switch from mixed to 100% mackerel bait and the increase in effort to compensate for potential decreased swordfish catches. Vessels in the Atlantic already fish on average 21 days per month, and this level of effort is already likely to be at a maximum as a result of factors such as weather constraints and time to reach distant water fishing grounds. Increasing this effort by ~4 days (21% effort) may not be practical. Additional effort may be more feasible in the Mediterranean regions, where they fish on average between 9 and 16 days per month (during the peak seasons) and there might be options to distribute any increased effort required during periods of the year in which turtles are less frequently caught. A detailed analysis of fleet data for each of the regions, their monthly effort during the year and the extent to which they are solely targeting swordfish during these times would be required in order to determine the feasibility of increasing effort due to a change in baiting regime. Such a study might also investigate practicalities of enforcing bait regulations which is likely to be problematic, particularly for distant water fleets.

Although the size and the probability of catching swordfish was higher for J hooks and squid bait compared to circle hooks and mackerel across all regions, it is important to emphasise that results emulate from trials which took place over relatively short periods of time and may not be representative of the entire fishing season in these locations. Despite the indication from these trials that swordfish catch rates might decline if squid bait were to be prohibited, this has not been the case in other fisheries where bait regulations have been enforced in an attempt to reduce bycatch of turtles. In the Hawaii-based longline swordfish fishery strict regulations were introduced in May 2004 after a two year closure in order to reduce turtle bycatch (Gilman et al., 2007). Measures include a switch from J hooks and squid bait to 10º offset 18/0 circle hooks and fish bait (based on results from the NMFS study carried out by Watson et al., 2005), annual limits on turtle captures within the entire fishery and 100% observer coverage (Gilman et al., 2007). During the first two years of enforcement, the fishery has not experienced a decrease in target catch numbers, with CPUE (numbers per 1000 hooks) actually increasing by 16% (Gilman et al., 2007). Unfortunately there is no information provided from this analysis of observer data on changes in catch rates by weight since regulations were enforced.

To summarise our key results, bait had the most effect on turtle catch rates in our trials, with mackerel reducing catch rates by greater than 50%. Scaling up these catch rates was only appropriate for the western Mediterranean data, but doing so predicted reduction in catch of 4675 turtles by shifting from mixed squid to only mackerel if assuming bait effects are linear for both bait types. There were decreased catch rates of swordfish on mackerel, but this decrease was not significant and likely to be acceptable to the industry. Assuming industry already uses 50-50 mackerel-squid bait mix, a change to mackerel only would require 20% increase in effort to catch same amount of swordfish based on 2006 ICCAT catch data. However, this increase in effort may only be feasible in the Mediterranean region.

This study did not show markedly decreased catch rates for turtles on circle hooks as other studies have indicated, despite similar sized turtles being caught in comparable studies. However, catch rates were generally higher on J hooks, but the difference was not significant and in the western Mediterranean, the probability of capture on 16/0 circle hooks was decreased, but again not significant. 18/0 hooks did not perform as well as has been reported in other areas of the Atlantic, and increased probability of capture in our regional trials in the south Atlantic. It is therefore in-appropriate to make recommendations for a change in hook type based on our catch rate results.

There was a significant effect upon numbers of swordfish caught, and overall patterns from predictions indicate a similar influence of hooks on swordfish probability of capture as those on the catch rate of turtles. The highest catch rates were on J hooks, greater than for 18/0 circle hooks, greater than 16/0 circles and therefore our results do not support a move from J hooks with respect to swordfish capture efficiency.

With respect to turtle hooking location, the largest 18/0 circle hooks, were less frequently swallowed than J hooks (which had no effect on hooking location) and 16/0 circle hooks were more frequently swallowed. Loggerheads were more likely to be externally hooked on 18/0 circle hooks. These variations among hooking location in hook type were not significant, and anecdotal evidence from one of our observers on difficulties experience in removing circle hooks both when hooked in mouth and when hooked internally deserves further investigation.

7 Conclusions and Recommendations

1. Results suggest that the greatest reduction in turtle bycatch in surface longline fisheries targeting swordfish in the regions where trials were carried out would be achieved through a move from mixed squid and mackerel bait to use of mackerel bait alone.
2. Timing a shift in bait type to mackerel during the summer periods (in the Mediterranean) when incidence of turtles in the fishing grounds of EU vessels is at it’s highest may provide the greatest benefits to loggerhead turtle conservation.
3. Results do not support a change from the traditional J hooks used in these fisheries to either of the two circle hooks (16/0 0° offset and 18/0 10° offset) tested in the trials, as these hooks did not consistently or significantly reduce turtle catch rates and had negative impacts on swordfish catches among the three regions.
4. Further investigation of post-hooking mortality in loggerhead turtles is required to determine secondary effects of J and circle hook types on overall impacts of these fisheries on turtle populations in the Mediterranean and Atlantic.
5. A detailed exploration of gear configurations and current practices within all EU fleets targeting swordfish in the Mediterranean and Atlantic, in addition to a more extensive evaluation of the acceptability within the industry of potential turtle bycatch reduction measures is recommended. Options to be addressed should include a shift to mackerel from mixed or squid baits, in addition to those identified through responses to our questionnaire, such as setting gear deeper and closed seasons or areas.
6. Raising awareness of kits available to de-hook turtles and providing training materials on use of this equipment, particularly within distant water fleets which are unlikely to be able to board turtles easily due to vessel size and species of turtles incidentally caught (e.g. leatherback turtles), could increase the numbers of turtles from which gear is successfully removed once hooked and potentially aid their survival.

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9 Appendix 1: Details of Phase 1 activities from Interim Report

9.1 Atlantic Fishing Experiments

9.1.1 Meetings with fishing industry (Task 4)

In preparation for the fishing experiments, two trips to Galicia (NW Spanish region where the Atlantic swordfish fishing fleet is based) were carried out by Dr. Esteban Puente (Head of the Fishing Technology Research Area in AZTI and responsible of the AZTI team in the project) between 19th-26th September 2006 and 16th-17th October 2006. The aims of those trips were:

- To establish personal contacts with the fishing owner associations representatives as well as with some individual fishing owners/skippers.
- To present the project technical approach and to ask for the collaboration of the fishing industry in some aspects of the project.
- To refine practical aspects referred to the implementation of relevant tasks dealing with the fishing sector, particularly the experimental fishing trials and the survey on fishing activity (implementation of the fishermen questionnaire).
- To collect information on gear configuration of the drifting longlines commonly used by the Atlantic fleet through interviews to the main gear suppliers and interviews to skippers.
- To establish personal contacts with the fishing owners and skipper of the vessel to be chartered and discuss/agree details about the conditions of the trials.

Four fishing owners associations were visited:

- Asociación Nacional de Armadores de Buques Palangreros de Altura/ANAPA –Vigo/Pontevedra- (interview with Edelmiro Ulloa –manager-),
- Organización de Pescadores de Altura de A Guarda -A Guarda/Pontevedra - ORPAGU (interview with Manuel Sequeiros –manager-),
- Asociación Empresarial Espaderos Guardeses -A Guarda/Pontevedra (interview with Javier Castro –chairman- and Concepción Ortega –manager-)
- Organización de Productores Pesqueros de Lugo/OP 7 -San Ciprián/Lugo-) (interview with Jose Manuel Fernández Beltrán –Secretary-).

The project, its objectives and methods were presented to industry representatives and discussions followed on the best practical way to carry out relevant tasks of the project, particularly those dealing with the fishing sector (e.g. trials at sea, fisher questionnaire). The collaboration of the Fishing Industry was requested and the availability of the project team was also offered for consultation about technical aspects of the study.

9.1.2 Vessel charter and procurement of gear (Task 10)

Through personal interviews with the fishing owners and the skippers in September and October 2006, initial contacts were established with a fishing company to charter a vessel for the Atlantic trials. According to the preliminary agreement, the period for the trials will be March-April 2007 (starting late February or early March 2007). Around 30 fishing days (30 longline sets) will be allocated for the trials. The date and location planned for the fishing trials is a compromise between the fishing trip activity of the fishing vessel (boats stay at sea for periods of 3 months), the location of swordfish fishing grounds in the period of the trials, and the expected likelihood of incidental catch of turtles. The latter was determined according to the skipper's experience in the South Atlantic and scientific information available on turtle ecology (Fretey, 2001[7]) and by-catch (Carranza *et al.*, 2006[8]), which in this region is rather scarce (See **Error! Reference source not found.**).

The preliminary chosen area for the trials is between the following coordinates: 12ºS to 26ºS and 7ºE to 7ºW. The conditions of the trials have been agreed with the owners and the skipper according to the experimental design defined in the project proposal (see **Error! Reference source not found.** and **Error! Reference source not found.**).

Prior to implementation of the fishermen questionnaire, a complementary survey was carried through two of the main gear suppliers in Galicia: POMBO S.L. (A Coruña) and A POUTADA (Sta. Eugenia de Ribeira) in order to collect information on the most common gear characteristics/components used by the Atlantic fleet. Some examples of the information collected are presented graphically in **Error! Reference source not found.**.

According to the preliminary information collected, most of the Atlantic vessels use the "American/Floridian" type longline. There seems to be little variation between vessels in gear components used, as the fishing companies utilise few gear suppliers. Moreover it also seems that there is little variation in the way the different vessels mount the gear (e.g. branchline length, distances between branchlines, the number of hooks between consecutive floats).

For practical reasons, the general characteristics of the longline for the trials will be the ones used by the commercial boat which corresponds fairly well to the general type used by the commercial fleet. The main changes on the commercial gear for the purpose of the trials will be:

1. The setting of the mainline in two equal pieces. Each one of them will be baited with one of the two main species used as bait (squid and mackerel) in order to test the fishing performance of both bait species for target and by-catch species as well as for the incidental catch of turtles. Previous studies of bait species effect on turtle by-catch in different geographical areas suggest a relevant effect of those bait species in the level of turtle catches of the gear (Garrison, 2003[9] in the Gulf of Mexico; Watson et al. 2004[10] in North East Atlantic)
2. The experimental hooks to be tested (circle hook size 16/0 offset 0º and 18/0 offset 10º) that will replace the J hooks in 2/3 of the common branch lines used daily by the vessel.

[7] Fretey, J. (2001) Biogeography and Conservation of Marine turtles of the Atlantic Coast of Africa/Biogéographie et conservation des tortues marines de la côte atlantique de l'Afrique. CMS Technical Series Publication Nº 6, UNEP/CMS Secretariat, Bonn, Germany, 429 pp.

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This experimental protocol is as specified in the tender and will be followed in each of the other trials but with slight modifications to gear configuration to reflect regional practices.

9.1.3 Selection and training of observers (Task 12 & 13)

AZTI will rely on its own staff of observers and technicians with experience in many fishing trips on different fishing modalities to carry out the observation work during the experimental fishing trials. The selection of observers has already been made internally in AZTI and training is ongoing.

Several aspects have been identified as being critical for the proper training of the observers in order to cope with the collection of information at sea as well as any other technical task during the fishing trials:

- Fishing operation in a longliner (tasks of the crew during setting and hauling of the gear and distribution of the tasks on board the vessels)
- Experimental design for the trials
- Observations tasks and daily data recording
- Fish species identification
- Turtle species identification
- Relevant morphometrics of fish and turtle species
- De-hooking and release of turtles
- Communication means with the project team at land for information on the development of the trials.
- Safety rules

The AZTI observer and AZTI's project coordinator have been onboard the Atlantic (October 2006) and Mediterranean (January 2007) vessels to be chartered in order to learn from the skippers the usual fishing practices as well as to co-ordinate with the skipper the observation tasks. Species identification materials have been collected both for fish species and turtles caught in the Atlantic in order for the observer to get familiar with the species caught in the longline.

A set of *ad-hoc* tools for de-hooking and release of turtles has been already bought by AZTI. Video footage and different printed materials have been acquired which illustrate how to handle turtles caught in a longline in order to minimize any damage to them. Regarding safety conditions at sea, AZTI observers have passed a training course focused on safety conditions on board fishing and oceanographic vessels. The communication facilities of the Atlantic chartered vessel has been requested from the fishing owner for the purpose of the project: e-mail, fax and phone communication are available for communication during the trials.

9.2 Western Mediterranean Fishing Experiments

9.2.1 Meetings with fishing industry (Task 4)

In preparation for the fishing experiments, two trips to Andalucía and Murcia (S and SE Spanish regions where most of the Spanish Mediterranean fishing fleet is based) were carried out by Dr. Esteban Puente (Head of the Fishing Technology Research Area in AZTI and responsible of the AZTI team in the project) between 21^{st} to 28^{th} November 2006 and between 4^{th}-5^{th} January 2007.

The aims of those trips were the same as those presented previously for the Atlantic fleet, and similarly the project, its objectives and methods were presented to industry representatives and discussions followed on the best practical way to carry out relevant tasks of the project, particularly those dealing with the fishing sector (e.g. trials at sea, fisher questionnaire). The collaboration of the Fishing Industry was requested and also the availability of the project team for consultation was also offered to the representatives of the fishing owner associations.

Two fishing owners associations were visited:

Andalucía:
- Pescadores de Carboneras S.C.A./CARBOPESCA -Carboneras/Almería- (interview with Pedro Hernández –manager-)

Murcia:
- Cofradía de Pescadores de Cartagena –Cartagena/Murcia (interview with Antonio Hernández Aguado –chairman-)

As a result of the trip, the main Spanish Mediterranean fishing association (CARBOPESCA) has offered its collaboration to facilitate both the implementation of the skipper's survey on fishing activity and the fishing trials.

9.2.2 Selection and training of observers (Task 12 & 13)

AZTI will rely again on its own staff of observers and technicians to carry out the observation work during the experimental fishing trials in the western Mediterranean. The observer has already been selected and training is ongoing. The same observer training scheme used for the Atlantic trials will be applied to the western Mediterranean and coordinated with the eastern Mediterranean observer training, emphasizing particulars of swordfish fishing in each region, specially those aspects dealing with the use of the "Spanish/traditional" longline whose use is common among the Mediterranean fleet.

9.3 Eastern Mediterranean Fishing Experiments

9.3.1 Meetings with fishing industry (Task 4)

A meeting with the fishing industry took place in the port of Kyllini in Western Peloponnese between the 5^{th} and 6^{th} of December by Dr. Triantaphyllidis, the Eastern Mediterranean Co-ordinator of the project. The specific port was selected because an increased number of fishing boats from this port fish swordfish in the area around Zakynthos, where the majority of sea turtles are encountered in Greece.

The meeting took place with individual fishermen that fish swordfish with drifting longlines

During this meeting, the project was disseminated to vessel owners and skippers, information on the fishing practices were collected and practical issues referring to the implementation of the trials were discussed. The first draft of the questionnaire was also tested during this meeting. The main outcomes relating to their fishing practices that were produced from this meeting are:

- In accordance with current Greek legislation, the drifting long line fishery is allowed between the first day of February and the last day of September. However, they are practising the fishery year round as they move to international waters (i.e. outside the limit of 6 n.m.) also.
- During summer squid-type bait is used more often as it is more resistant to predators (turtles included). During winter mackerel is used instead. A major factor for the bait choice is the actual price that they can find during a certain period, as baiting cost is a significant factor of the fishing activity.
- In the area of Kyllini, one day trips are the usual practise. They set the longlines from 16:00 – 17:00 to 19:00 – 20:00, leaving the drifting gear at sea, they come back to the port and they start retrieving at dawn. Larger vessels might operate for 2-3 days.
- According to the actual legislation the vessels that may apply for this license must have an orientation only to longlines. The vessels that wish to operate drifting longlines have to be larger than 12 m and they have to prove that they have operated this fishery systematically in the past.
- In Greece, two types of long lines are used The first type is the one with the well-known line basket while the second type, the more modern, is the so-called “Karoula”. This gear requires a winch and is used in larger vessels. Most of the fishermen in smaller vessels use the classic basket long line which is the traditional one.
- The baskets carry approximately 200 hooks. The fishermen usually drop three baskets of longlines attached to each other thus forming in this way a longline set of approximately 600 hooks. The longline is kept fishing in the desired depth using floats. The number of branch lines between two floats, is varying between three and one branch lines.
- Apart from the technical differences of the two fishing gears, the deployments of the gear using the “Karoula” winch takes place at a relatively high boat speed (7 knots) while the deployment of the basket line gear takes place at lower speed (4 knots).
- The Greek drifting longline fishery is mainly targeting one species, the swordfish. Occasionally, some other pelagic species are caught like bluefin tuna and dogfishes. The drifting longline fishing fleet was consisted of 495 vessels in 1998 with average power of 40,7 Kw and 6,6 GRT but in 2006 987 vessels have this licence with average power of 49,18 Kw and 8,09 GRT. This is due to the fact that since June 1999, a special license is required in order to operate swordfish fishery. This new regulation was activated in 1999 and further restricted the longline fishery. The license is issued on an annual basis and the large pelagic fishing fleet becomes a dynamic fleet in terms of size. According to the actual legislation the vessels that may apply for this license must have an orientation only to longlines. The vessels that wish to operate drifting longlines have to be larger than 12 m and they have to prove that they have operated this fishery systematically in the past. This regulation changed again in 2004, allowing vessels smaller than 12 m to issue such a licence.

- The fishing effort of the drifting longline fleet is monitored on a monthly basis by the Marine Information Systems team of the former Institute of Marine Biology in Crete (now Hellenic Centre for Marine Research - HCMR) since 1995. Table 33 shows the characteristics of the fleet as well as the estimated total fishing effort per year for the last eleven years (HCMR data). The effort is expressed in days at sea per year. The estimated catches are ICCAT data.

Table 33 Estimated catches from ICCAT data.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Number of vessels	500	495	495	321	337	333	327	299	565	546	987
Average Power (Kw)	43,4	41,7	40,7	78,4	77,3	76,49	76,60	76,03	47,54	46,02	49,18
Average Capacity (GRT)	7,1	6,8	6,6	13,5	13,3	12,01	12,03	12,05	7,32	7,42	8,09
Average Length	8,3	8,3	8,3	11,5	11,5	11,42	11,41	11,38	9,69	9,68	9,94
Average Effort (Days/Year)	132,5	123,2	137,7	132,4	139,4	191,9	196,4	197,8	183,6	119,6	NA
Estimated catches (in tons, ICCAT data)	1237	750	1650	1520	1960	1730	1680	1230	1120	1311	NA

9.3.2 Vessel charter and procurement of gear (Task 10)

The initial link with the fishing vessel that will be involved in the fishing trial for Eastern Mediterranean was made during the preparation of the proposal for this project. Further contacts were developed with the owner and skipper of the vessel in November and December 2006 in order to arrange all details for the chartering of his commercial fishing vessel to carry out the experimental fishing trials.

The vessel will be fishing swordfish in the Ionian Sea, in the area that extends western and southern of Kyllini, up to the island of Zakynthos and the islands of Othonoi. The vessel is usually fishing swordfish in this area and the expected likelihood of incidental catch of turtles is very high, due to the high density of sea turtles encountered in this geographical location. It will be chartered for 60 fishing days from the end of May until the end of August.

Chartering of the vessel is arranged on the basis that the crew will fish as normal, adopting modified gear and bait as instructed, and will be entitled to keep the target species' catch. Any turtles that are caught alive will be released.

The vessel's name is AGIOS NIKOLAOS and it is 14,88 meters long and has an engine has power of 150 hp. It is the type of long line equipped with a winch. The main changes that will be introduced include:

- Setting of two sets of linear lines, each one with approximately 500-600 hooks. As common practice, the vessel set only one line so far.
- The replacement and specific configuration of the hooks and the bait. The vessel has been fishing only with J hooks, a number of which will be replaced now with circle hooks of two different sizes and offsets and they will also be configured in a specific way. Finally, the vessel during the summer used to fish only with squid-type bait, while now, the second set will be replaced with mackerel.

Equipment such as hooks, fishing line, floats, de-hooking and line cutting tools, will be provided for the fishing trials. The skipper provided the details and characteristics of the commonly used gear which are presented in **Error! Reference source not found.**, **Error! Reference source not found.**.

In order to identify the most common hook used for swordfish fishing in Greece, interviews took place with the main suppliers for fishing gear. The suppliers were further identified in such a way as to present a broad coverage of geographic locations from where fishermen get their gear (Athens – Central Greece, Thessaloniki – Northern Greece and Chania – Southern Greece).

The main outcome that resulted was that for swordfish fishing the most common hooks are from the brand Mustad, type 2330 sizes 2 and 3 and type 2331 sizes 2 and 3 (Note: size number 1 is the biggest hook and the hook is getting smaller when the size increases) (See **Error! Reference source not found.**, 6.2 Commonly used hooks).

The suppliers further indicated that the size that fishermen obtain depends also with the time period. When younger and therefore smaller swordfish are available, fishermen ask for the smaller size and vice versa.

Additionally there is a preference for type 2131 as it is shorter and therefore it requires a lesser amount of bait since, as the suppliers mentioned, there are not so many big swordfish available in recent years.

9.3.3 Selection and training of observers (Task 12 and 13)

Initial actions have been made for the identification of appropriate observers. A pool of observers has already been detected, mainly with focus in fisheries and general knowledge on marine conservation issues. The selection of the most appropriate candidate will be accomplished after the contract with the fishing vessel owner is signed for practicality issues.

9.4 Coordination of observer training

Previous sections have described the individual training that observers will receive for the different experiments. We are, however, keen that observer training is coordinated between the different experiements. To this end we have produced common observer guidance notes for training purposes, and a common data recording format.

There will be a 1 day workshop prior to departure for the Atlantic trial, for database training with the MRAG database designer. The location for this is yet to be determined.

9.5 Experimental fishing protocol

9.5.1 Protocol design verification (Task 5)

The second consortium meeting In January 2007 allowed for discussion of the level of standardisation feasible amongst the three regional trials with respect to data collection protocols and control and experimental hooks to be tested. Data collection protocols and data sheets were discussed in detail with respect to practicalities on board the different vessels to be charted for the regional trials and the feasibility of the data collection protocols assigned to both observers and crew members. The meeting enabled feedback from the Spanish observers who will be gathering data on board the Spanish vessels in the Atlantic and Western Mediterranean trials.

In order to be as comparable as possible, the three experiments will use the same test hooks and bait types. Test hooks for all three regional trials will be purchased from the same supplier. However, on order to reflect the usual fishing practice in each region, slight differences in traditional gear configuration will be maintained for number of hooks per puente (described as magazine in the tender), length of line, hook spacing and the control hook.

9.5.2 Observer protocol preparation and database construction (Tasks 7 and 11)

Preparation of the data collection protocols has been carried out concurrently with the construction of the database, in order to determine key fields and ensure that key data requirements are incorporated to ensure effective statistical analysis of the key factors and variables.

Draft observer protocols have been designed specifically for the trials, but compared with a number of international observer program protocols for consistency. They consist of the following data entry sheets:

- Longline Gear Description Records
- Longline Setting Records: time, position, environmental conditions, bait
- Longline Hauling Records: time, position, environmental conditions, bait
- Longline Hook Survey Recording Form: target and by-catch data
- Turtle Biological Data and Catch Details Recording Forms
- Sea Mammal and Sea Bird Bycatch Data Recording Form
- Photo ID Recording forms

Corresponding guideline notes are currently being prepared for each set of data to be recorded by the observer.

Microsoft access is being used to provide the database architecture, the entity relationship diagram of which is shown in Figure 76.

The diagram only shows the tables that hold data relevant to the analysis. The actual database also contains a number of lookup tables that hold information such as species codes. The ERD shown here also only shows the attributes (fields) that are key to the tables or involved in relationships. The attributes that are underlined and have a PK next to them are the primary keys for that table. Attributes that have a FK next to them are foreign keys, and so are involved in a relationship with another table. The direction of the arrow in a relationship indicates the cardinality of the relationship. The arrow points to the table that will only have one record for the attribute, were as the other table many have many records, for example during one haul there may be more that one type species in the catch so that the relationship between haul and catch is one haul record to many catches.

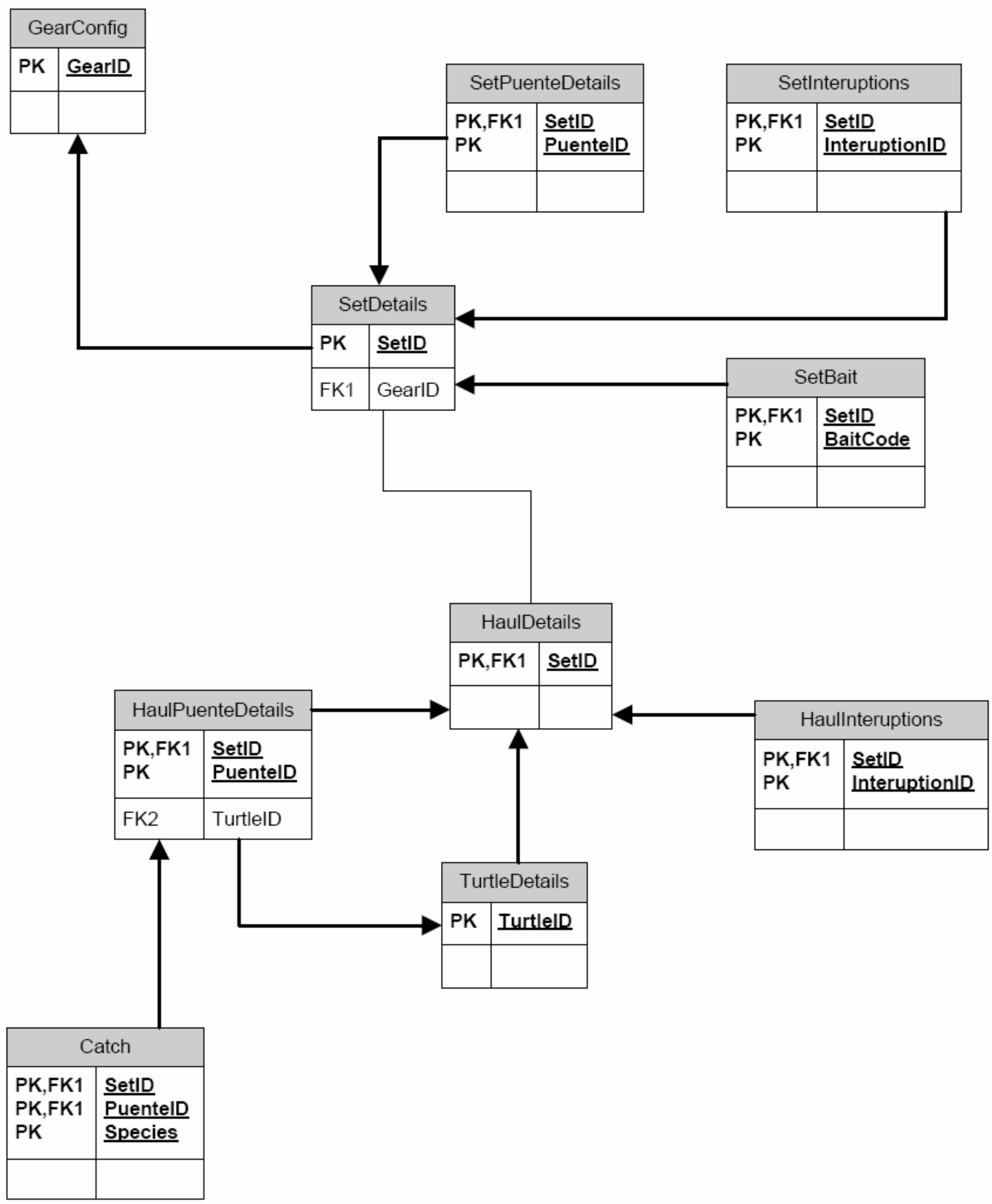


Figure 76 Experimental Database ERD

The database has data entry forms that speed up data entry, Information from different table can be entered on the same form, and attributes that are involved in relationships will be filled in automatically in the child table to ensure that the referential integrity is maintained at all times. Referential integrity is also ensured by having cascade updates and deletions applied so that no orphan records can be created. Were appropriate there is data validation of data entry to ensure that impossible values are not entered, for example values over 180 can not be entered in the longitude attributes.

As mentioned in 9.1.3, training materials include videos for safe handling of turtles and removal of fishing gear provided on the SEFSC and NOAA websites (http://www.sefsc.noaa.gov/) and printed guidelines include relevant exerts from the following documents:

1. Epperly, S., Stokes, L.., and S. Dick (2004). Careful release protocols for sea turtle release with minimal injury. NOAA Technical Memorandum NMFS-SEFSC-524. 42p.
2. European Commission DG Fish (1999) Assessing marine turtle bycatch in European drifting longline and trawl fisheries for identifying fishing regulations. Project 98/008. Protocol Manual 1999. 16p
3. Carpenter, K.E. (ed.) The living marine resources of the Western Central Atlantic. Volume 3: Bony fishes part 2 (Opistognathidae to Molidae), sea turtles and marine mammals. FAO Species Identification Guide for Fishery Purposes and American Society of Ichthyologists and Herpetologists Special Publication No. 5. Rome, FAO. 2002. pp. 1375-2127 y4162e54.pdf for Swordfish species; y4162e73.pdf for turtles
4. Fischer, W., Bianchi G. & W.B. Scott (eds). 1981 FAO species identification sheets for fishery purposes. Eastern Central Atlantic; fishing area 34, 47 (in part). Canada Funds-in-Trust. Ottawa, Department of Fisheries and Oceans Canada, by arrangement with the Food and Agriculture Organization of the United Nations, vols. 1-7:pag.var.
5. Fischer, W., M.-L. Bauchot et M. Schneider (rédac-1987 teurs), Fiches FAO d_identification desespèces pour les besoins de la péche. (Révision 1). Méditerranée et mer Noire.Zone de péche 37. Volume II. Vertébrés. Publication préparée par la FAO, résultat d'un accord entre la FAO et la Commission des Communautés Européennes (Projet GCP/INT/422/EEC) financée conjointement par ces deux organisations. Rome, FAO, Vol.2:761-1530.

9.6 Project website

Initial content and design for the project website has been drafted on an internal website (www.turtles.mrag.net) for clearance from DG-Fisheries and Commission officials for appropriateness. A word version of the text can be found in **Error! Reference source not found.**. The domain name http://www.turtle.eu is currently available, but requires clearance by the Commission before it is purchased and any material is posted live on the site. Once the website content has been finalised, translations into Spanish, Greek and Italian will be provided on the site.

10 Appendix 2: Statistical Analysis Methods

10.1 Treatment effects on turtle catch

The GLM routine was modelled within the R statistical environment which maximises the binomial likelihood over all observations:

7. $$P\left(T \mid H, \rho^t_{o,b,h}\right) = \prod_{o=1}^{n^o} \prod_{b=1}^{n^b} \prod_{h=1}^{n^h} \binom{H_{o,b,h}}{T_{o,b,h}} \cdot \left(\rho^t_{o,b,h}\right)^{T_{o,b,h}} \cdot \left(1-\rho^t_{o,b,h}\right)^{H_{o,b,h}-T_{o,b,h}}$$

where *T* are the number of turtles observed, *H* is the number of hooks set, *n* refers to the total number of categories of each effect type. Again, the subscripts *o*, *b*, and *h* refer to the ocean region, bait type and hook type.

10.1.1.1 Treatment effects on anatomical hooking location of turtles caught

The multinomial model states that the probability of hooking a turtle in location L_j (internal, mouth and external) given it is caught by hook type *h* with bait type *b* is:

8. $$P\left(L^{obs}_{b,h} = L^{\exp}_j\right) = \frac{\exp\left(\kappa_{b,h,j}\right)}{\sum_{i=1}^{n^L} \exp\left(\kappa_{b,h,j}\right)}$$

Where the predictor *κ* is determined by a linear combination of effect terms:

9. $$\kappa_{b,h,j} = \nu_{i,j} + \nu_{b,j} + \nu_{h,j}$$

Note that there are a complete series of effect terms for the intercept, bait type and hook type for each response category (hooking location).

10.1.1.2 Treatment effects on size of turtles caught

Loggerhead turtle straight carapace length data were modelled by the linear combination of categorical effects corresponding to ocean, bait and hook types using a lognormal GLM. The likelihood function maximised was:

10. $$P\left(L^t \mid \mu, \sigma\right) = \prod_{o=1}^{n^o} \prod_{b=1}^{n^b} \prod_{h=1}^{n^h} \prod_{r=1}^{n^r} \left(\frac{1}{L^t_{o,b,h,r} \cdot \sigma \cdot \sqrt{2\pi}} \exp\left(- \frac{\left(\log\left(L^t_{o,b,h,r}\right) - \mu_{o,b,h}\right)^2}{2\sigma^2} \right) \right)$$

where L^t is the length of each turtle in replicate *r* of ocean *o,* bait type *b,* and hook type *h.* The logarithm of the median length of turtles for each combination of treatments is predicted by the linear model:

10.1.1.3 Treatment effects on target catch, swordfish

The joint likelihood function of the delta lognormal model to be maximised was:

11.

$$P\left(X,W \mid S,\eta,\sigma,\rho^{s}_{o,b,h}\right)=\prod_{o=1}^{n^o}\prod_{b=1}^{n^b}\prod_{h=1}^{n^h}\binom{S_{o,b,h}}{X_{o,b,h}}\cdot\left(\rho^{s}_{o,b,h}\right)^{X_{o,b,h}}\cdot\left(1-\rho^{s}_{o,b,h}\right)^{S_{o,b,h}-X_{o,b,h}}\cdot$$

$$\prod_{r=1}^{n^r}\left(\frac{1}{W^{s}_{o,b,h,r}\cdot\sigma\cdot\sqrt{2\pi}}\exp\left(-\frac{(\log(W^{s}_{o,b,h,r})-\eta_{o,b,h})^2}{2\sigma^2}\right)\right).$$

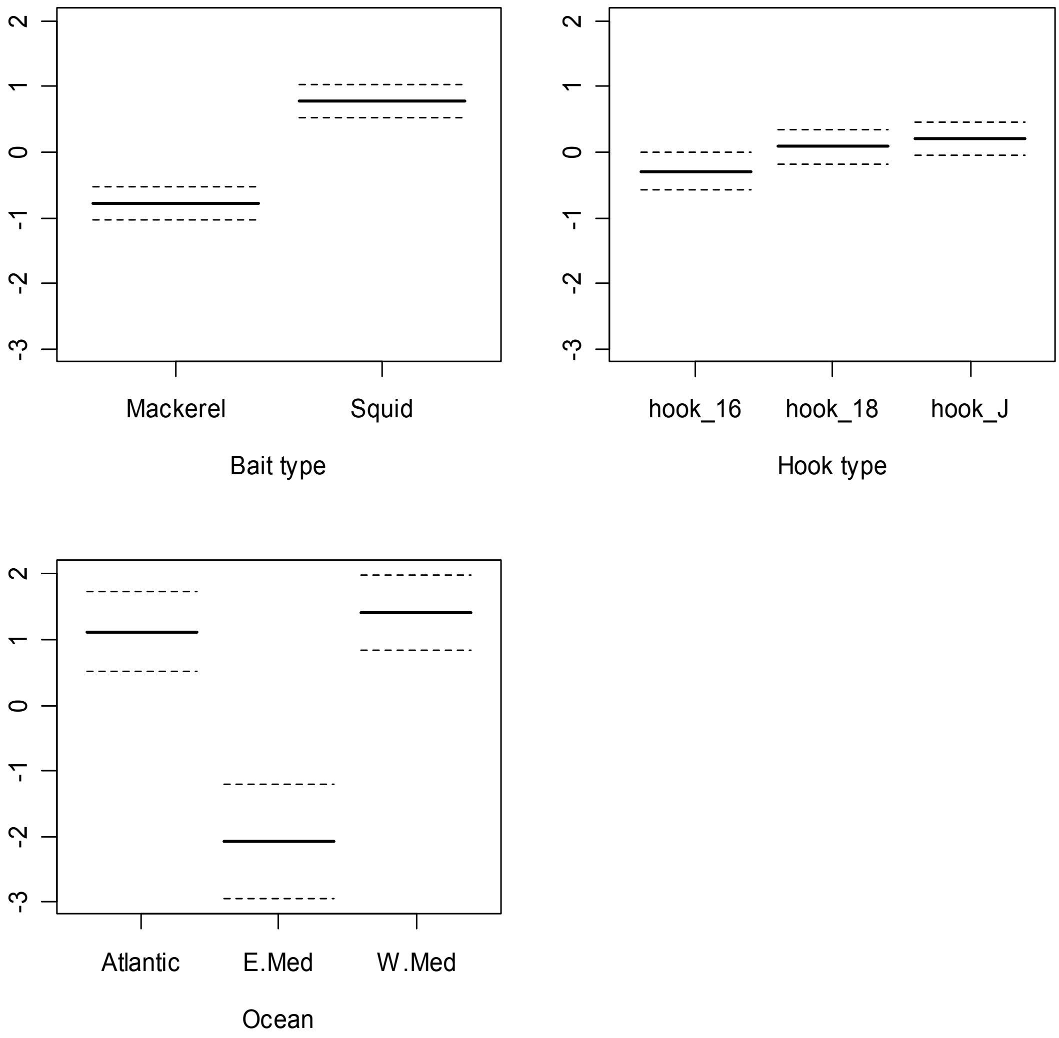
where *X* are the number of swordfish (*Xiphias* spp) caught out of *S* sets, *W* is the average weight per hook of swordfish for each replicate set *r.*

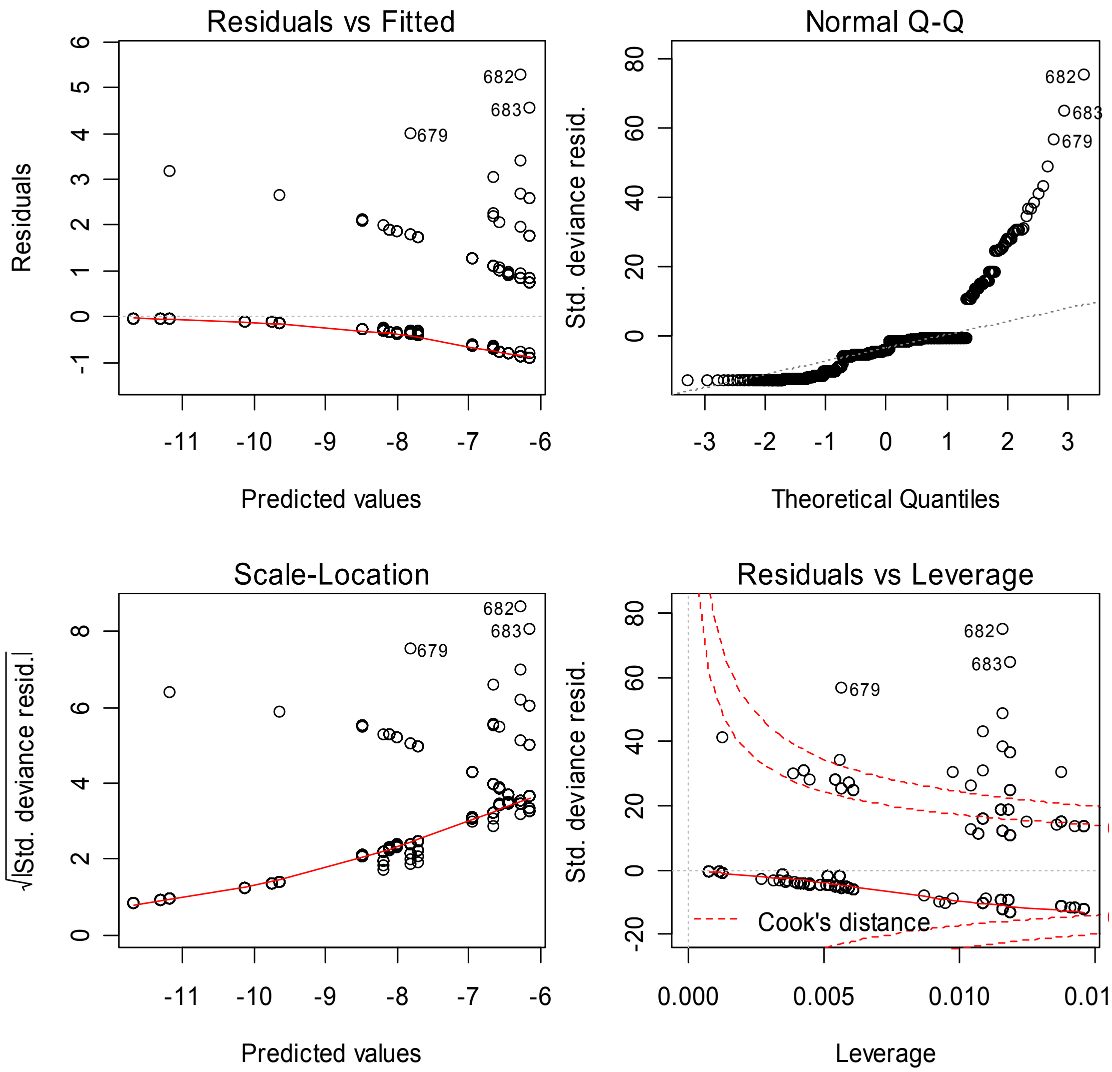
11 Appendix 3: Detailed statistical output

11.1 Probability of turtle capture over all regions.

```
Call:
glm(formula = Tres ~ BaitCode + HookType + DataBase, family = binomial(link
= "logit"),
    contrasts = list(BaitCode = "contr.sum", HookType = "contr.sum",
        DataBase = "contr.sum"))

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.92495  -0.42616  -0.29782  -0.06797   5.27048

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -8.38395    0.25858 -32.422  < 2e-16 ***
BaitCode1   -0.77535    0.12305  -6.301 2.95e-10 ***
HookType1   -0.29063    0.14499  -2.004 0.045023 *
HookType2    0.08626    0.13133   0.657 0.511291
DataBase1    0.96368    0.26329   3.660 0.000252 ***
DataBase2   -2.22149    0.47602  -4.667 3.06e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 579.04  on 929  degrees of freedom
Residual deviance: 441.08  on 924  degrees of freedom
AIC: 634.49

Number of Fisher Scoring iterations: 8


Full coefficients are

(Intercept):      -8.383953
BaitCode:          Mackerel       Squid
                  -0.775346    0.775346
HookType:           hook_16     hook_18      hook_J
                -0.29062732  0.08626213  0.20436518
DataBase:          Atlantic       E.Med       W.Med
                  0.9636793  -2.2214906   1.2578114


The odds ratios:
Full coefficients are

(Intercept):    0.0002285049
BaitCode:           Mackerel     Squid
                   0.4605444 2.1713431
HookType:            hook_16   hook_18    hook_J
                   0.7477943 1.0900920 1.2267461
DataBase:           Atlantic     E.Med     W.Med
                   2.6213233 0.1084473 3.5177140




Analysis of Deviance Table
```

```
Model: binomial, link: logit

Response: Tres

Terms added sequentially (first to last)


          Df Deviance Resid. Df Resid. Dev P(>|Chi|)
NULL                        929     579.04
BaitCode   1    52.80       928     526.24 3.694e-13
HookType   2     4.61       926     521.63      0.10
DataBase   2    80.55       924     441.08 3.222e-18
```

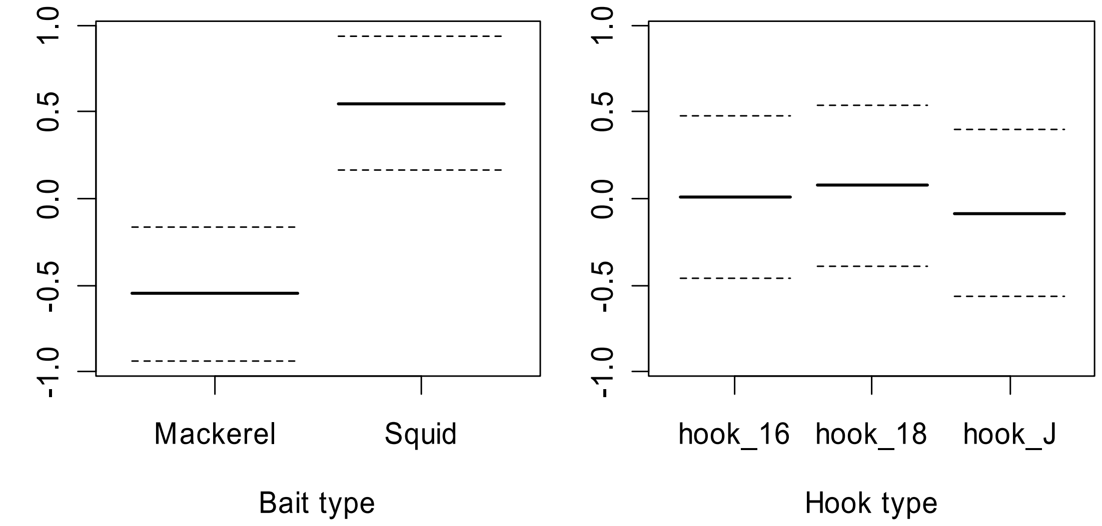




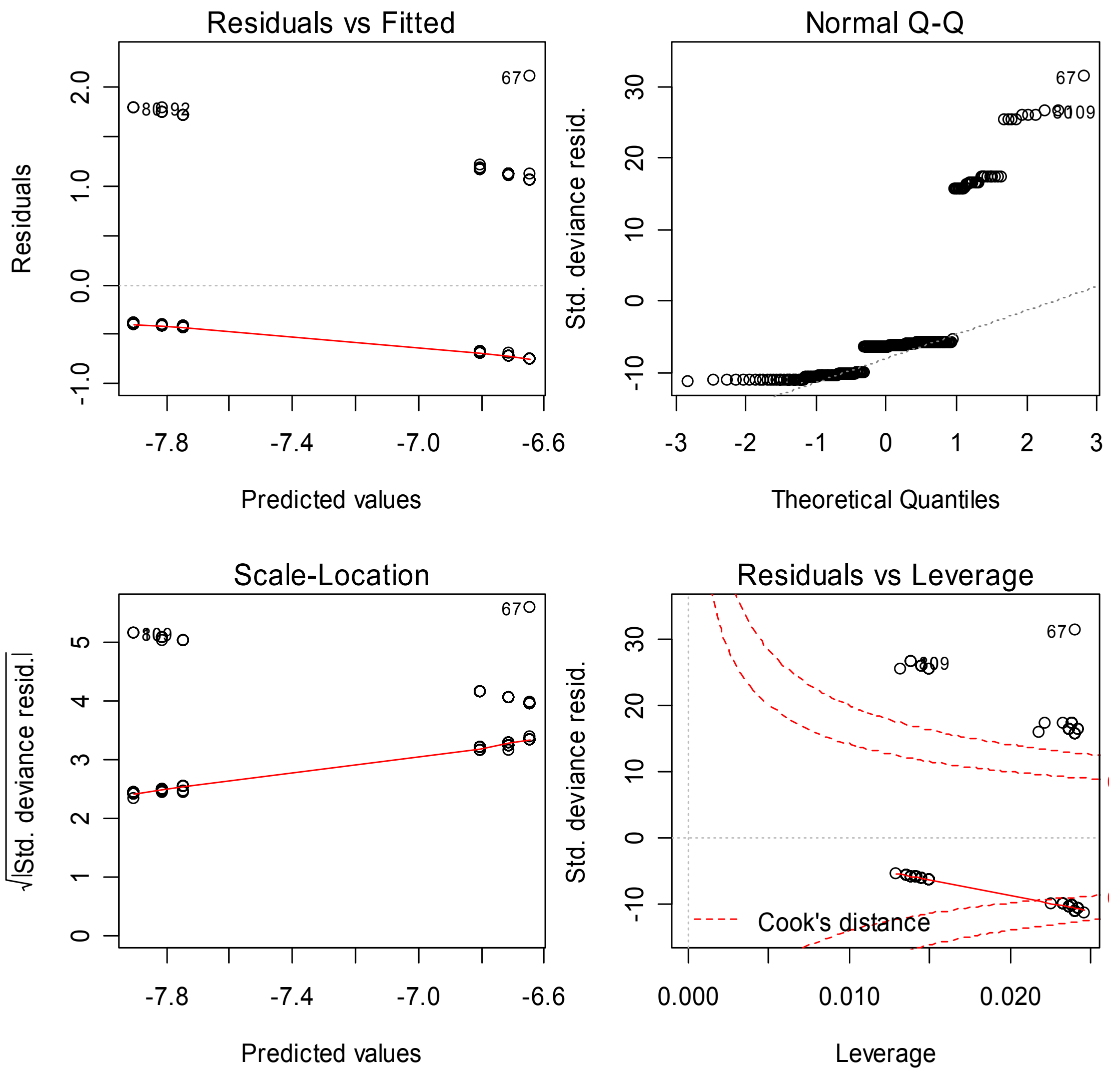
Residuals vs Fitted
Residuals
Predicted values
682
683
679
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Residuals vs Leverage
Cook's distance
Leverage

11.2 Probability of turtle capture for the Atlantic.

```
Call:
glm(formula = Tres ~ B + H, family = binomial(link = "logit"),
    contrasts = list(B = "contr.sum", H = "contr.sum"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.7560  -0.6955  -0.4317  -0.3940   2.1093

Coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept) -7.269725   0.192852 -37.696  < 2e-16 ***
B1          -0.549046   0.192509  -2.852  0.00434 **
H1           0.008705   0.236096   0.037  0.97059
H2           0.075241   0.231525   0.325  0.74520
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 130.05  on 209  degrees of freedom
Residual deviance: 120.50  on 206  degrees of freedom
AIC: 198.95

Number of Fisher Scoring iterations: 6


Full coefficients are

(Intercept):       -7.269725
B:                  Mackerel        Squid
                  -0.5490462    0.5490462
H:                   hook_16      hook_18       hook_J
                 0.008705154  0.075241080 -0.083946235


The odds ratios:
Full coefficients are

(Intercept):    0.0006963035
B:                  Mackerel     Squid
                   0.5775003 1.7316007
H:                   hook_16   hook_18    hook_J
                   1.0087432 1.0781440 0.9194807



Analysis of Deviance Table

Model: binomial, link: logit

Response: Tres

Terms added sequentially (first to last)


      Df Deviance Resid. Df Resid. Dev P(>|Chi|)
NULL                    209    130.053
B      1    9.398       208    120.655     0.002
H      2    0.152       206    120.503     0.927
```



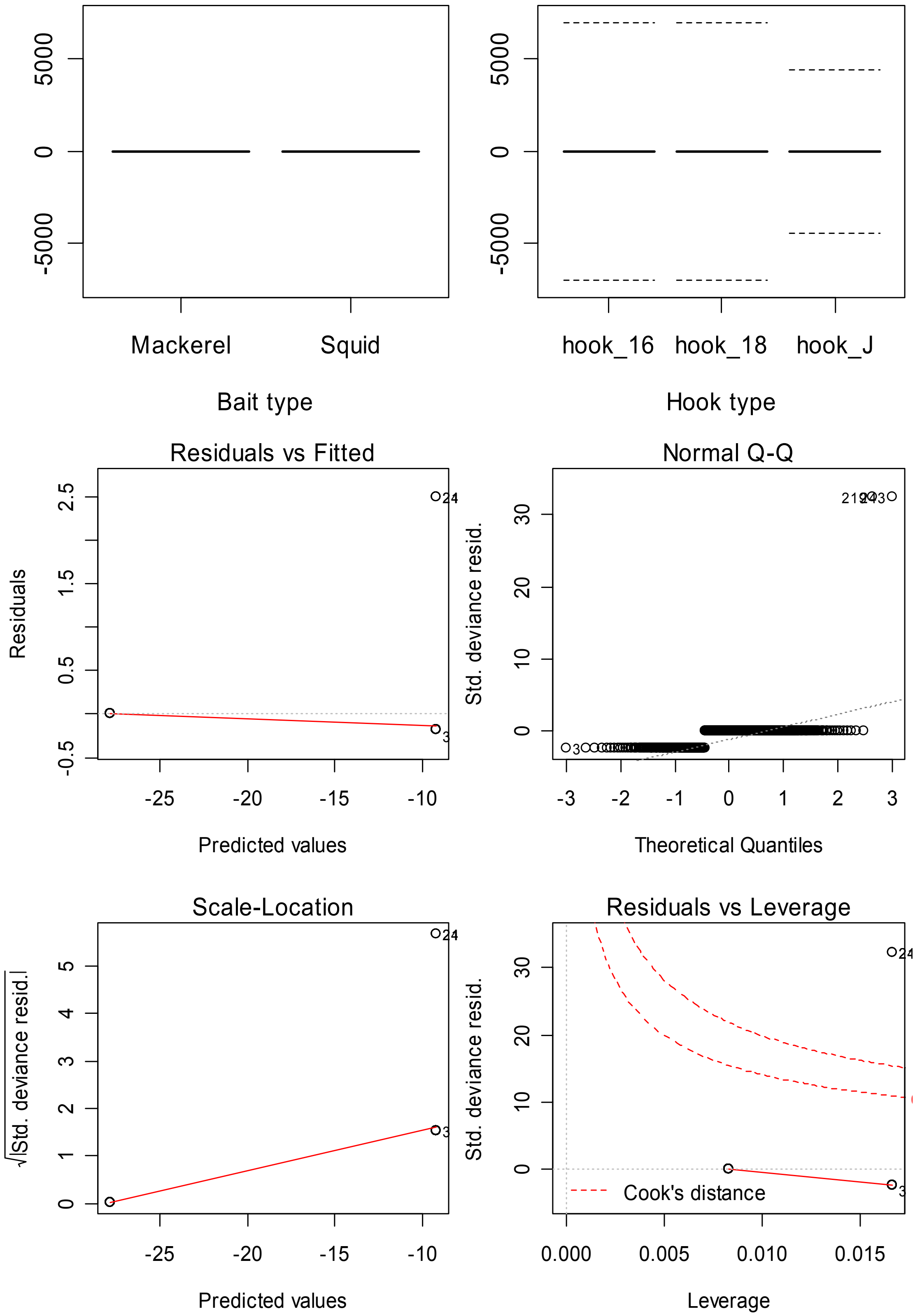
Mackerel
Squid
Bait type
hook_16
hook_18
hook_J
Hook type



Residuals vs Fitted
Residuals
Predicted values
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. deviance resid.
Cook's distance
Leverage

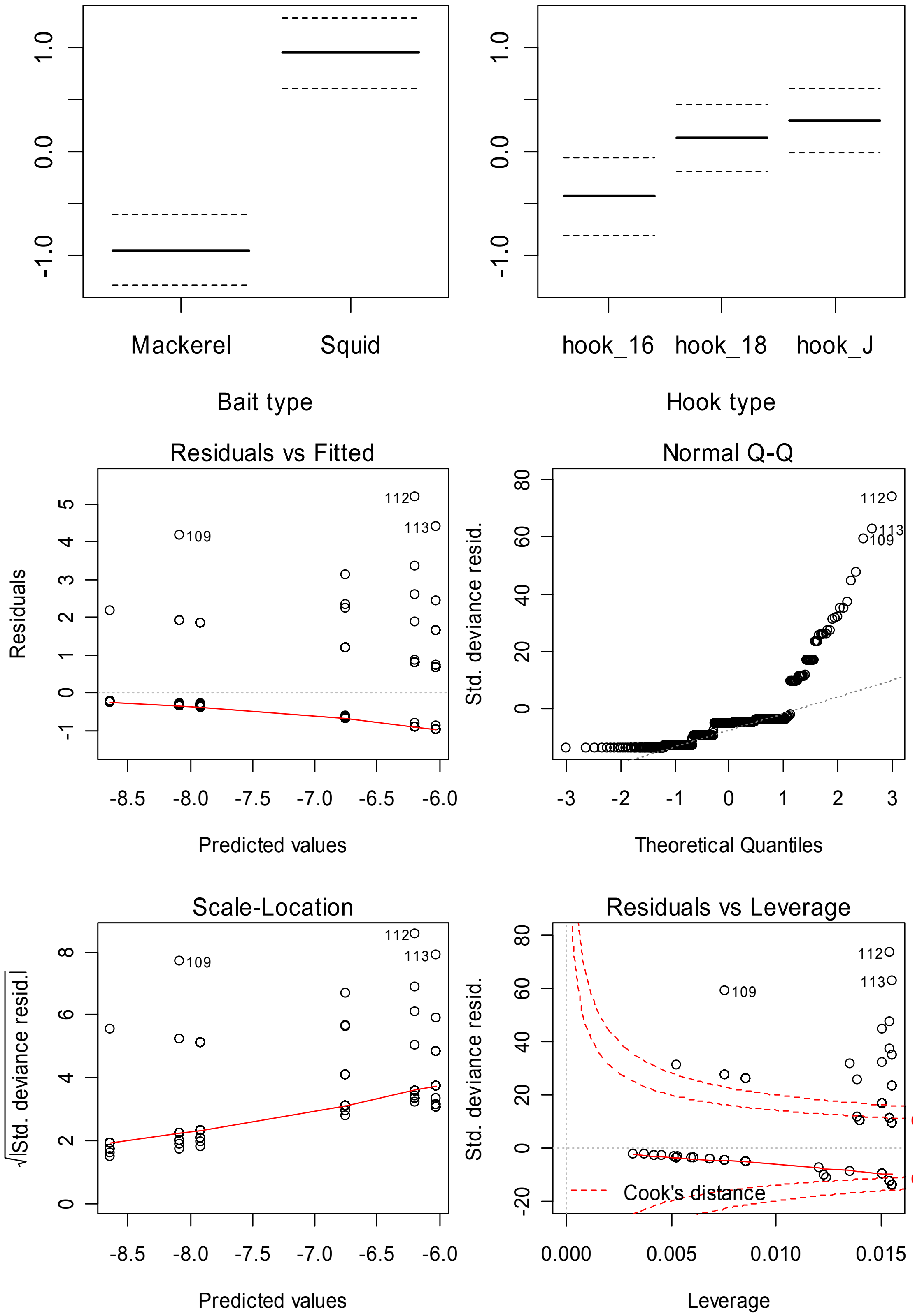
11.3 Probability of turtle capture for the eastern Mediterranean.

```
Call:
glm(formula = Tres ~ B + H, family = binomial(link = "logit"),
    contrasts = list(B = "contr.sum", H = "contr.sum"))

Deviance Residuals:
       Min          1Q      Median          3Q         Max
-1.826e-01  -1.826e-01  -1.664e-05  -1.664e-05   2.496e+00

Coefficients:
              Estimate Std. Error  z value Pr(>|z|)
(Intercept) -2.161e+01  2.219e+03   -0.010    0.992
B1          -1.061e-19  7.071e-01 -1.5e-19    1.000
H1          -6.192e+00  3.508e+03   -0.002    0.999
H2          -6.222e+00  3.508e+03   -0.002    0.999

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 20.824  on 359  degrees of freedom
Residual deviance: 16.389  on 356  degrees of freedom
AIC: 28.377

Number of Fisher Scoring iterations: 22



Full coefficients are

(Intercept):        -21.61453
B:                   Mackerel         Squid
                -1.061409e-19  1.061409e-19
H:                    hook_16       hook_18    hook_J
                    -6.192359     -6.221984 12.414343


The odds ratios:
Full coefficients are

(Intercept):    4.101360e-10
B:                  Mackerel        Squid
                           1            1
H:                   hook_16      hook_18       hook_J
                2.044996e-03 1.985303e-03 2.463093e+05



Analysis of Deviance Table

Model: binomial, link: logit

Response: Tres

Terms added sequentially (first to last)


      Df  Deviance Resid. Df Resid. Dev P(>|Chi|)
NULL                     359    20.8241
B      1 2.487e-14       358    20.8241    1.0000
H      2    4.4348       356    16.3893    0.1089
```


5000
0
-5000
Mackerel
Squid
Bait type
hook_16
hook_18
hook_J
Hook type
Residuals vs Fitted
Residuals
Predicted values
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. deviance resid.
Cook's distance
Leverage

11.4 Probability of turtle capture for the western Mediterranean.

```
Call:
glm(formula = Tres ~ B + H, family = binomial(link = "logit"),
    contrasts = list(B = "contr.sum", H = "contr.sum"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.9822  -0.8850  -0.3816  -0.2656   5.1773

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -7.2688     0.1733 -41.942  < 2e-16 ***
B1           -0.9460     0.1695  -5.580 2.40e-08 ***
H1           -0.4285     0.1875  -2.285   0.0223 *
H2            0.1319     0.1619   0.815   0.4153
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 347.42  on 359  degrees of freedom
Residual deviance: 294.43  on 356  degrees of freedom
AIC: 409.41

Number of Fisher Scoring iterations: 6


Full coefficients are

(Intercept):     -7.268765
B:                Mackerel      Squid
                -0.9460043  0.9460043
H:                 hook_16    hook_18     hook_J
                -0.4284737  0.1319226  0.2965511


The odds ratios:
Full coefficients are

(Intercept):    0.0006969722
B:                  Mackerel     Squid
                   0.3882894 2.5753986
H:                   hook_16   hook_18    hook_J
                   0.6515027 1.1410200 1.3452113

Analysis of Deviance Table

Model: binomial, link: logit

Response: Tres

Terms added sequentially (first to last)


      Df Deviance Resid. Df Resid. Dev P(>|Chi|)
NULL                    359     347.42
B      1    46.65       358     300.77 8.472e-12
H      2     6.35       356     294.43      0.04
```

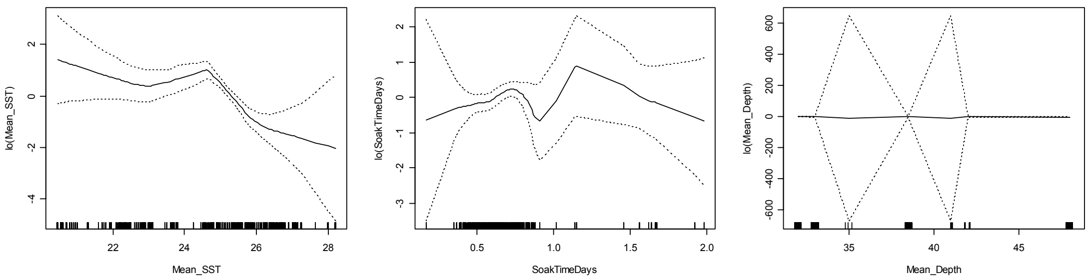


1.0
0.0
-1.0
Mackerel
Squid
Bait type
hook_16
hook_18
hook_J
Hook type
Residuals vs Fitted
Residuals
Predicted values
112
113
109
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. deviance resid.
Cook's distance
Leverage

11.5 The effect of other factors on the probability of capturing a turtle

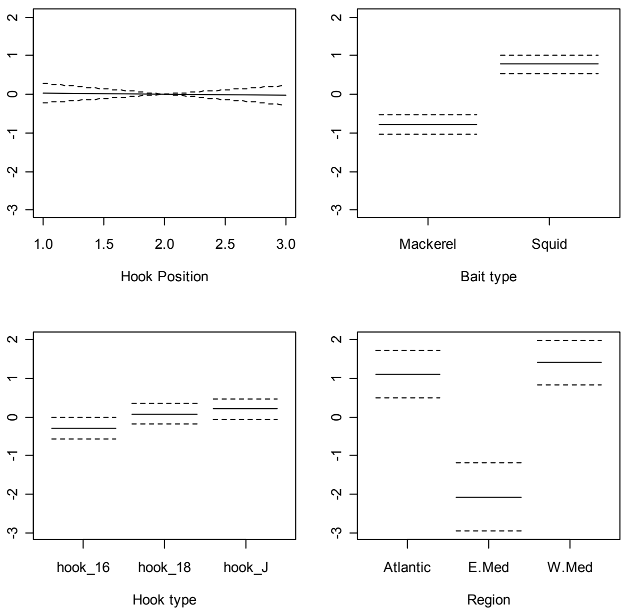
```
Call:
glm(formula = Tres ~ poly(Mean_SST,3) + poly(SoakTimeDays,3) +
poly(Mean_Depth,3) + DataBase + BaitCode + HookType, family = binomial(link
= "logit"))

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.48605  -0.48055  -0.24404  -0.01909   4.00301

Coefficients (based on linear model):
                Estimate Std. Error z value Pr(>|z|)
(Intercept)     15.85782    3.91447   4.051 5.10e-05 ***
Mean_SST        -0.93326    0.15593  -5.985 2.16e-09 ***
SoakTimeDays     0.25182    0.35940   0.701 0.483514
Mean_Depth      -0.08184    0.03560  -2.299 0.021528 *
DataBaseE.Med   -3.84686    0.84587  -4.548 5.42e-06 ***
DataBaseW.Med    2.36085    0.66443   3.553 0.000381 ***
BaitCodeSquid    1.58598    0.24642   6.436 1.23e-10 ***
HookTypehook_18  0.37782    0.24536   1.540 0.123600
HookTypehook_J   0.49649    0.23990   2.070 0.038492 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 579.04  on 929  degrees of freedom
Residual deviance: 396.78  on 921  degrees of freedom
AIC: 596.2

Number of Fisher Scoring iterations: 9


Full coefficients are

(Intercept):        15.85782
Mean_SST:         -0.9332556
SoakTimeDays:      0.2518151
Mean_Depth:      -0.08183623
DataBase:           Atlantic     E.Med     W.Med
                    0.000000 -3.846858  2.360845
BaitCode:           Mackerel     Squid
                    0.000000  1.585979
HookType:            hook_16   hook_18    hook_J
                   0.0000000 0.3778212 0.4964943

Analysis of Deviance Table

Model: binomial, link: logit

Response: Tres

Terms added sequentially (first to last)


              Df Deviance Resid. Df Resid. Dev P(>|Chi|)
NULL                            929     579.04
Mean_SST       1     3.04       928     576.00      0.08
SoakTimeDays   1     0.82       927     575.18      0.37
Mean_Depth     1     2.07       926     573.11      0.15
DataBase       2   116.64       924     456.47 4.689e-26
```

BaitCode	1	55.01	923	401.45	1.198e-13
HookType	2	4.67	921	396.78	0.10



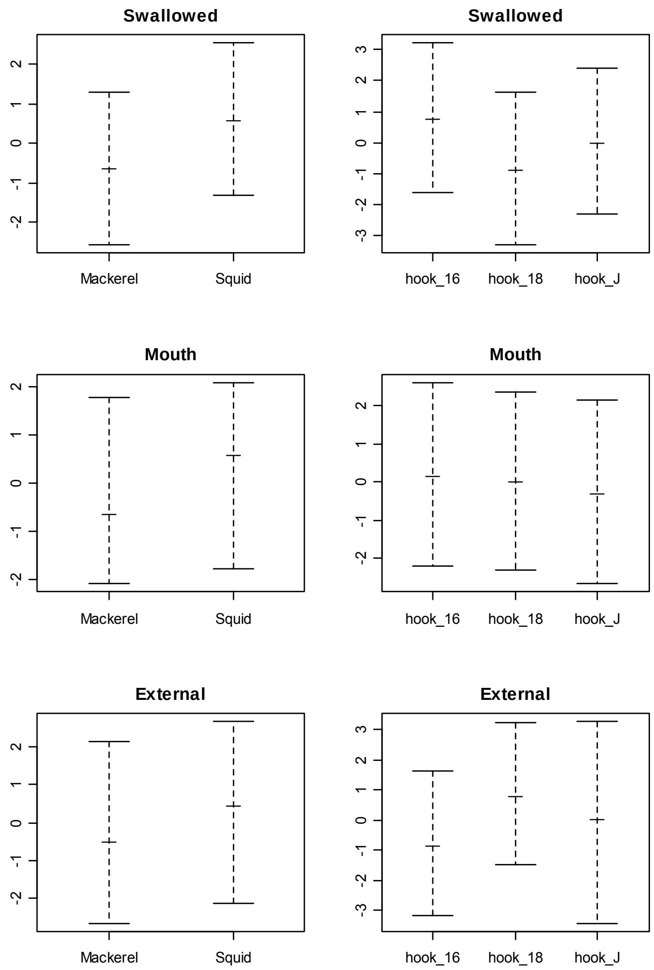
11.6 The effect of hook position on the probability of turtle capture

```
Call:
glm(formula = TPres ~ HP + B + H + O, family = binomial(link = "logit"))

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.59225  -0.31699  -0.17630  -0.06197   4.32529

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -8.43031    0.38206 -22.065  < 2e-16 ***
HP          -0.03123    0.12522  -0.249    0.803
BSquid       1.55069    0.24609   6.301 2.95e-10 ***
Hhook_18     0.37689    0.24531   1.536    0.124
Hhook_J      0.49499    0.23984   2.064    0.039 *
OE.Med      -3.18517    0.72612  -4.387 1.15e-05 ***
OW.Med       0.29413    0.20204   1.456    0.145
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 775.20  on 2789  degrees of freedom
Residual deviance: 637.18  on 2783  degrees of freedom
AIC: 850.1

Number of Fisher Scoring iterations: 9

Full coefficients are

(Intercept):      -8.430307
HP:              -0.03122901
B:                 Mackerel      Squid
                   0.000000   1.550693
H:                  hook_16    hook_18     hook_J
                  0.0000000  0.3768897  0.4949928
O:                 Atlantic      E.Med      W.Med
                  0.0000000 -3.1851701  0.2941323
```



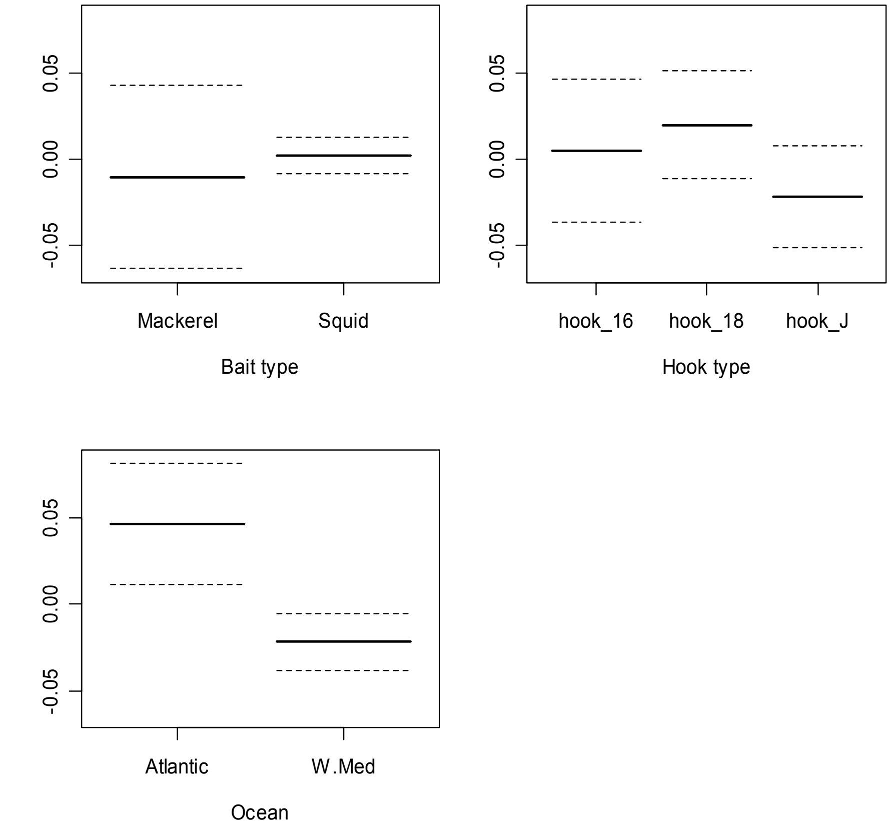
11.7 Multinomial modelling of anatomical hooking location

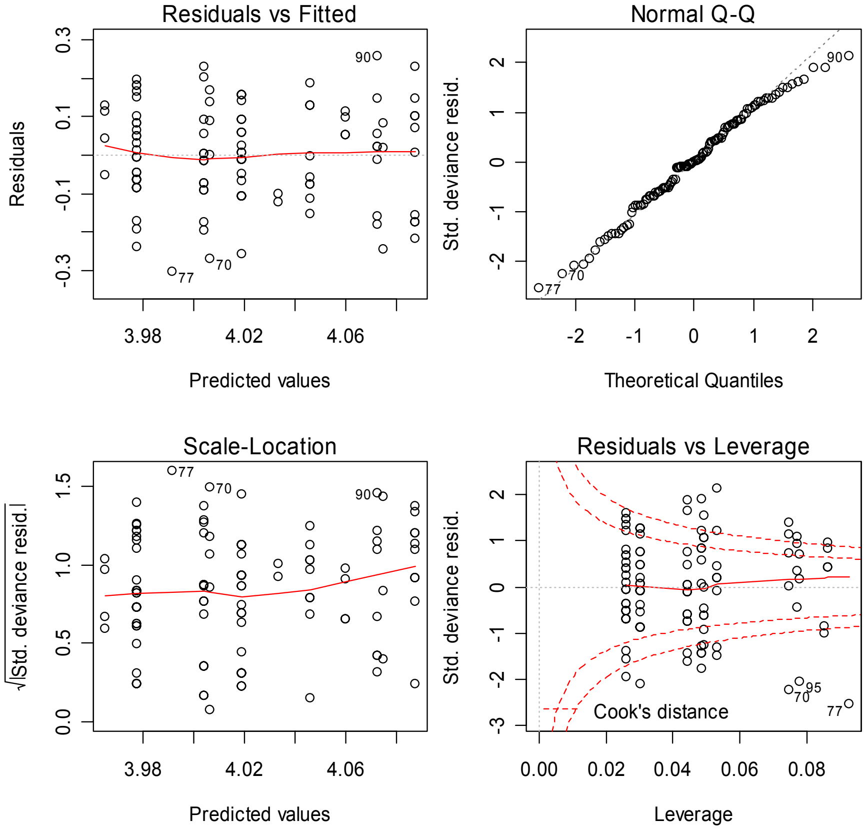
```
Loggerheads only:

Call:
multinom(formula = Locres ~ B + H, contrasts = list(B = "contr.sum",
    H = "contr.sum"))

Coefficients:
         (Intercept)         B1        H1          H2
Int         1.556097 -0.6117664 0.8079143 -0.83992568
IntMouth    2.038955 -0.1376462 0.2094211  0.05532955

Std. Errors:
         (Intercept)        B1       H1       H2
Int         1.246751 0.9746872 1.237256 1.210782
IntMouth    1.210904 0.8971245 1.214343 1.221067

Value/SE (Wald statistics):
         (Intercept)         B1        H1          H2
Int         1.248122 -0.6276541 0.6529888 -0.69370514
IntMouth    1.683829 -0.1534304 0.1724564  0.04531246

Residual Deviance: 178.3367
AIC: 194.3367
```



11.8 Lognormal analysis of turtle length

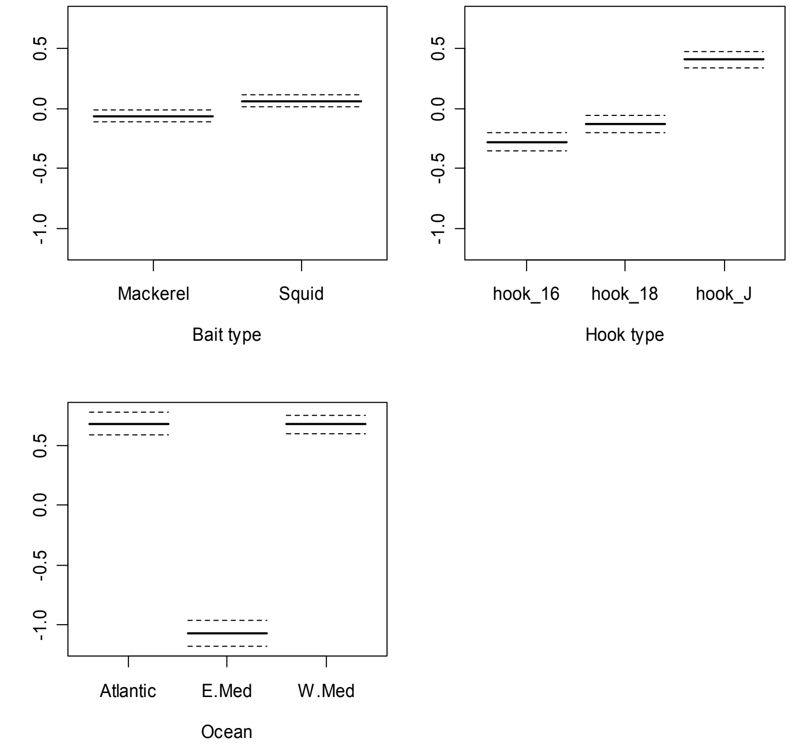
```
Loggerheads only:

Call:
glm(formula = L ~ B + H + O, family = gaussian, contrasts = list(B =
"contr.sum",
    H = "contr.sum", O = "contr.sum"))

Deviance Residuals:
       Min          1Q      Median          3Q         Max
-0.3027479  -0.0855426   0.0007251   0.0918949   0.2582052

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.028193   0.016079 250.518  < 2e-16 ***
B1          -0.006185   0.015888  -0.389  0.69780
H1           0.003885   0.018281   0.213  0.83211
H2           0.018866   0.016441   1.147  0.25374
O1           0.034265   0.012865   2.663  0.00892 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.01554505)

    Null deviance: 1.8387  on 112  degrees of freedom
Residual deviance: 1.6789  on 108  degrees of freedom
AIC: -142.97

Number of Fisher Scoring iterations: 2



Full coefficients are

(Intercept):        4.028193
B:                  Mackerel        Squid
                -0.006185444  0.006185444
H:                   hook_16      hook_18       hook_J
                 0.003884851  0.018865581 -0.022750431
O:                  Atlantic        W.Med
                  0.03426498  -0.03426498


Analysis of Deviance Table

Model: gaussian, link: identity

Response: L

Terms added sequentially (first to last)


      Df Deviance Resid. Df Resid. Dev      F  Pr(>F)
NULL                    112    1.83872
B      1  0.00023       111    1.83849 0.0148 0.90350
H      2  0.04935       109    1.78913 1.5874 0.20919
O      1  0.11027       108    1.67887 7.0934 0.00892 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

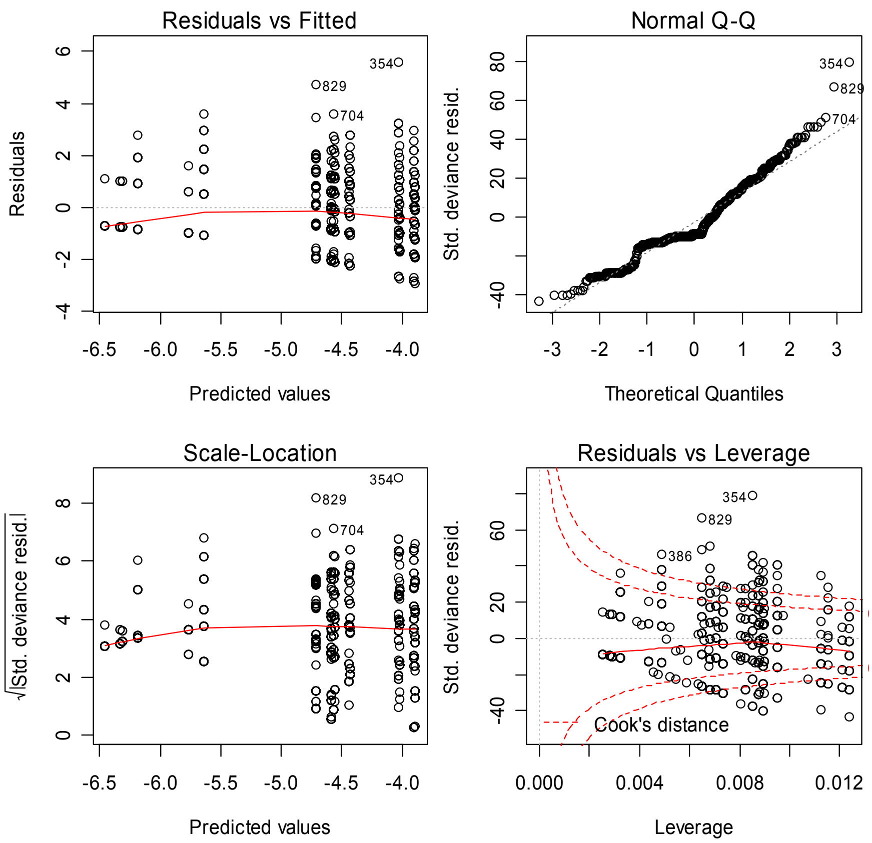

Mackerel
Squid
Bait type
hook_16
hook_18
hook_J
Hook type
Atlantic
W.Med
Ocean


Residuals vs Fitted
Residuals
Predicted values
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. deviance resid.
Cook's distance
Leverage

11.9 Binomial modelling of the probability of capturing swordfish

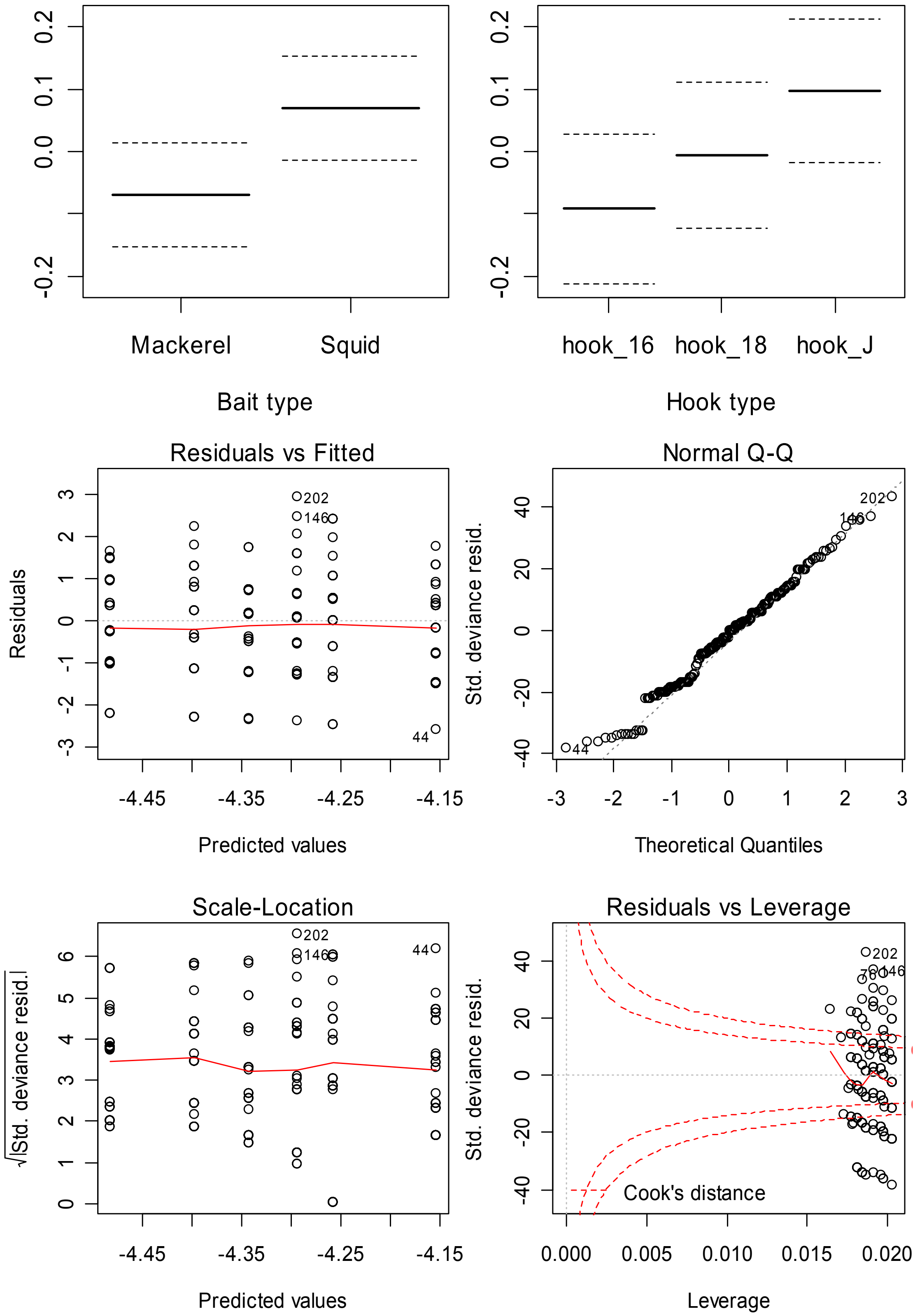
```
Call:
glm(formula = Sres ~ BaitCode + HookType + DataBase, family = binomial(link
= "logit"),
    contrasts = list(BaitCode = "contr.sum", HookType = "contr.sum",
        DataBase = "contr.sum"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.9515  -0.9317  -0.7204   0.5596   5.5556

Coefficients:
            Estimate Std. Error  z value Pr(>|z|)
(Intercept) -4.94679    0.03418 -144.718  < 2e-16 ***
BaitCode1   -0.06386    0.02476   -2.579 0.009895 **
HookType1   -0.27928    0.03874   -7.208 5.66e-13 ***
HookType2   -0.13008    0.03718   -3.499 0.000467 ***
DataBase1    0.58456    0.04108   14.228  < 2e-16 ***
DataBase2   -1.16438    0.05931  -19.632  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 2159.6  on 929  degrees of freedom
Residual deviance: 1380.5  on 924  degrees of freedom
AIC: 2970.4

Number of Fisher Scoring iterations: 5

Full coefficients are

(Intercept):      -4.946791
BaitCode:           Mackerel       Squid
                 -0.06386093  0.06386093
HookType:            hook_16     hook_18     hook_J
                  -0.2792761  -0.1300837  0.4093598
DataBase:           Atlantic       E.Med      W.Med
                   0.5845567  -1.1643786  0.5798219

The odds ratios:
Full coefficients are

(Intercept):    0.007106173
BaitCode:           Mackerel     Squid
                   0.9381355 1.0659442
HookType:            hook_16   hook_18    hook_J
                    0.756331  0.878022  1.505853
DataBase:           Atlantic     E.Med     W.Med
                   1.7941954 0.3121166 1.7857204

Analysis of Deviance Table

Model: binomial, link: logit

Response: Sres

Terms added sequentially (first to last)


          Df Deviance Resid. Df Resid. Dev  P(>|Chi|)
NULL                        929    2159.63
BaitCode   1     6.93       928    2152.70       0.01
HookType   2   154.61       926    1998.09  2.666e-34
DataBase   2   617.62       924    1380.46 7.666e-135
```


Mackerel
Squid
Bait type
hook_16
hook_18
hook_J
Hook type
Atlantic
E.Med
W.Med
Ocean


Residuals vs Fitted
Residuals
Predicted values
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. deviance resid.
Cook's distance
Leverage

11.10 Binomial modelling of the probability of capturing swordfish in the Atlantic

```
Call:
glm(formula = Sres ~ B + H, family = binomial(link = "logit"),
    contrasts = list(B = "contr.sum", H = "contr.sum"))

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-2.58792  -1.03046  -0.09068   0.55338   2.94513

Coefficients:
             Estimate Std. Error  z value Pr(>|z|)
(Intercept) -4.321519   0.041699 -103.637   <2e-16 ***
B1          -0.069620   0.041580   -1.674    0.094 .
H1          -0.091524   0.060218   -1.520    0.129
H2          -0.006099   0.058771   -0.104    0.917
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 273.31  on 209  degrees of freedom
Residual deviance: 267.00  on 206  degrees of freedom
AIC: 827.92

Number of Fisher Scoring iterations: 5

Full coefficients are

(Intercept):       -4.321519
B:                   Mackerel        Squid
                 -0.06961956   0.06961956
H:                    hook_16      hook_18       hook_J
                -0.091523850 -0.006099464  0.097623315

The odds ratios:
Full coefficients are

(Intercept):    0.01327970
B:                 Mackerel     Squid
                 0.9327486 1.0721002
H:                  hook_16   hook_18    hook_J
                 0.9125396 0.9939191 1.1025474


Analysis of Deviance Table
Model: binomial, link: logit

Response: Sres

Terms added sequentially (first to last)


      Df Deviance Resid. Df Resid. Dev P(>|Chi|)
NULL                    209    273.310
B      1    2.830       208    270.480     0.093
H      2    3.477       206    267.003     0.176
```

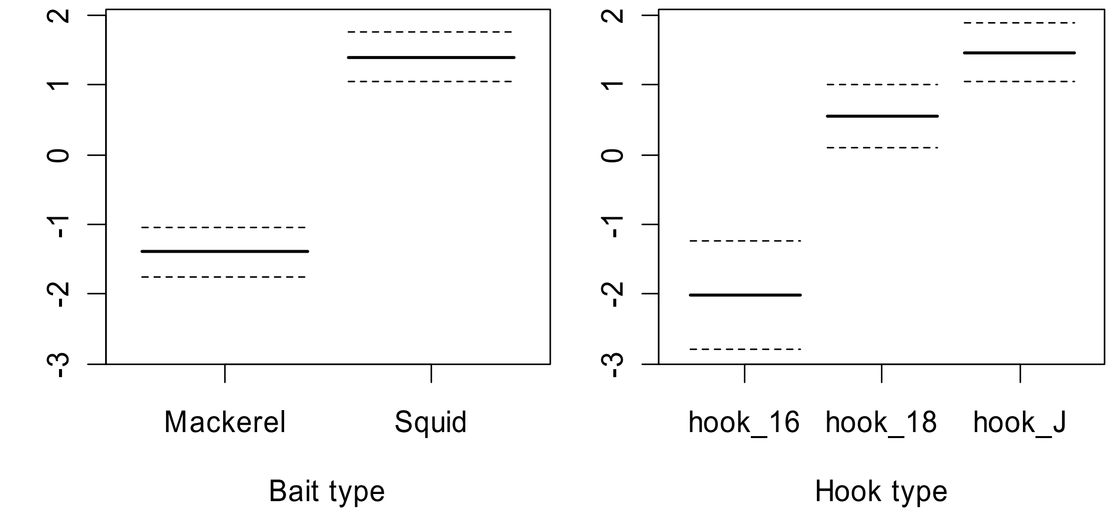


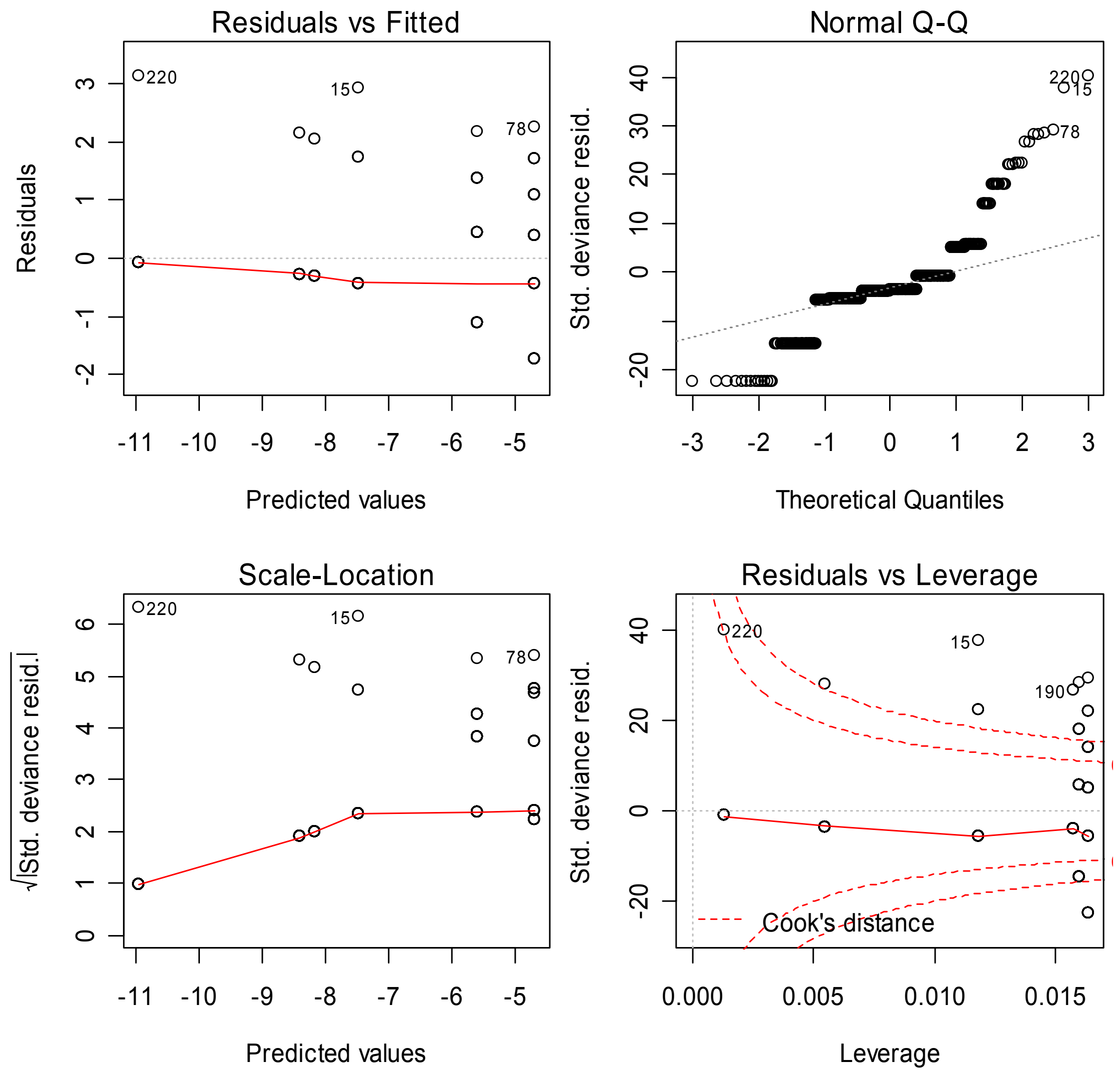
0.2
0.1
0.0
-0.2
Mackerel
Squid
Bait type
hook_16
hook_18
hook_J
Hook type
Residuals vs Fitted
Residuals
Predicted values
-4.45
-4.35
-4.25
-4.15
202
146
44
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Residuals vs Leverage
Cook's distance
Leverage
0.000
0.005
0.010
0.015
0.020

11.11 Binomial modelling of the probability of capturing swordfish in the eastern Mediterranean

11.11.1.1.1.1

```
Call:
glm(formula = Sres ~ B + H, family = binomial(link = "logit"),
    contrasts = list(B = "contr.sum", H = "contr.sum"))

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.74052  -0.42955  -0.27658  -0.07563   3.11864

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -7.5490     0.2588 -29.170  < 2e-16 ***
B1           -1.4014     0.1822  -7.693 1.44e-14 ***
H1           -2.0126     0.3900  -5.160 2.47e-07 ***
H2            0.5510     0.2222   2.480   0.0131 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 446.18  on 359  degrees of freedom
Residual deviance: 201.95  on 356  degrees of freedom
AIC: 403.51

Number of Fisher Scoring iterations: 7




Full coefficients are

(Intercept):     -7.549045
B:                Mackerel      Squid
                 -1.401360   1.401360
H:                 hook_16    hook_18     hook_J
                -2.0125995  0.5510485  1.4615510



The odds ratios:
Full coefficients are

(Intercept):    0.000526613
B:                 Mackerel     Squid
                  0.2462619 4.0607175
H:                  hook_16   hook_18    hook_J
                  0.1336408 1.7350713 4.3126434

Analysis of Deviance Table

Model: binomial, link: logit

Response: Sres

Terms added sequentially (first to last)


      Df Deviance Resid. Df Resid. Dev P(>|Chi|)
NULL                    359     446.18
B      1   131.74       358     314.44 1.708e-30
H      2   112.49       356     201.95 3.740e-25
```

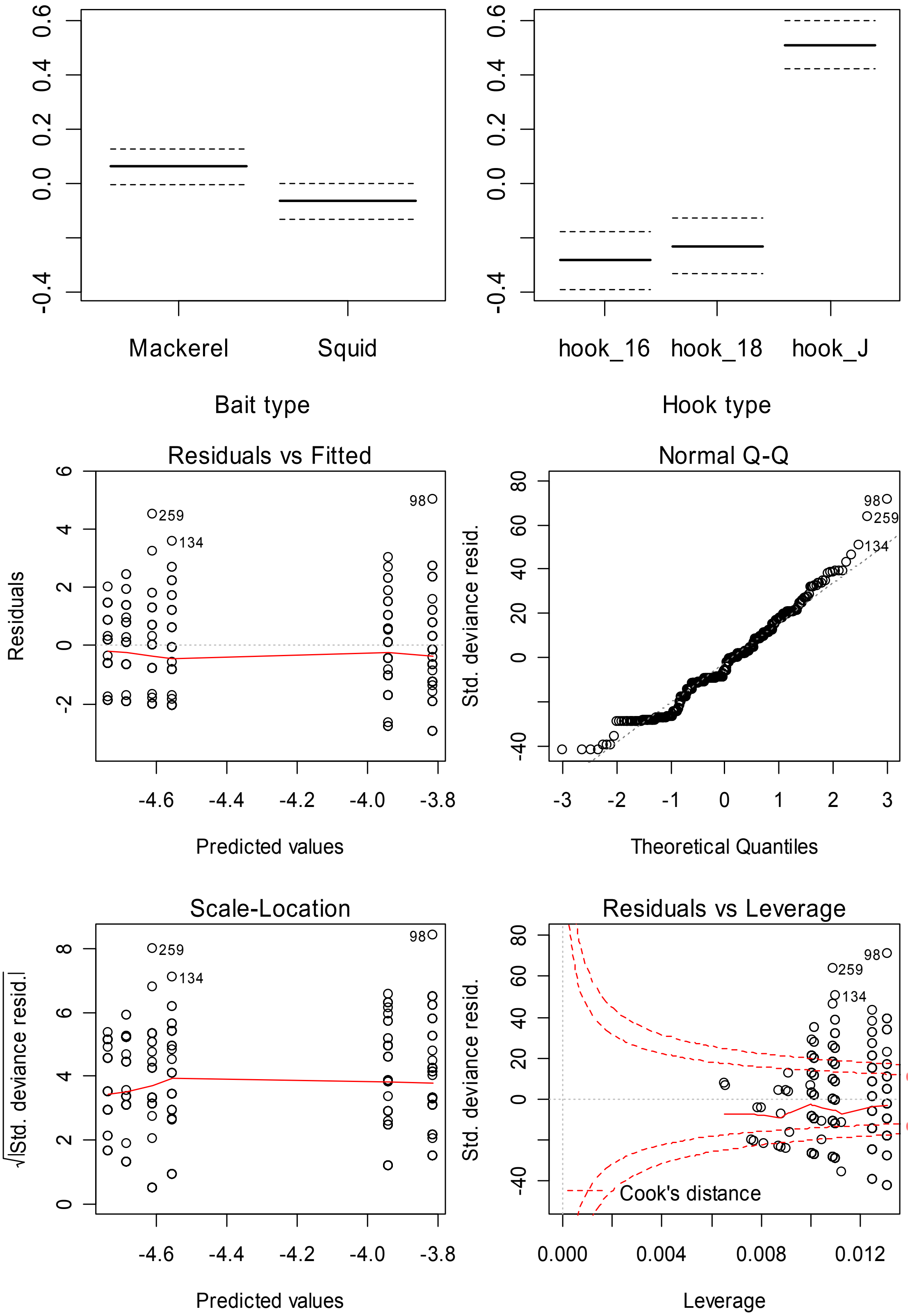

Mackerel
Squid
Bait type
hook_16
hook_18
hook_J
Hook type


Residuals vs Fitted
Residuals
Predicted values
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. deviance resid.
Cook's distance
Leverage

11.12 Binomial modelling of the probability of capturing swordfish in the western Mediterranean

11.12.1.1.1.1

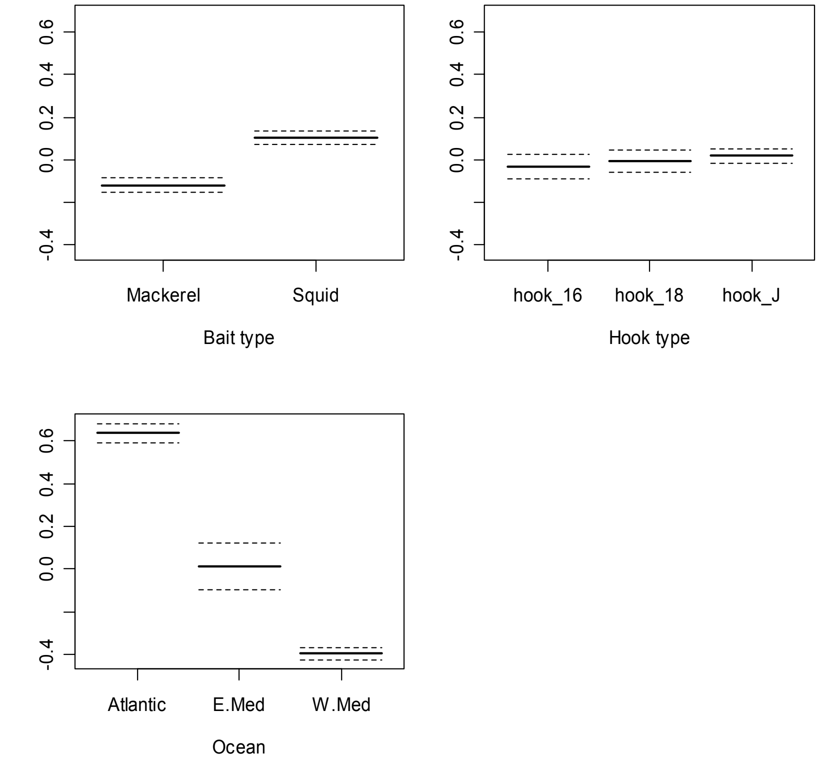
```
Call:
glm(formula = Sres ~ B + H, family = binomial(link = "logit"),
    contrasts = list(B = "contr.sum", H = "contr.sum"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.9533  -1.0277  -0.4337   0.6814   5.0036

Coefficients:
            Estimate Std. Error  z value Pr(>|z|)
(Intercept) -4.38953    0.03511 -125.022  < 2e-16 ***
B1           0.06374    0.03304    1.929   0.0537 .
H1          -0.28236    0.05252   -5.376 7.62e-08 ***
H2          -0.22874    0.05177   -4.418 9.95e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 821.5  on 359  degrees of freedom
Residual deviance: 684.7  on 356  degrees of freedom
AIC: 1524.2

Number of Fisher Scoring iterations: 5




Full coefficients are

(Intercept):     -4.389531
B:                Mackerel      Squid
                 0.0637351 -0.0637351
H:                 hook_16    hook_18     hook_J
                -0.2823618 -0.2287388  0.5111006



The odds ratios:
Full coefficients are

(Intercept):    0.01240655
B:                Mackerel     Squid
                 1.0658100 0.9382535
H:                 hook_16   hook_18    hook_J
                 0.7540008 0.7955363 1.6671250

Analysis of Deviance Table

Model: binomial, link: logit

Response: Sres

Terms added sequentially (first to last)


      Df Deviance Resid. Df Resid. Dev P(>|Chi|)
NULL                    359     821.49
B      1     3.72       358     817.77      0.05
H      2   133.08       356     684.70 1.265e-29
```

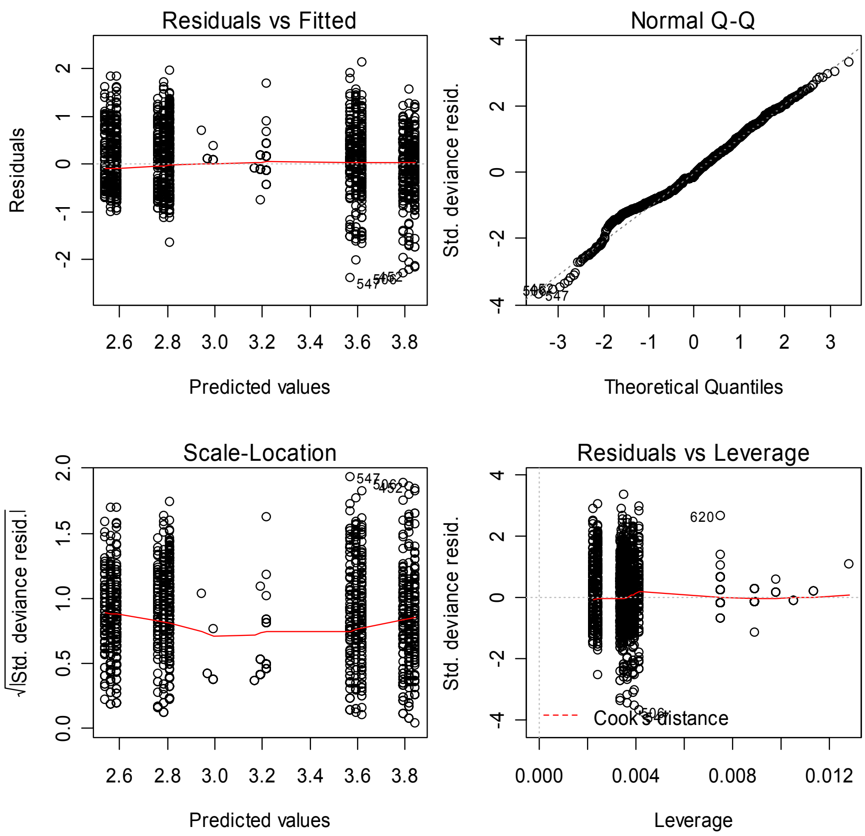


Bait type
Mackerel
Squid
Hook type
hook_16
hook_18
hook_J
-0.4
0.0
0.2
0.4
0.6
Residuals vs Fitted
Residuals
Predicted values
-4.6
-4.4
-4.2
-4.0
-3.8
98
259
134
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
-3
-2
-1
0
1
2
3
Scale-Location
√|Std. deviance resid.|
Residuals vs Leverage
Leverage
0.000
0.004
0.008
0.012
Cook's distance

11.13 Lognormal modelling of swordfish catch weight

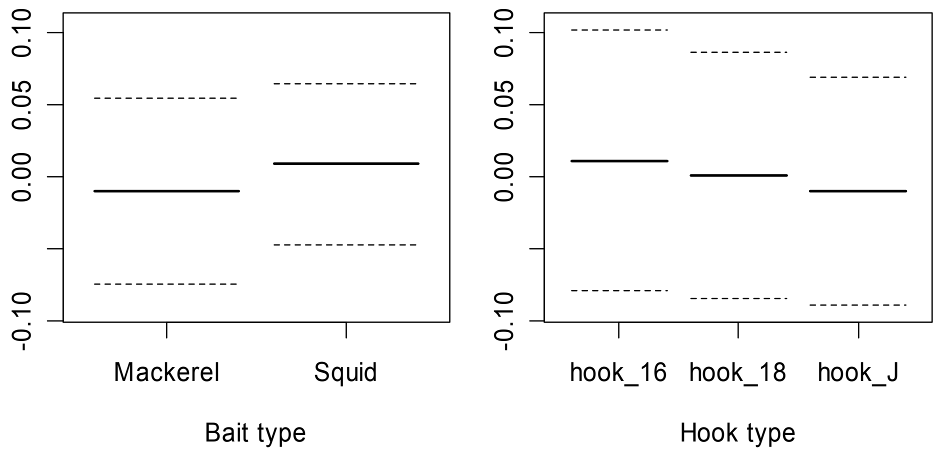
```
Call:
glm(formula = W ~ B + H + O, family = gaussian, contrasts = list(B =
"contr.sum",
    H = "contr.sum", O = "contr.sum"))

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-2.38520  -0.47105  -0.08141   0.42157   2.13790

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.1554962  0.0230341 136.993  < 2e-16 ***
B1          -0.1106213  0.0164484  -6.725 2.41e-11 ***
H1          -0.0248808  0.0252412  -0.986   0.3244
H2           0.0001575  0.0239822   0.007   0.9948
O1           0.5530473  0.0272925  20.264  < 2e-16 ***
O2          -0.0722288  0.0398997  -1.810   0.0704 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.4143527)

    Null deviance: 1088.51  on 1646  degrees of freedom
Residual deviance:  679.95  on 1641  degrees of freedom
AIC: 3230.9

Number of Fisher Scoring iterations: 2



Full coefficients are

(Intercept):          3.155496
B:                    Mackerel         Squid
                    -0.1106213     0.1106213
H:                     hook_16       hook_18        hook_J
                 -0.0248808286  0.0001574842  0.0247233444
O:                    Atlantic         E.Med         W.Med
                    0.55304731   -0.07222877   -0.48081855


Analysis of Deviance Table

Model: gaussian, link: identity

Response: W

Terms added sequentially (first to last)


       Df Deviance Resid. Df Resid. Dev       F    Pr(>F)
NULL                    1646    1088.51
B       1    32.62      1645    1055.89  78.725 < 2.2e-16 ***
H       2     4.17      1643    1051.72   5.035  0.006607 **
O       2   371.77      1641     679.95 448.614 < 2.2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```


Mackerel
Squid
Bait type
hook_16
hook_18
hook_J
Hook type
Atlantic
E.Med
W.Med
Ocean

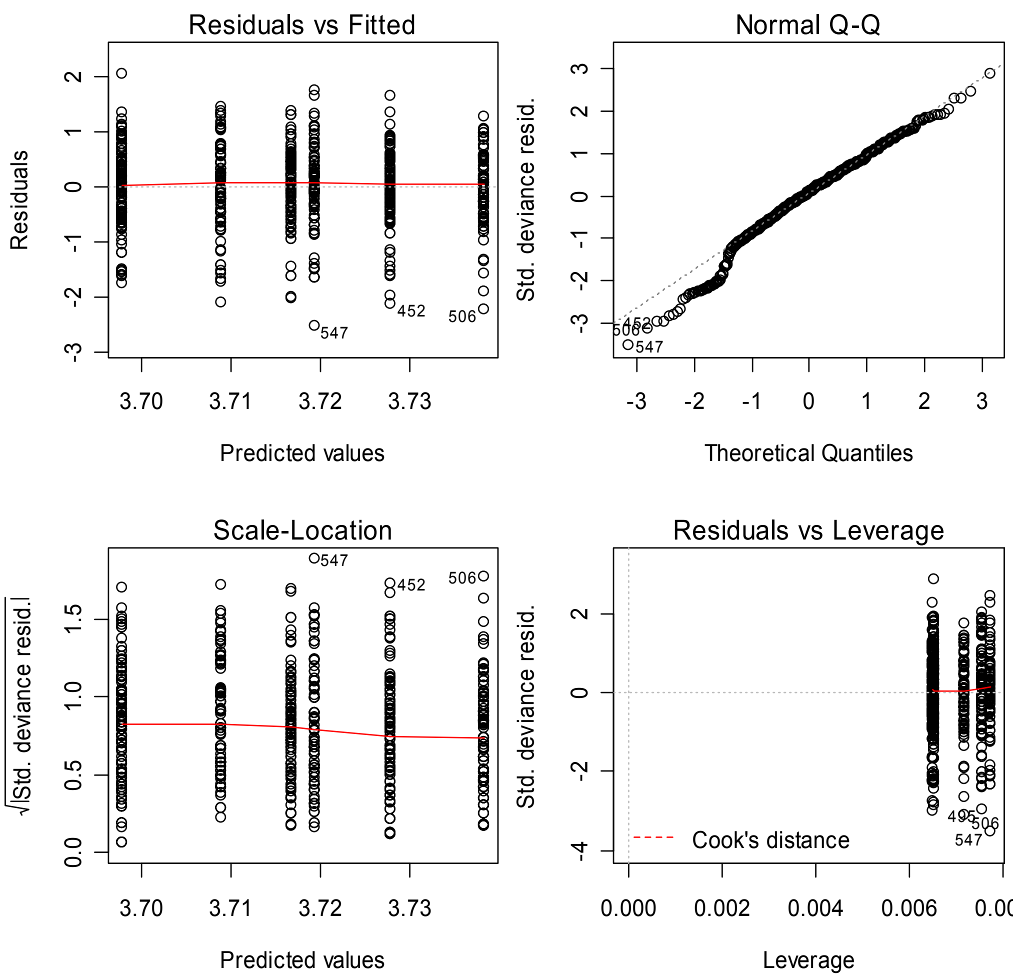

Residuals vs Fitted
Residuals
Predicted values
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. deviance resid.
Cook's distance
Leverage

11.14 Lognormal modelling of swordfish catch weights in the Atlantic

```
Call:
glm(formula = W ~ B + H, family = gaussian, contrasts = list(B = 
"contr.sum", 
    H = "contr.sum"))

Deviance Residuals: 
    Min       1Q   Median       3Q      Max  
-2.5315  -0.3951   0.0633   0.4789   2.0626  

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  3.7181756  0.0300697 123.652   <2e-16 ***
B1          -0.0094570  0.0300463  -0.315    0.753    
H1           0.0106097  0.0433122   0.245    0.807    
H2           0.0002085  0.0424764   0.005    0.996    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 

(Dispersion parameter for gaussian family taken to be 0.515924)

    Null deviance: 295.72  on 576  degrees of freedom
Residual deviance: 295.62  on 573  degrees of freedom
AIC: 1261.6

Number of Fisher Scoring iterations: 2


Full coefficients are

(Intercept):         3.718176                                   
B:                   Mackerel         Squid                     
                 -0.009457004   0.009457004                     
H:                    hook_16       hook_18        hook_J
                 0.0106097186  0.0002084900 -0.0108182086



Analysis of Deviance Table

Model: gaussian, link: identity

Response: W

Terms added sequentially (first to last)


      Df Deviance Resid. Df Resid. Dev      F Pr(>F)
NULL                    576    295.723              
B      1    0.055       575    295.669 0.1062 0.7446
H      2    0.044       573    295.624 0.0427 0.9582
```



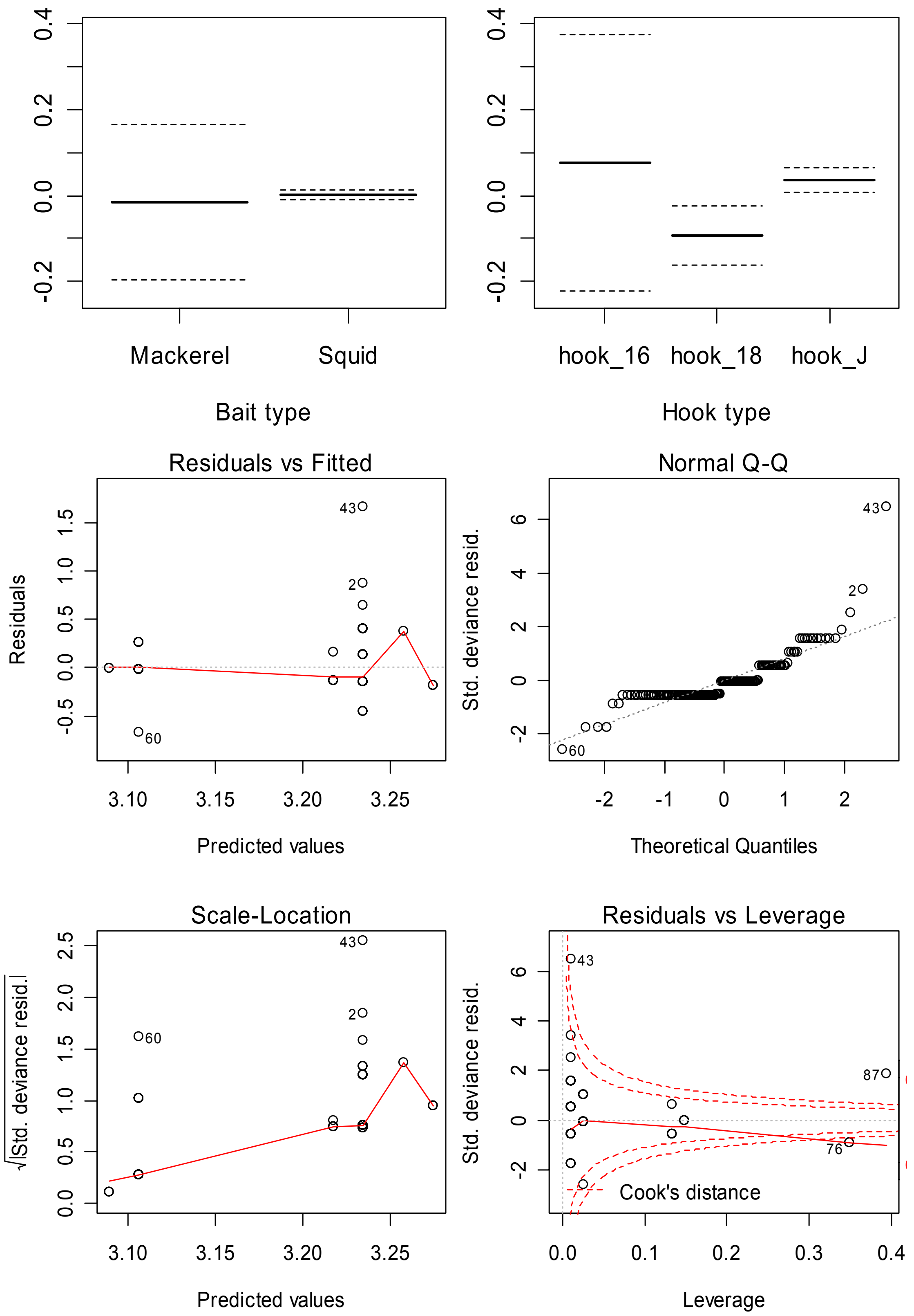
0.10
0.05
0.00
-0.10
Mackerel
Squid
Bait type
hook_16
hook_18
hook_J
Hook type



Residuals vs Fitted
Residuals
Predicted values
547
452
506
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. deviance resid.
Cook's distance
495
Leverage

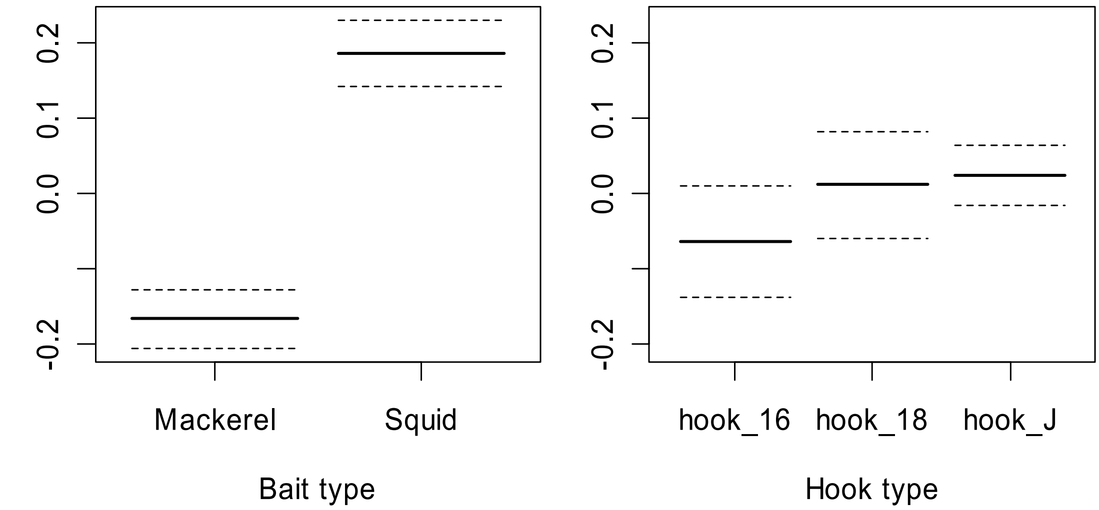
11.15 Lognormal modelling of swordfish catch weight in the eastern Mediterranean

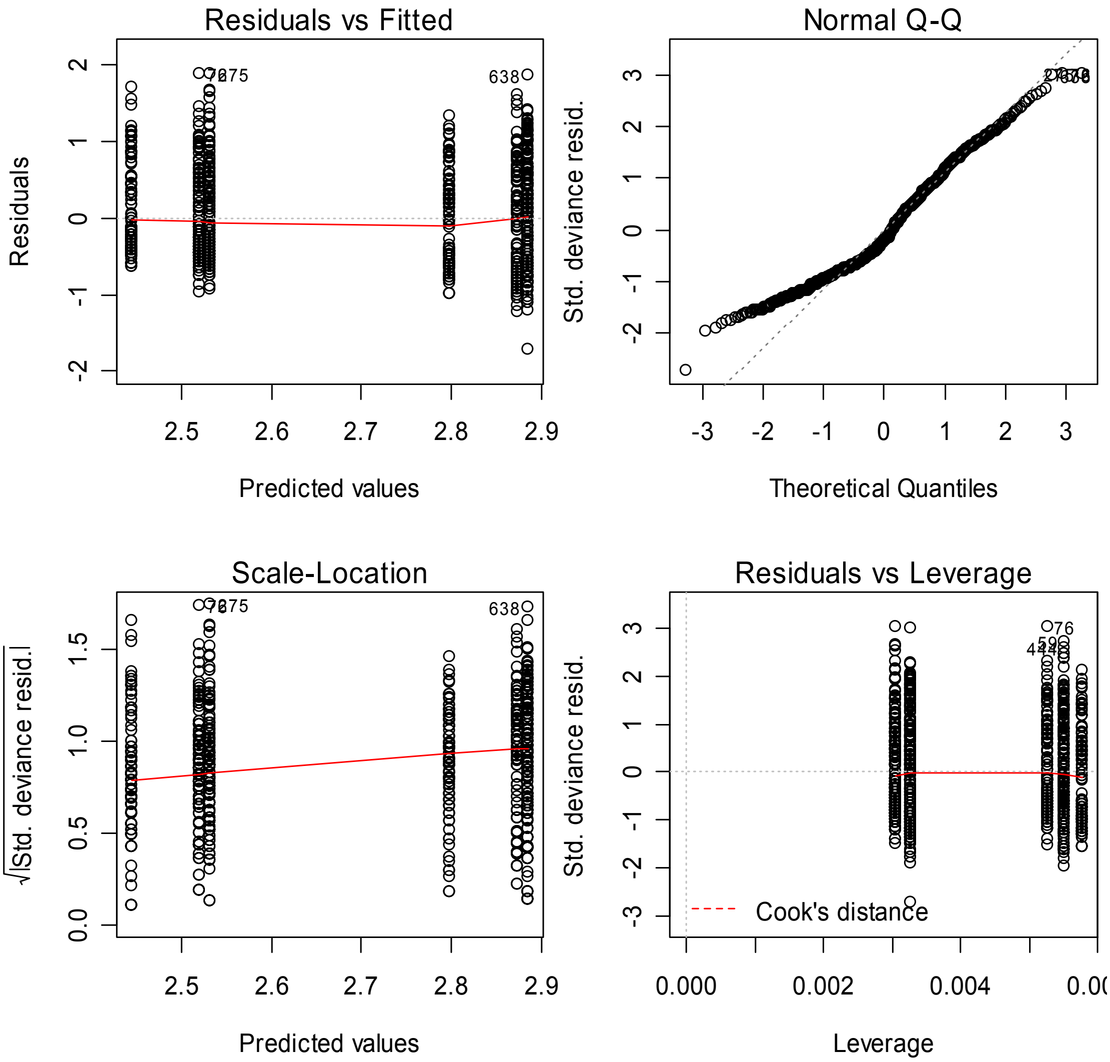
```
Call:
glm(formula = W ~ B + H, family = gaussian, contrasts = list(B =
"contr.sum",
    H = "contr.sum"))

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.66872  -0.14820  -0.02022   0.13640   1.66792

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.196873   0.062404  51.229   <2e-16 ***
B1          -0.008567   0.047846  -0.179   0.8582
H1           0.069491   0.102465   0.678   0.4988
H2          -0.098735   0.058151  -1.698   0.0918 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.0669027)

    Null deviance: 9.5119  on 138  degrees of freedom
Residual deviance: 9.0319  on 135  degrees of freedom
AIC: 24.478

Number of Fisher Scoring iterations: 2


Full coefficients are

(Intercept):        3.196873
B:                  Mackerel        Squid
                -0.008567426  0.008567426
H:                   hook_16      hook_18      hook_J
                  0.06949106  -0.09873537  0.02924431


Analysis of Deviance Table

Model: gaussian, link: identity

Response: W

Terms added sequentially (first to last)


      Df Deviance Resid. Df Resid. Dev      F  Pr(>F)
NULL                    138     9.5119
B      1   0.0004       137     9.5114 0.0065 0.93590
H      2   0.4796       135     9.0319 3.5842 0.03043 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```


0.4
0.2
0.0
-0.2
Mackerel
Squid
Bait type
hook_16
hook_18
hook_J
Hook type
Residuals vs Fitted
Residuals
1.5
1.0
0.5
0.0
-0.5
43
2
60
3.10
3.15
3.20
3.25
Predicted values
Normal Q-Q
Std. deviance resid.
6
4
2
0
-2
-1
1
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
2.5
2.0
Residuals vs Leverage
87
76
Cook's distance
0.1
0.3
Leverage

11.16 Lognormal modelling of swordfish catch weight in the western Mediterranean

```
Call:
glm(formula = W ~ B + H, family = gaussian, contrasts = list(B =
"contr.sum",
    H = "contr.sum"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.7153  -0.4965  -0.1400   0.4641   1.8953

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.67564    0.02190 122.175   <2e-16 ***
B1          -0.17605    0.02057  -8.558   <2e-16 ***
H1          -0.05414    0.03280  -1.650   0.0992 .
H2           0.02111    0.03229   0.654   0.5133
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.3927349)

    Null deviance: 394.05  on 930  degrees of freedom
Residual deviance: 364.07  on 927  degrees of freedom
AIC: 1777.9

Number of Fisher Scoring iterations: 2


Full coefficients are

(Intercept):       2.675641
B:                 Mackerel       Squid
                 -0.1760453   0.1760453
H:                  hook_16     hook_18      hook_J
                -0.05413990  0.02111453  0.03302537


Analysis of Deviance Table

Model: gaussian, link: identity

Response: W

Terms added sequentially (first to last)


      Df Deviance Resid. Df Resid. Dev       F Pr(>F)
NULL                    930     394.05
B      1    28.80       929     365.25 73.3399 <2e-16 ***
H      2     1.18       927     364.07  1.5072 0.2221
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

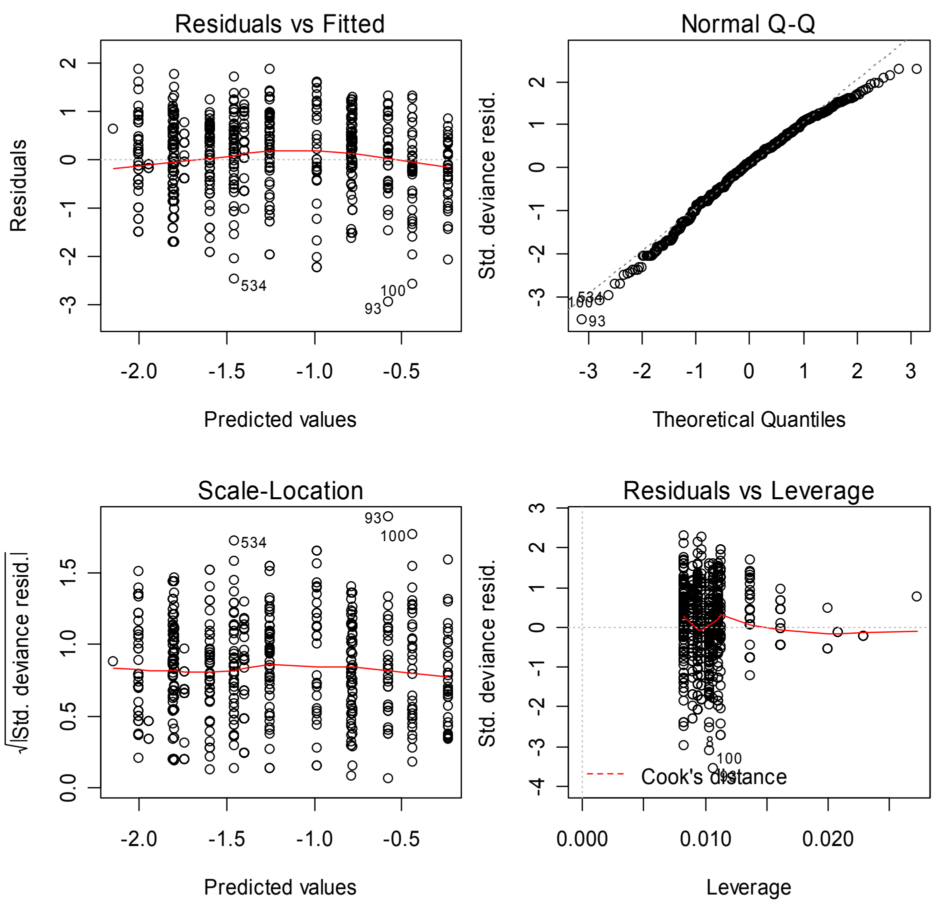

0.2
0.1
0.0
-0.2
Mackerel
Squid
Bait type
hook_16
hook_18
hook_J
Hook type


Residuals vs Fitted
Residuals
Predicted values
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. deviance resid.
Cook's distance
Leverage

11.17 Delta-lognormal modelling of swordfish catch rate over all regions

```
Call:
glm(formula = S ~ B + H + O, family = gaussian, contrasts = list(B =
"contr.sum",
    H = "contr.sum", O = "contr.sum"))

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-2.93026  -0.51963   0.07871   0.58511   1.88873

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.35961    0.04225 -32.179  < 2e-16 ***
B1          -0.10162    0.03649  -2.785  0.00554 **
H1          -0.25226    0.05267  -4.789 2.14e-06 ***
H2          -0.04619    0.04985  -0.926  0.35461
O1           0.72787    0.05419  13.433  < 2e-16 ***
O2          -0.43527    0.07069  -6.157 1.41e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.6842897)

    Null deviance: 546.17  on 570  degrees of freedom
Residual deviance: 386.62  on 565  degrees of freedom
AIC: 1411.8

Number of Fisher Scoring iterations: 2


Full coefficients are

(Intercept):      -1.359611
B:                 Mackerel       Squid
                 -0.1016216   0.1016216
H:                  hook_16     hook_18      hook_J
                -0.25225861 -0.04618751  0.29844612
O:                 Atlantic       E.Med       W.Med
                  0.7278746  -0.4352684  -0.2926062


Call:
glm(formula = S_D ~ B + H + O, family = binomial(link = "logit"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.0369  -0.6260   0.2643   0.5482   2.4706

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)   1.3349     0.2847   4.689 2.75e-06 ***
BSquid        1.4730     0.2063   7.142 9.22e-13 ***
Hhook_18      0.5291     0.2264   2.337  0.01946 *
Hhook_J       1.7936     0.2518   7.124 1.05e-12 ***
OE.Med       -4.3383     0.3234 -13.414  < 2e-16 ***
OW.Med       -0.9885     0.3005  -3.289  0.00100 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 1240.5  on 929  degrees of freedom
Residual deviance:  726.8  on 924  degrees of freedom
```

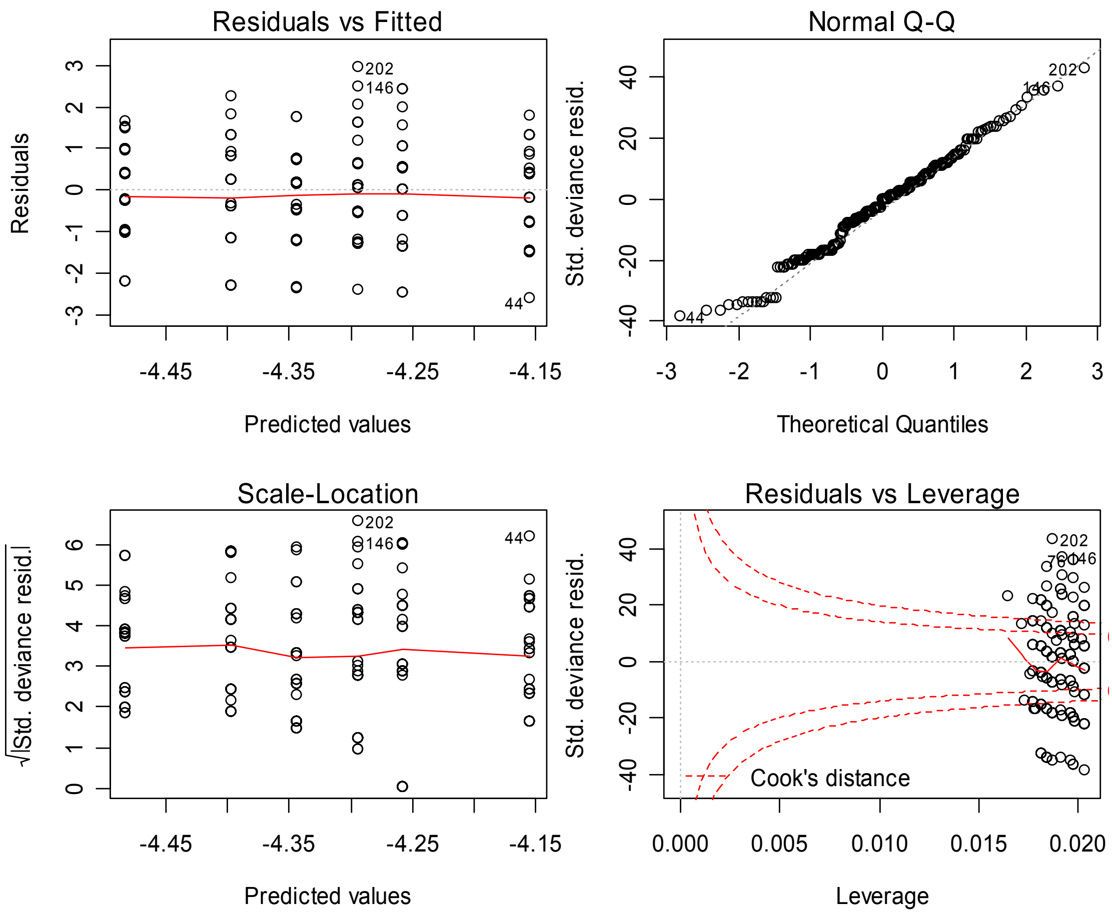
```
AIC: 738.8

Number of Fisher Scoring iterations: 5


Full coefficients are

(Intercept):      1.334869
B:                Mackerel      Squid
                  0.000000   1.472975
H:                 hook_16    hook_18     hook_J
                 0.0000000 0.5290572 1.7936215
O:                Atlantic      E.Med      W.Med
                  0.000000 -4.338324 -0.988549


The odds ratios:
Full coefficients are

(Intercept):       3.799499
B:                 Mackerel       Squid
                   1.000000    4.362192
H:                  hook_16     hook_18      hook_J
                   1.000000    1.697331    6.011183
O:                 Atlantic       E.Med       W.Med
                 1.00000000 0.01305840 0.37211621
```



11.18 Delta-lognormal modelling of swordfish catch rate in the Atlantic

```
Call:
glm(formula = S ~ B + H, family = gaussian, contrasts = list(B =
"contr.sum",
    H = "contr.sum"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.0202  -0.4693   0.1018   0.6293   1.5464

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.62618    0.06216 -10.074   <2e-16 ***
B1          -0.08012    0.06216  -1.289    0.199
H1          -0.10749    0.08797  -1.222    0.223
H2           0.05973    0.08870   0.673    0.502
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.7443941)

    Null deviance: 143.04  on 192  degrees of freedom
Residual deviance: 140.69  on 189  degrees of freedom
AIC: 496.7

Number of Fisher Scoring iterations: 2



Full coefficients are

(Intercept):     -0.6261847
B:                 Mackerel       Squid
                -0.08011645  0.08011645
H:                  hook_16     hook_18      hook_J
                -0.10748718  0.05973294  0.04775424


Call:
glm(formula = S_D ~ B + H, family = binomial(link = "logit"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.8251  -1.1645   0.6475   0.9828   1.3141

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -0.3157     0.1349  -2.339   0.0193 *
BSquid        0.7924     0.1404   5.643 1.67e-08 ***
Hhook_18      0.2853     0.1651   1.728   0.0841 .
Hhook_J       0.9792     0.1751   5.592 2.24e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 1240.5  on 929  degrees of freedom
Residual deviance: 1175.2  on 926  degrees of freedom
AIC: 1183.2

Number of Fisher Scoring iterations: 4
```

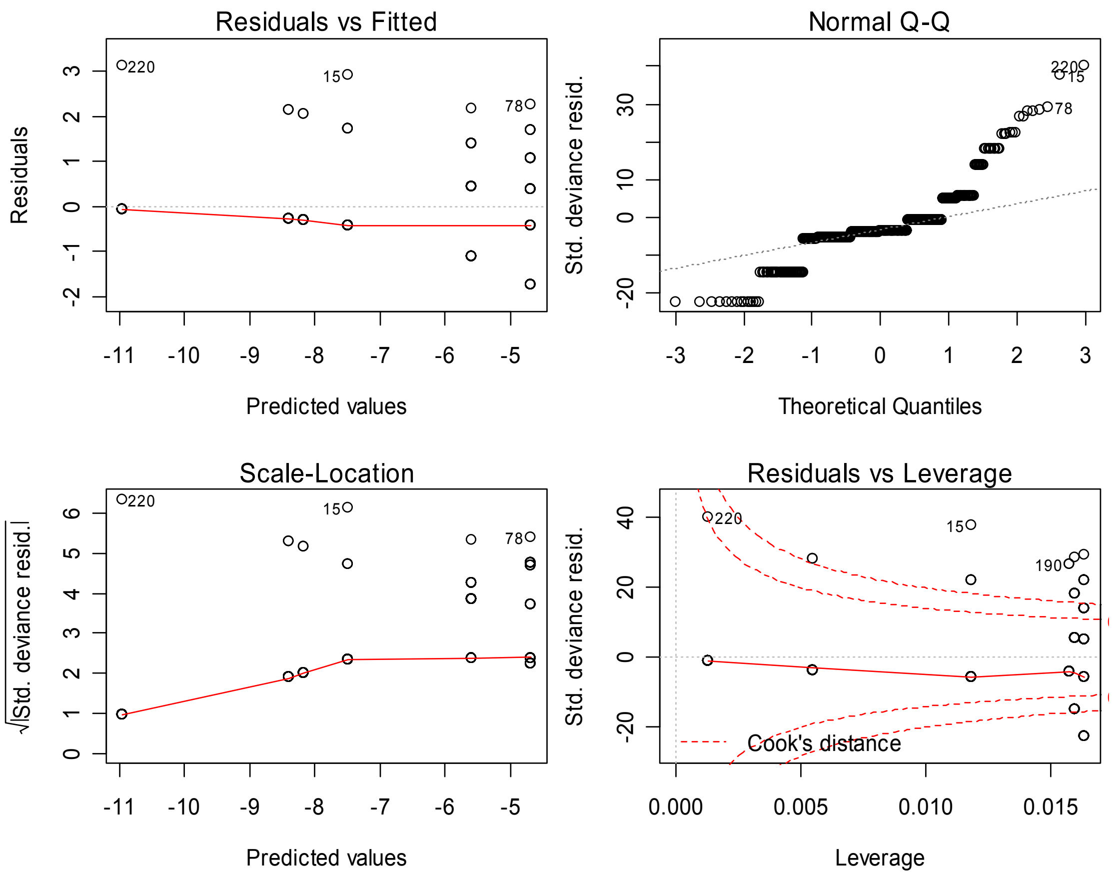
```
Full coefficients are

(Intercept):     -0.3156621
B:                 Mackerel      Squid
                  0.0000000 0.7923963
H:                  hook_16    hook_18     hook_J
                  0.0000000 0.2852749 0.9792081


The odds ratios:
Full coefficients are

(Intercept):     0.7293058
B:                Mackerel     Squid
                  1.000000 2.208683
H:                 hook_16   hook_18    hook_J
                  1.000000 1.330128 2.662347
```



11.19 Delta-lognormal modelling of swordfish catch rate in the eastern Mediterranean

```
Call:
glm(formula = S ~ B + H, family = gaussian, contrasts = list(B =
"contr.sum",
    H = "contr.sum"))

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.04922  -0.32941   0.01165   0.40456   1.34868

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -1.7997     0.1358 -13.250   <2e-16 ***
B1           -0.1648     0.1098  -1.501    0.137
H1           -0.1201     0.2182  -0.551    0.583
H2           -0.1560     0.1294  -1.206    0.232
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.2993422)

    Null deviance: 27.694  on 81  degrees of freedom
Residual deviance: 23.349  on 78  degrees of freedom
AIC: 139.7

Number of Fisher Scoring iterations: 2



Full coefficients are

(Intercept):     -1.799685
B:                Mackerel      Squid
                -0.1648363  0.1648363
H:                 hook_16    hook_18     hook_J
                -0.1201167 -0.1560052  0.2761218



Call:
glm(formula = S_D ~ B + H, family = binomial(link = "logit"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.8251  -1.1645   0.6475   0.9828   1.3141

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -0.3157     0.1349  -2.339   0.0193 *
BSquid        0.7924     0.1404   5.643 1.67e-08 ***
Hhook_18      0.2853     0.1651   1.728   0.0841 .
Hhook_J       0.9792     0.1751   5.592 2.24e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 1240.5  on 929  degrees of freedom
Residual deviance: 1175.2  on 926  degrees of freedom
AIC: 1183.2

Number of Fisher Scoring iterations: 4
```

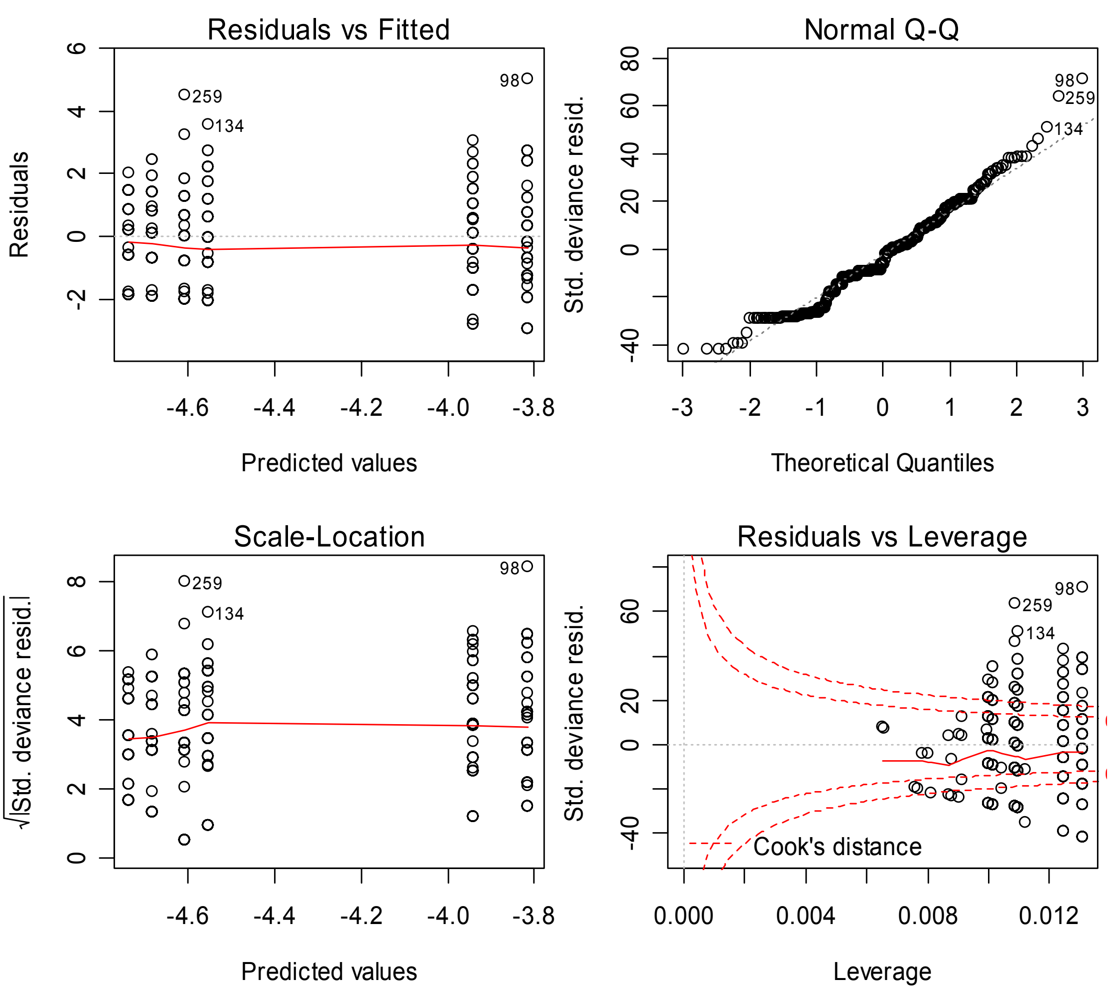
```
Full coefficients are

(Intercept):     -0.3156621
B:                 Mackerel      Squid
                  0.0000000 0.7923963
H:                  hook_16    hook_18     hook_J
                  0.0000000 0.2852749 0.9792081


The odds ratios:
Full coefficients are

(Intercept):     0.7293058
B:                Mackerel     Squid
                  1.000000 2.208683
H:                 hook_16   hook_18    hook_J
                  1.0       1.330128 2.662347
```



11.20 Delta-lognormal modelling of swordfish catch rate in the western Mediterranean

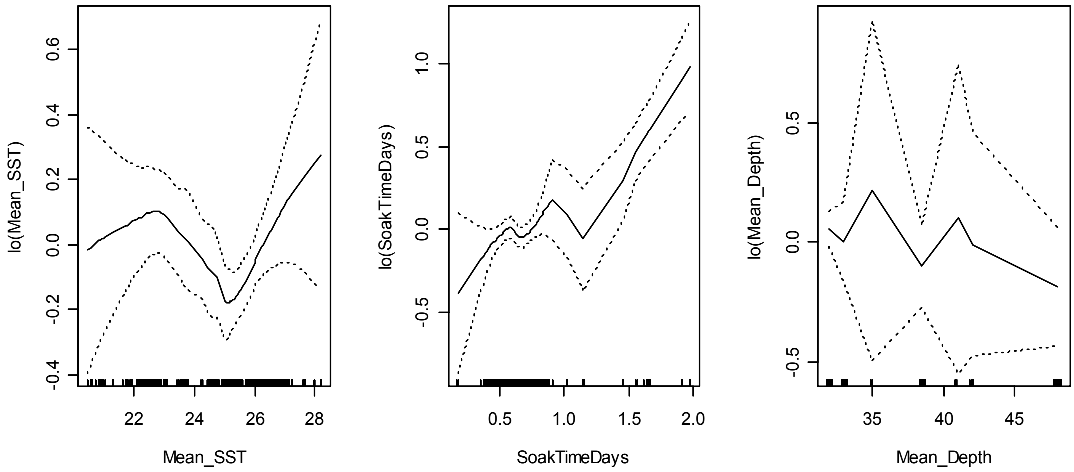
```
Call:
glm(formula = S ~ B + H, family = gaussian, contrasts = list(B =
"contr.sum",
    H = "contr.sum"))

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-2.58444  -0.57886   0.08971   0.62664   1.99344

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.66131    0.04981 -33.352  < 2e-16 ***
B1          -0.10982    0.04963  -2.213   0.0277 *
H1          -0.35015    0.07113  -4.923 1.43e-06 ***
H2          -0.09339    0.07173  -1.302   0.1940
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.727957)

    Null deviance: 249.71  on 295  degrees of freedom
Residual deviance: 212.56  on 292  degrees of freedom
AIC: 752

Number of Fisher Scoring iterations: 2



Full coefficients are

(Intercept):      -1.661305
B:                 Mackerel       Squid
                 -0.1098186   0.1098186
H:                  hook_16     hook_18      hook_J
                -0.35014560 -0.09339056  0.44353617


Call:
glm(formula = S_D ~ B + H, family = binomial(link = "logit"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.8251  -1.1645   0.6475   0.9828   1.3141

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -0.3157     0.1349  -2.339   0.0193 *
BSquid        0.7924     0.1404   5.643 1.67e-08 ***
Hhook_18      0.2853     0.1651   1.728   0.0841 .
Hhook_J       0.9792     0.1751   5.592 2.24e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 1240.5  on 929  degrees of freedom
Residual deviance: 1175.2  on 926  degrees of freedom
AIC: 1183.2

Number of Fisher Scoring iterations: 4
```

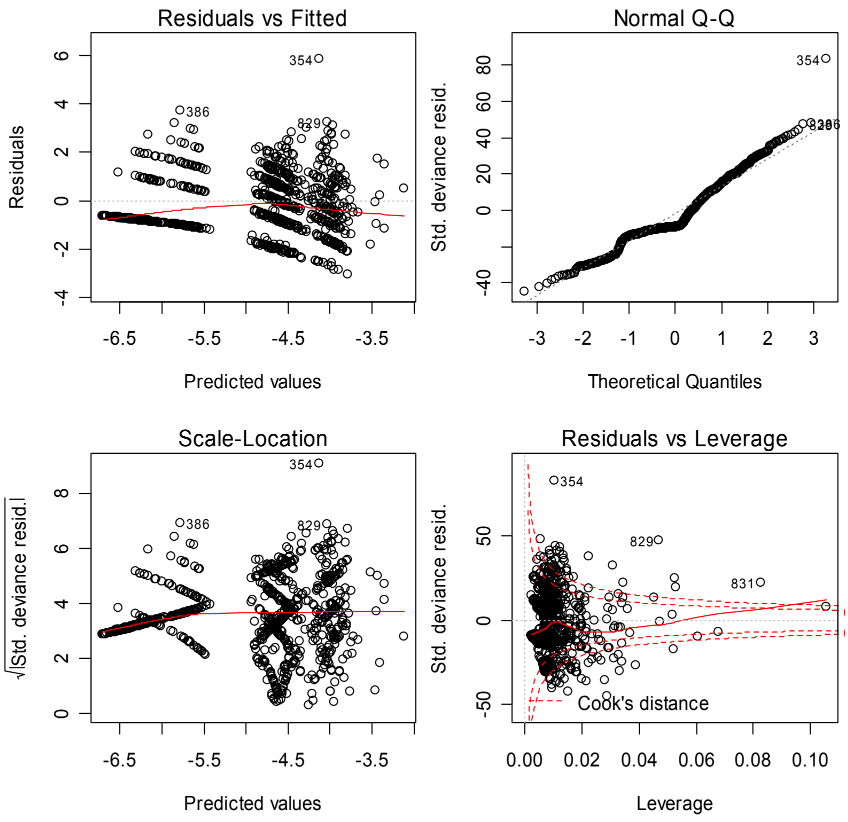
```
Full coefficients are

(Intercept):     -0.3156621
B:                 Mackerel      Squid
                  0.0000000 0.7923963
H:                   hook_16    hook_18     hook_J
                  0.0000000 0.2852749 0.9792081


The odds ratios:
Full coefficients are

(Intercept):     0.7293058
B:                Mackerel     Squid
                  1.000000 2.208683
H:                 hook_16   hook_18    hook_J
                    1.0    1.330128 2.662347
```



11.21 The effect of other factors on the probability of capturing a swordfish

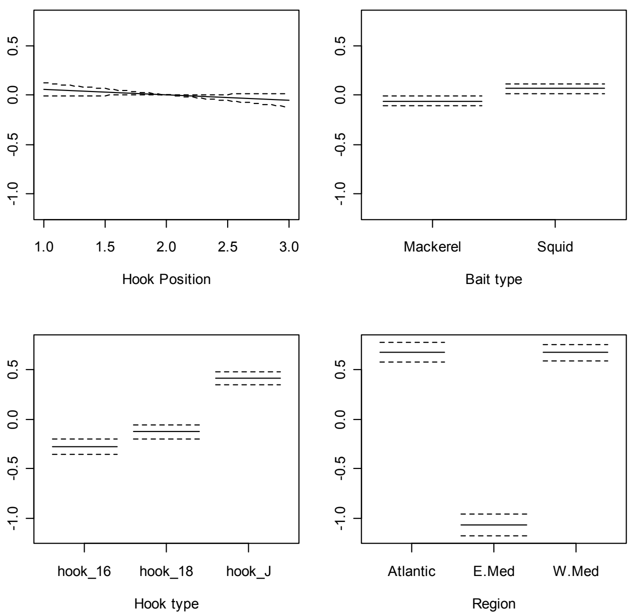
```
Call:
glm(formula = Tres ~ s(Mean_SST) + s(SoakTimeDays) + s(Mean_Depth) +
DataBase +
    BaitCode + HookType, family = binomial(link = "logit"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.0607  -0.8835  -0.6913   0.5767   5.8384

Coefficients:
                 Estimate Std. Error z value Pr(>|z|)
(Intercept)     -5.425167   0.779648  -6.958 3.44e-12 ***
Mean_SST         0.043186   0.030023   1.438   0.1503
SoakTimeDays     0.582894   0.083113   7.013 2.33e-12 ***
Mean_Depth      -0.013687   0.009752  -1.403   0.1605
DataBaseE.Med   -2.040366   0.176976 -11.529  < 2e-16 ***
DataBaseW.Med   -0.381100   0.177535  -2.147   0.0318 *
BaitCodeSquid    0.121709   0.049533   2.457   0.0140 *
HookTypehook_18  0.149159   0.068388   2.181   0.0292 *
HookTypehook_J   0.688695   0.061669  11.168  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 2159.6  on 929  degrees of freedom
Residual deviance: 1332.1  on 921  degrees of freedom
AIC: 2928

Number of Fisher Scoring iterations: 5


Full coefficients are

(Intercept):       -5.425167
Mean_SST:         0.04318624
SoakTimeDays:       0.582894
Mean_Depth:      -0.01368706
DataBase:           Atlantic      E.Med      W.Med
                   0.0000000 -2.0403662 -0.3810999
BaitCode:           Mackerel      Squid
                   0.0000000  0.1217092
HookType:            hook_16    hook_18     hook_J
                   0.0000000  0.1491593  0.6886951


Analysis of Deviance Table

Model: binomial, link: logit

Response: Tres

Terms added sequentially (first to last)


             Df Deviance Resid. Df Resid. Dev  P(>|Chi|)
NULL                           929    2159.63
Mean_SST      1     3.77       928    2155.85       0.05
SoakTimeDays  1    71.83       927    2084.02  2.341e-17
Mean_Depth    1    53.37       926    2030.65  2.764e-13
DataBase      2   538.73       924    1491.92 1.036e-117
BaitCode      1     6.11       923    1485.81       0.01
HookType      2   153.76       921    1332.05  4.094e-34
```


lo(Mean_SST)
Mean_SST
22
24
26
28
-0.4
-0.2
0.0
0.2
0.4
0.6
lo(SoakTimeDays)
SoakTimeDays
0.5
1.0
1.5
2.0
-0.5
0.0
0.5
1.0
lo(Mean_Depth)
Mean_Depth
35
40
45
-0.5
0.0
0.5


Residuals vs Fitted
Residuals
Predicted values
-6.5
-5.5
-4.5
-3.5
354
386
829
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
-3
-2
-1
0
1
2
3
354
Scale-Location
√|Std. deviance resid.|
Predicted values
354
386
829
Residuals vs Leverage
Std. deviance resid.
Leverage
0.00
0.02
0.04
0.06
0.08
0.10
354
829
831
Cook's distance

11.22 The effect of hook position on the probability of swordfish capture

```
Call:
glm(formula = SPres ~ HP + B + H + O, family = binomial(link = "logit"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.9060  -0.8830  -0.4828   0.2067   4.0687

Coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept) -4.609758   0.088256 -52.232   <2e-16 ***
HP          -0.053555   0.033250  -1.611   0.1073
BSquid       0.127725   0.049515   2.579   0.0099 **
Hhook_18     0.149195   0.068377   2.182   0.0291 *
Hhook_J      0.688650   0.061657  11.169   <2e-16 ***
OE.Med      -1.748954   0.094528 -18.502   <2e-16 ***
OW.Med      -0.004735   0.053013  -0.089   0.9288
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 3591.3  on 2789  degrees of freedom
Residual deviance: 2809.6  on 2783  degrees of freedom
AIC: 5106.2

Number of Fisher Scoring iterations: 6


Full coefficients are

(Intercept):       -4.609758
HP:               -0.05355483
B:                  Mackerel        Squid
                   0.0000000    0.1277245
H:                   hook_16      hook_18       hook_J
                   0.0000000    0.1491947    0.6886496
O:                  Atlantic        E.Med        W.Med
                 0.000000000 -1.748954121 -0.004734850
```



11.23 Predicted catch tables

Turtles per hook

	Atlantic_mu	Atlantic_SE	E_Med_mu	E_Med_SE	W_Med_mu	W_Med_SE
Mackerel_16	4.055E-04	1.654E-04	-	-	1.763E-04	6.817E-05
Mackerel_18	4.334E-04	1.735E-04	-	-	3.087E-04	1.081E-04
Mackerel_J	3.696E-04	1.544E-04	1.010E-04	1.010E-04	3.639E-04	1.246E-04
Squid_16	1.215E-03	3.696E-04	-	-	1.168E-03	2.963E-04
Squid_18	1.298E-03	3.809E-04	-	-	2.044E-03	3.962E-04
Squid_J	1.107E-03	3.501E-04	1.010E-04	1.010E-04	2.409E-03	4.320E-04

Kg swordfish per hook

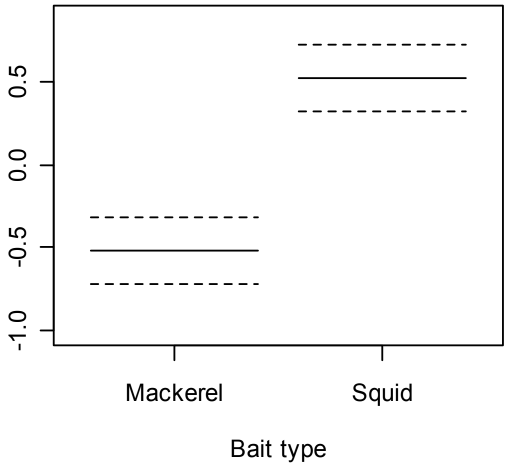
	Atlantic_mu	Atlantic_SE	E_Med_mu	E_Med_SE	W_Med_mu	W_Med_SE
Mackerel_16	1.869E-01	1.255E-01	5.244E-02	3.482E-01	5.056E-02	1.021E-01
Mackerel_18	2.579E-01	1.280E-01	5.907E-02	2.283E-01	7.631E-02	1.036E-01
Mackerel_J	3.416E-01	1.219E-01	1.220E-01	2.163E-01	1.750E-01	9.521E-02
Squid_16	3.209E-01	1.235E-01	1.067E-01	3.242E-01	9.213E-02	1.000E-01
Squid_18	4.192E-01	1.240E-01	1.137E-01	1.027E-01	1.316E-01	1.010E-01
Squid_J	4.927E-01	1.228E-01	2.084E-01	7.934E-02	2.678E-01	9.475E-02

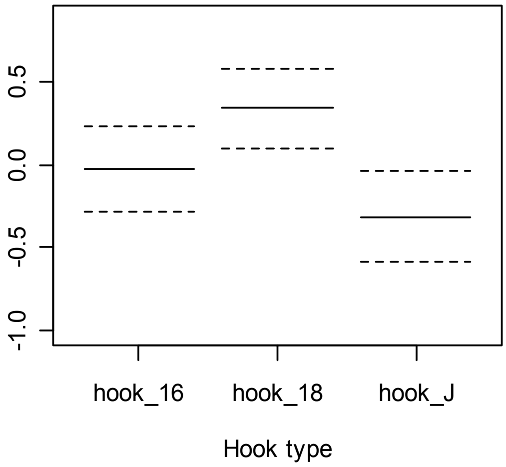
Turtles per tonne of swordfish

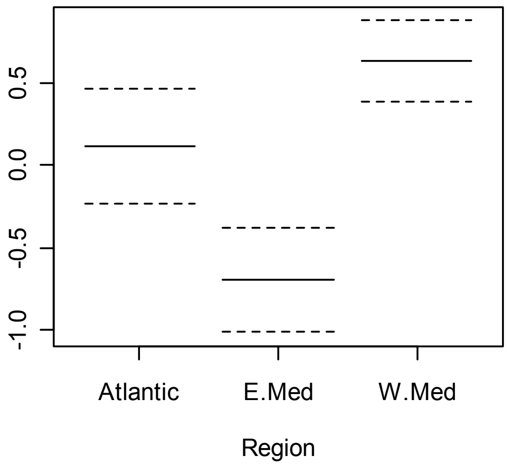
	Atlantic_mu	Atlantic_SE	E_Med_mu	E_Med_SE	W_Med_mu	W_Med_SE
Mackerel_16	2.180	0.927	-	-	3.497	1.414
Mackerel_18	1.696	0.716	-	-	4.076	1.503
Mackerel_J	1.089	0.474	0.872	0.920	2.084	0.733
Squid_16	3.809	1.263	-	-	12.785	3.547
Squid_18	3.112	0.996	-	-	15.583	3.409
Squid_J	2.256	0.773	0.491	0.497	9.047	1.840

11.24 Binomial modelling of tuna bycatch rate

```
Call:
glm(formula = TUNAres ~ B + H + O, family = binomial(link = "logit"),
    contrasts = list(B = "contr.sum", H = "contr.sum", O = "contr.sum"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.9493  -0.5616  -0.3749  -0.2672   3.2808

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -7.57240    0.11937 -63.435  < 2e-16 ***
B1          -0.52535    0.10106  -5.198 2.01e-07 ***
H1          -0.02515    0.12941  -0.194  0.84592
H2           0.33951    0.11900   2.853  0.00433 **
O1           0.09721    0.14964   0.650  0.51590
O2          -0.71046    0.17259  -4.116 3.85e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 563.36  on 929  degrees of freedom
Residual deviance: 490.49  on 924  degrees of freedom
AIC: 726.16

Number of Fisher Scoring iterations: 6


Full coefficients are

(Intercept):      -7.572404
B:                 Mackerel       Squid
                 -0.5253537   0.5253537
H:                  hook_16     hook_18      hook_J
                -0.02514794  0.33950706 -0.31435912
O:                 Atlantic       E.Med       W.Med
                 0.09721494 -0.71045750  0.61324256


The odds ratios:
Full coefficients are

(Intercept):    0.0005144545
B:                  Mackerel     Squid
                   0.5913462 1.6910568
H:                   hook_16   hook_18    hook_J
                   0.9751656 1.4042552 0.7302567
O:                  Atlantic     E.Med     W.Med
                   1.1020972 0.4914193 1.8464088
```

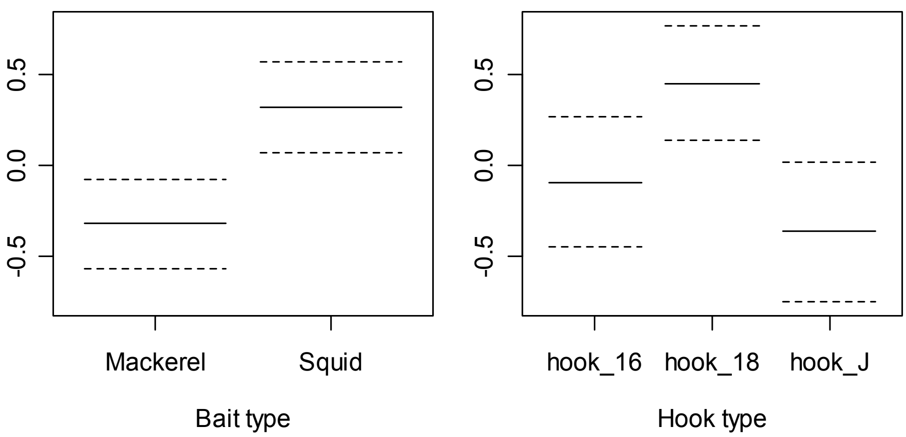

0.5
0.0
-0.5
-1.0
Mackerel
Squid
Bait type


0.5
0.0
-0.5
-1.0
hook_16
hook_18
hook_J
Hook type


0.5
0.0
-0.5
-1.0
Atlantic
E.Med
W.Med
Region

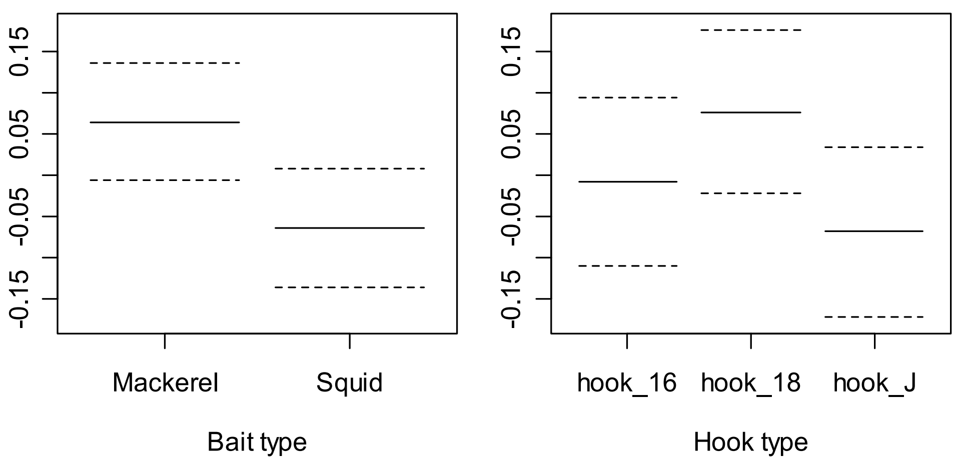
11.25 Binomial modelling of Bluefin tuna bycatch rates in the western Mediterranean

```
Call:
glm(formula = BFTres ~ B + H, family = binomial(link = "logit"),
    contrasts = list(B = "contr.sum", H = "contr.sum"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.8917  -0.6472  -0.5943  -0.4314   3.3749

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -6.99093    0.12979 -53.862  < 2e-16 ***
B1          -0.32061    0.12339  -2.598  0.00936 **
H1          -0.08918    0.17671  -0.505  0.61381
H2           0.45052    0.15688   2.872  0.00408 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 274.20  on 359  degrees of freedom
Residual deviance: 258.49  on 356  degrees of freedom
AIC: 392.01

Number of Fisher Scoring iterations: 6


Full coefficients are

(Intercept):       -6.99093
B:                 Mackerel       Squid
                 -0.3206119   0.3206119
H:                  hook_16     hook_18      hook_J
                -0.08917525  0.45051557 -0.36134031


The odds ratios:
Full coefficients are

(Intercept):    0.0009201903
B:                  Mackerel     Squid
                   0.7257048 1.3779707
H:                   hook_16   hook_18    hook_J
                   0.9146853 1.5691210 0.6967418
```



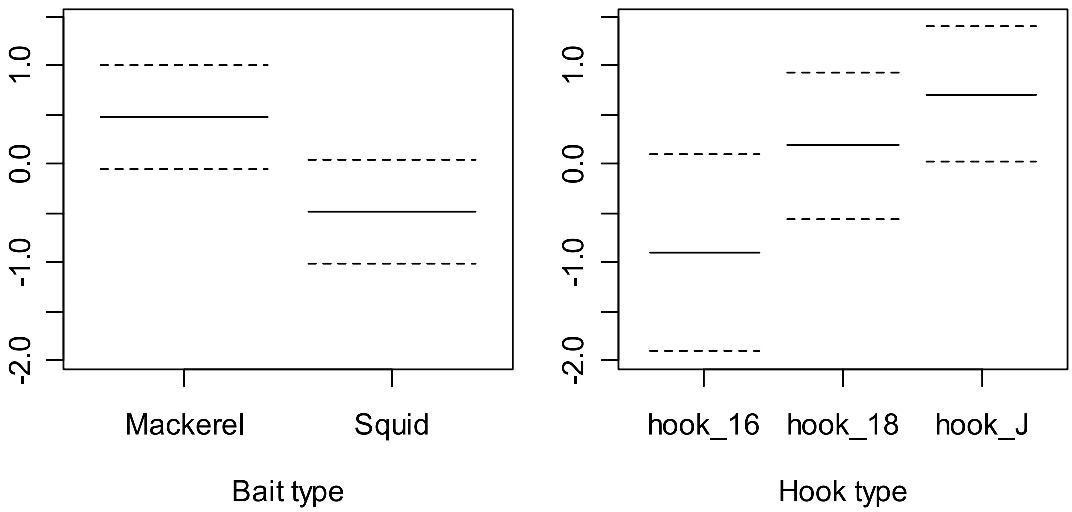
11.26 Binomial modelling of blue shark bycatch rates in the Atlantic

```
Call:
glm(formula = SHKres ~ B + H, family = binomial(link = "logit"),
    contrasts = list(B = "contr.sum", H = "contr.sum"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.9822  -1.0971  -0.2027   0.8219   4.3829

Coefficients:
             Estimate Std. Error  z value Pr(>|z|)
(Intercept) -4.009109   0.035814 -111.943   <2e-16 ***
B1           0.064442   0.035746    1.803   0.0714 .
H1          -0.007791   0.050678   -0.154   0.8778
H2           0.076553   0.049538    1.545   0.1223
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 394.34  on 209  degrees of freedom
Residual deviance: 388.27  on 206  degrees of freedom
AIC: 1003.3

Number of Fisher Scoring iterations: 5

Full coefficients are

(Intercept):       -4.009109
B:                   Mackerel        Squid
                   0.06444164  -0.06444164
H:                    hook_16      hook_18       hook_J
                 -0.007790508  0.076553395 -0.068762887

The odds ratios:
Full coefficients are

(Intercept):    0.01814955
B:                 Mackerel     Squid
                  1.0665633 0.9375908
H:                  hook_16   hook_18    hook_J
                  0.9922398 1.0795598 0.9335480
```



11.27 Binomial modelling of billfish bycatch rates in the Atlantic

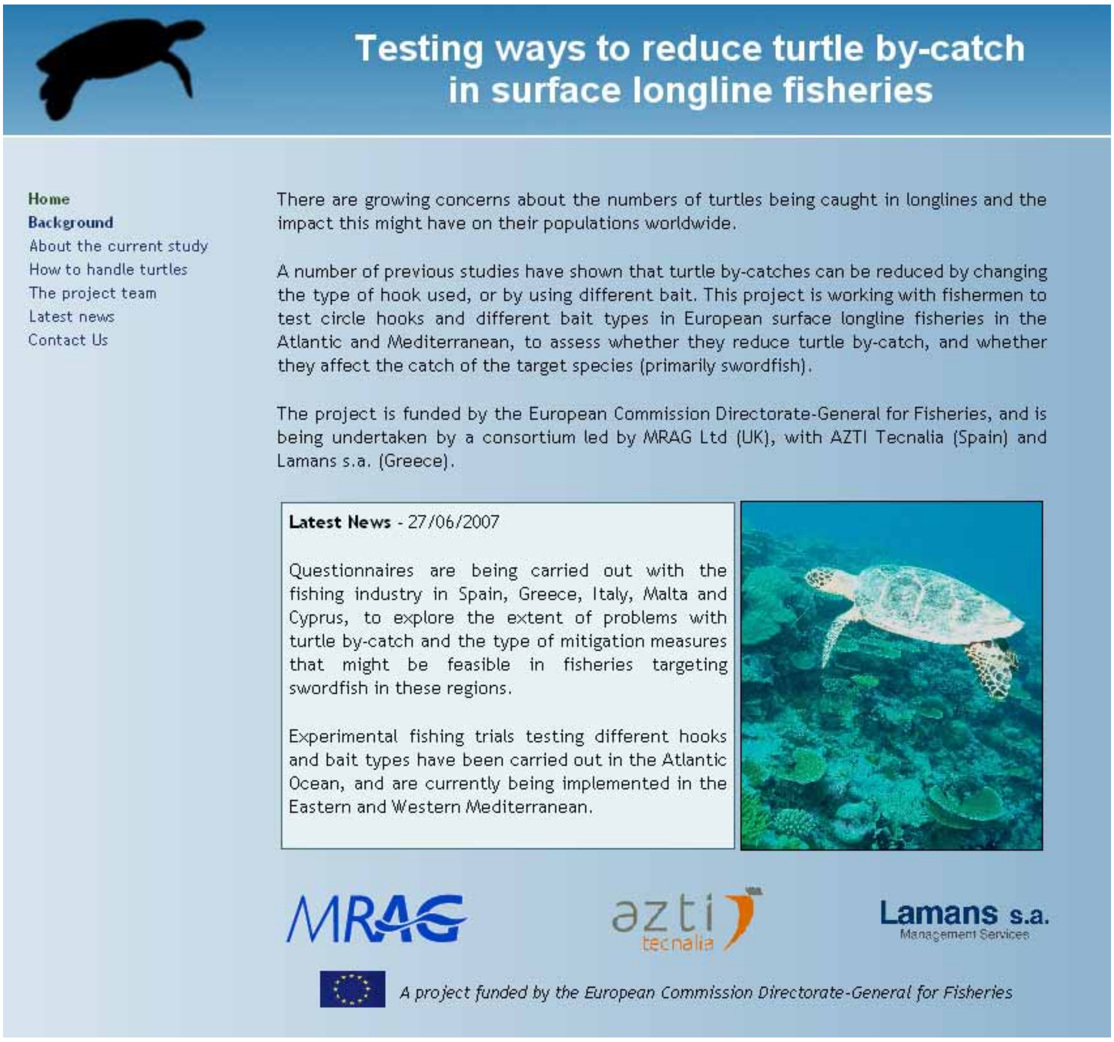
```
Call:
glm(formula = BILLres ~ B + H, family = binomial(link = "logit"),
    contrasts = list(B = "contr.sum", H = "contr.sum"))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.3268  -0.2425  -0.1555  -0.1280   2.6657

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -9.4928     0.3144 -30.190   <2e-16 ***
B1            0.4808     0.2631   1.827   0.0676 .
H1           -0.8987     0.5018  -1.791   0.0733 .
H2            0.1872     0.3752   0.499   0.6177
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 138.18  on 929  degrees of freedom
Residual deviance: 128.63  on 926  degrees of freedom
AIC: 172.54

Number of Fisher Scoring iterations: 8

Full coefficients are

(Intercept):     -9.492795
B:                Mackerel      Squid
                 0.4808413 -0.4808413
H:                 hook_16    hook_18     hook_J
                -0.8986524  0.1872494  0.7114030

The odds ratios:
Full coefficients are

(Intercept):    7.53931e-05
B:                 Mackerel     Squid
                   1.617435  0.618263
H:                  hook_16   hook_18    hook_J
                  0.4071179 1.2059280 2.0368469
```



1.0
0.0
-1.0
-2.0
Mackerel
Squid
Bait type
1.0
0.0
-1.0
-2.0
hook_16
hook_18
hook_J
Hook type

12 Appendix 4: Website screen shots

The website is currently hosted at http://www.mrag.co.uk/turtle



Testing ways to reduce turtle by-catch in surface longline fisheries

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The problem with turtles and longlines

All species of marine turtles are protected reptiles and are considered to be endangered or threatened. Depending on geographic region, the two species most commonly caught in longlines are loggerhead turtles (*Caretta caretta*) and leatherback turtles (*Dermochelys coriacea*).

Turtles become caught on longlines mainly due to their general ecology, feeding behaviour and the overlap in their geographical and depth distributions with the target species of major longline fisheries - tuna, swordfish and other billfish. The leatherback and loggerhead turtles dive within the same depths at which these species forage and at which the lines are set, and are also attracted to the bait used to attract the large pelagic fish.

Loggerhead turtle, *Caretta caretta*

Leatherback turtle, *Dermochelys coriacea*

Leatherback turtles are highly migratory species that spend considerable periods of their life in the open ocean, travelling large distances between their nesting, development and feeding areas. They are highly carnivorous, primarily feeding on jelly fish and other invertebrates, often foraging along oceanic fronts where upwelling occurs.

Loggerheads also make considerable migrations, using warm currents such as the Gulf Stream which are considered as feeding grounds and developing habitats for the final juvenile stages. Their feeding behaviour may change with age to target more benthic prey, but loggerheads are primarily carnivorous, feeding on jellyfish, floating molluscs and egg clusters, fish, small crustaceans and squids during their migrations in the open sea.

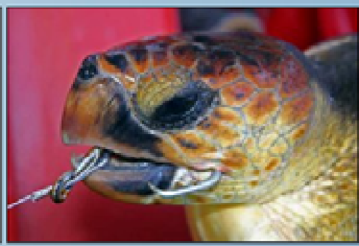
It is these prey preferences and residence in surface waters whilst foraging along oceanic fronts, eddies and gyres that leads these two turtle species to become so frequently caught in longlines targeting swordfish.

Reducing turtle bycatch

Surface longline fisheries traditionally use 'J-hooks' (a hook shaped like a J) and often use squid bait. Previous research has indicated that using circle hooks and mackerel bait can significantly reduce the number of turtles incidentally caught in surface longlines.

Large circle hooks are suggested to be more difficult for turtles to swallow than the usual J-type hooks. As a result, it is believed that turtles are more likely to be hooked in the mouth rather than more deeply within the oesophagus or stomach with circle hooks, making it easier for the turtle to be released which can increase the turtle's chances of survival. There are also suggested to be fewer incidences of turtles becoming foul-hooked on another part of their body, such as a flipper, with circle hooks.

J-hook and circle hook



Turtle hooked in its mouth

Studies have also shown that using mackerel as bait rather than squid can reduce the number of turtles caught. It is possible that the turtles are less attracted to the fish bait compared to squid, but another attribute which reduces the risk of the turtle hooking itself, is that fish bait tends to come free of the hook more readily than squid bait during their successive attempts to remove it.

Clearly, gear modifications may also have an effect on the ability of the gear to catch the target species, swordfish. This is obviously a prime concern of fishermen and any measures adopted to reduce turtle by-catch should also attempt to minimise any detrimental effect on catches of swordfish.

Testing ways to reduce turtle by-catch in surface longline fisheries

About the Current Study

The current project will carry out pilot fishing trials within European Union fishing fleets to test the effects of different hook and bait types (which have shown promising results in fisheries elsewhere) on both turtle and swordfish catch rates.

Hooks to be tested include:

- 0^{o} offset 16/0 circle hooks
- 10^{o} offset 18/0 circle hooks

against the traditional J-type hooks used in these fisheries, in combination with either squid or whole fish bait (mackerel).

J-hook and circle hook

Bait: thawing mackerel next to boxes of squid

The trials will be conducted in collaboration with industry in the following fisheries:

- Greek longline fishery in eastern Mediterranean
- Spanish longline fishery in western Mediterranean
- Spanish distant water longline fishery in Atlantic Ocean

Experimental fishing will be carried out by one vessel in each region with observers collecting data on turtle bycatch and on target species to determine whether mitigation measures negatively impact their catch rates.

Vessel from the Greek swordfish fishery

Spanish swordfish longliner in the Atlantic

Involvement of the fishing industry at each stage of the project is key to its success, as to be effective, the mitigation measure must be acceptable to fishers and in addition practical and capable of maintaining the economic viability of the fisheries concerned.

The project will also conduct a questionnaire survey with the fishing industry to determine their usual gear configurations, fishing areas and the areas in which most problems with turtle by-catches are experienced. The questionnaire also aims to identify the extent to which turtle by-catch is a problem for the industry, and the type of gear and bait modifications that might be acceptable to them. It provides a platform for the industry to contribute to the development of potential mitigation measures to reduce turtle bycatch in their fleets.

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How to handle turtles

When you are fishing and you accidentally catch a turtle on your line, you can help the turtle survive by following these guidelines.

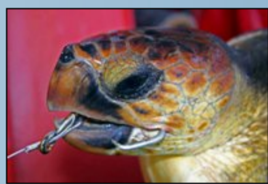
Bringing the turtle on board:

- Bring the turtle on board using a dip net. Do not use a gaff or pull the line.
- If the turtle is too large to bring on board, cut the line as close to the hook as possible.

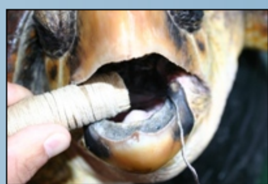
- When handling the turtle, hold it securely by its shell. Do not grab the eye sockets or hold the turtle by its flippers.

- Place the turtle on a tyre to immobilise it.
- Leave it in a secure shaded location and covered with wet towels, without covering the turtle's nostrils. Spray with water every few hours, avoiding spraying the turtle in the face.

Removing the hook:



- If the turtle is hooked lightly in the mouth or flippers, and the hook can be easily removed, remove it with a dehooking device, or pare the hook with bolt cutters and remove it.



- If the turtle is hooked more deeply in the throat and the hook barb cannot be seen, cut the line as close to the hook as possible.
- A gag such as a wooden handle or piece of rope can be useful so the turtle does not bite.

Assess the turtle's condition - is it conscious or unconscious?

- **Unconscious** - perform a reflex test every three hours by gently touching the eye or lightly pulling the tail. If there is a response, begin to treat the turtle as conscious. If there is no response after 24 hours, return the turtle to the ocean.
- **Conscious** - Keep the turtle on board for at least 4 hours or until it appears healthy before releasing into the ocean.

Releasing the turtle:

- Make sure the vessel is stopped and out of gear. Use a dip net to gently lower the turtle to the ocean and slide the turtle head first back into the water. Ensure the turtle is clear of the vessel before motoring away.

Further information and guidelines:

- UNEP Manual for fishermen on management of marine turtles (external links to RAC-SPA site):

English: Sea Turtle Handling Guidebook for Fishermen
Español: Guia para Pescadores sobre el Manejo de las Tortugas Marinas
Ελληνικά: Εγχειρίδιο Διάσωσης των Θαλάσσιων Χελωνών (για τους ψαράδες)

- National Marine Fisheries Service Turtle Handling Placard:

English: Turtle Handling Placard
Español: Poster Información para el Manejo de Tortugas

- Guidelines on reducing turtle by-catch produced by Blue Ocean Institute:

English: Catch fish not turtles using longlines (English)

- NOAA National Marine Fisheries Service - detailed protocols on handling turtles

English: Epperley et al (2004) Careful release protocols for sea turtle release with minimal injury. NOAA Technical Memorandum NMFS-SEFSC-524, 42p.
Español: Epperley et al (2004) Procedimientos casi inocuos para la suelta de tortugas marinas. Memorando Technico de NOAA NMFS-SEFSC-524, 48p.

- Training leaflet for handling turtles:

Ελληνικά: Τι μπορείς να κάνεις εσύ

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The Project Team

The project is being coordinated by MRAG Ltd with AZTI Tecnalia and Lamans s.a. running the experimental fishing trials.

MRAG

MRAG is a unique and highly motivated consulting firm dedicated to promoting sustainable use of aquatic resources through sound integrated management policies and practices. As a leader in this field, MRAG has a long and highly productive history of designing and implementing integrated resource management systems in marine, estuarine, riverine and floodplain environments. For nearly two decades, MRAG has been working worldwide. It now has accumulated experience in more than 60 countries for government agencies, international financing institutions, the European Commission, non-governmental organisations and private sector companies.

MRAG has hands-on experience of fisheries management and implementing observer schemes, having managed all aspects of the fisheries of the Falkland Islands, South Georgia and British Indian Ocean Territories for more than 10 years. This has included resource assessment, catch quotas and management, licensing, international negotiation, MCS and introducing measures that have reduced bycatch of birds in longlining operations from several thousand per year to zero.

www.mrag.co.uk

azti tecnalia

Azti Tecnalia is a non-profit foundation, funded by the Department of Agriculture and Fisheries of the Autonomous Basque Government (Spain). Since its creation in 1984, AZTI has become a centre of excellence in the research, technological development and transference in the areas of Fisheries and Food Technology, Oceanography and Marine Environment. AZTI is currently working on more than 30 EU projects. The marine research unit of AZTI carries out research in order to provide innovative solutions for the requirements of the sector, administrations and society, in order to achieve sustainable management of the marine resources. Relevant to this project some specific work has included: Hake semi-pelagic longline selectivity and evaluation of selectivity models for hook and line gear, 2000; Fishing efficiency and selectivity of new hook designs in the semi-pelagic longline fishery targetting hake, 1996; and Bigeye (Thunnus obesus) bycatch estimates from the albacore Spanish surface fishery in the north east Atlantic: 2002-2003.

www.azti.es

Lamans s.a.
Management Services

Lamans is the largest fisheries and aquaculture consultancy in Greece, with over 25 years' experience. Lamans started its business activities focusing on the agricultural sector and subsequently expanded its services to regional development and the public sector. The company now provides management consultancy on issues of Business Organisation and Administration, Project and Program Management, Information Technology, Regional Development, Fisheries and Aquaculture, Environment and Quality Assurance. Lamans has extensive experience in the fisheries sector, in particular with Mediterranean fisheries and has excellent links with the Greek fishing fleets. It is the lead in the current consortium in the EU framework for "Strengthening Fishery Products Health Conditions in ACP/OCT Countries" and was involved, together with MRAG, in the feasibility study for DG Fisheries to examine the impact, setting and structure of a Community Fisheries Control Agency (CFCA) with responsibility for a Joint Inspection Structure (JIS). Lamans is also coordinating a trans-national Vocational Training Programme for Sustainable Fisheries Management of the Mediterranean Sea and its living resources.

www.lamans.gr

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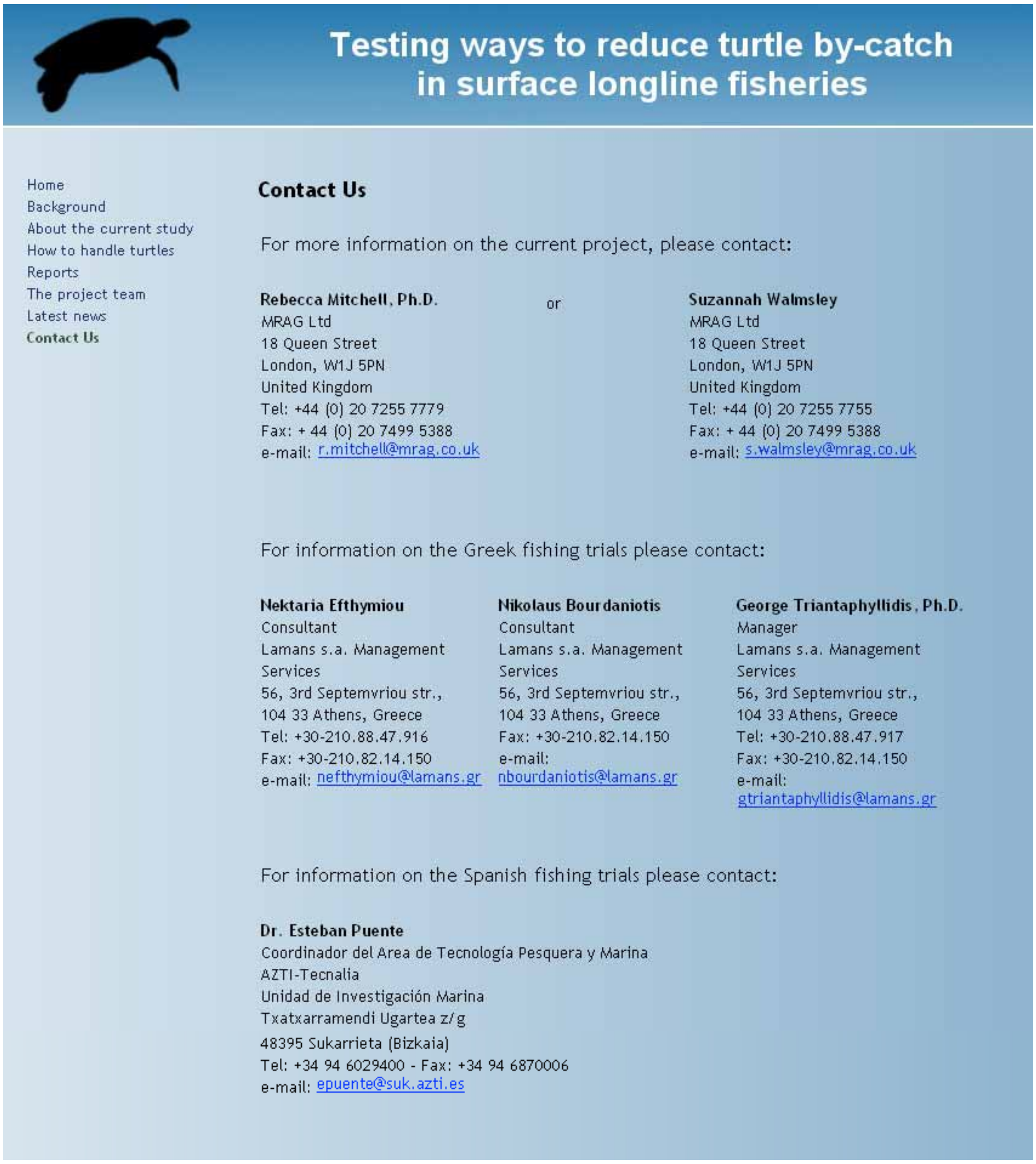
Latest news

27/06/2007

Questionnaires are being carried out with the fishing industry in Spain, Greece, Italy, Malta and Cyprus, to explore the extent of problems with turtle by-catch and the type of mitigation measures that might be feasible in fisheries targeting swordfish in these regions.

Experimental fishing trials testing different hooks and bait types have been carried out in the Atlantic Ocean, and are currently being implemented in the Eastern and Western Mediterranean.



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Tel: +34 94 6029400 - Fax: +34 94 6870006
e-mail: epuente@suk.azti.es

13 Appendix 5: Web Server Statistics for MRAG/turtle/

Program started at Mon-12-Nov-2007 15:26.
Analysed requests from Tue-16-Oct-2007 08:44 to Mon-12-Nov-2007 14:44 (27.25 days).

13.1 General Summary

(**Go To**: Top | General Summary | Monthly Report | Daily Summary | Domain Report | Search Word Report | Operating System Report | File Size Report | File Type Report | Directory Report | Request Report)

This report contains overall statistics.

Figures in parentheses refer to the 7-day period ending 12-Nov-2007 15:26.

Successful requests: 1,528 (19)
Average successful requests per day: 56 (2)
Successful requests for pages: 219 (3)
Average successful requests for pages per day: 8 (0)
Failed requests: 490 (6)
Distinct files requested: 46 (10)
Distinct hosts served: 52 (2)
Corrupt logfile lines: 1
Unwanted logfile entries: 57,027
Data transferred: 101.95 megabytes (1.02 megabytes)
Average data transferred per day: 3.74 megabytes (149.50 kilobytes)

13.2 Monthly Report

(**Go To**: Top | General Summary | Monthly Report | Daily Summary | Domain Report | Search Word Report | Operating System Report | File Size Report | File Type Report | Directory Report | Request Report)

This report lists the activity in each month.

Each unit ( ) represents 5 requests for pages or part thereof.

month	reqs	pages	
Oct 2007	1406	206	
Nov 2007	122	13	

Busiest month: Oct 2007 (206 requests for pages).

13.3 Daily Summary

(**Go To**: Top | General Summary | Monthly Report | Daily Summary | Domain Report | Search Word Report | Operating System Report | File Size Report | File Type Report | Directory Report | Request Report)

This report lists the total activity for each day of the week, summed over all the weeks in the report.

Each unit ( ) represents 2 requests for pages or part thereof.

day	reqs	pages	
Sun	0	0	
Mon	144	22	
Tue	537	84	
Wed	607	81	
Thu	211	27	
Fri	29	5	
Sat	0	0	

13.4 Domain Report

(**Go To**: Top | General Summary | Monthly Report | Daily Summary | Domain Report | Search Word Report | Operating System Report | File Size Report | File Type Report | Directory Report | Request Report)

This report lists the countries of the computers which requested files.

Listing domains, sorted by the amount of traffic.

reqs	%bytes	domain
1528	100%	[unresolved numerical addresses]

13.5 Search Word Report

(**Go To**: Top | General Summary | Monthly Report | Daily Summary | Domain Report | Search Word Report | Operating System Report | File Size Report | File Type Report | Directory Report | Request Report)

This report lists which words people used in search engines to find the site.

Listing query words, sorted by the number of requests.

reqs	search term
1	ÔÉÌÇ
1	kwh
1	ÂÉÏÌÇ×ÁÍÉÊÇÓ

13.6 Operating System Report

(**Go To**: Top | General Summary | Monthly Report | Daily Summary | Domain Report | Search Word Report | Operating System Report | File Size Report | File Type Report | Directory Report | Request Report)

This report lists the operating systems used by visitors.

Listing operating systems, sorted by the number of requests for pages.

no.	reqs	pages	OS
1	1528	219	Windows
	1080	160	Windows XP
	404	53	Windows 2000
	44	6	Unknown Windows

13.7 File Size Report

(**Go To**: Top | General Summary | Monthly Report | Daily Summary | Domain Report | Search Word Report | Operating System Report | File Size Report | File Type Report | Directory Report | Request Report)

This report lists the sizes of files.

size	reqs	%bytes
0	398	
1B- 10B	0	
11B- 100B	0	
101B- 1kB	125	0.05%
	469	1.58%

size	reqs	%bytes
1kB- 10kB		
10kB-100kB	402	7.82%
100kB- 1MB	95	42.45%
1MB- 10MB	39	48.10%

13.8 File Type Report

(**Go To**: Top | General Summary | Monthly Report | Daily Summary | Domain Report | Search Word Report | Operating System Report | File Size Report | File Type Report | Directory Report | Request Report)

This report lists the extensions of files.

Listing extensions with at least 0.1% of the traffic, sorted by the amount of traffic.

reqs	%bytes	extension
86	61.64%	.pdf [Adobe Portable Document Format]
688	35.72%	.jpg [JPEG graphics]
395	1.58%	.gif [GIF graphics]
151	0.52%	.htm [Hypertext Markup Language]
99	0.35%	.css [Cascading Style Sheets]
68	0.17%	[directories]
41	0.02%	[not listed: 1 extension]

13.9 Directory Report

(**Go To**: Top | General Summary | Monthly Report | Daily Summary | Domain Report | Search Word Report | Operating System Report | File Size Report | File Type Report | Directory Report | Request Report)

This report lists the directories from which files were requested. (The figures for each directory include all of its subdirectories.)

Listing directories with at least 0.01% of the traffic, sorted by the amount of traffic.

reqs	%bytes	directory
1528	100%	/turtle/

13.10 Request Report

(**Go To**: Top | General Summary | Monthly Report | Daily Summary | Domain Report | Search Word Report | Operating System Report | File Size Report | File Type Report | Directory Report | Request Report)

This report lists the files on the site.

Listing files, sorted by the number of requests.

reqs	%bytes	last time	file
43	68.65%	5/Nov/07 09:20	/turtle/docs/training_leaflet_gr.pdf
38	0.25%	8/Nov/07 12:56	/turtle/team.htm
32	0.25%	5/Nov/07 09:20	/turtle/handlingturtles.htm
23	18.88%	24/Oct/07 11:43	/turtle/docs/noaa_release_protocols.pdf
22	0.10%	31/Oct/07 12:13	/turtle/objectives.htm
18	0.11%	31/Oct/07 12:12	/turtle/background.htm
17	0.03%	31/Oct/07 12:12	/turtle/news.htm
12	5.43%	24/Oct/07 11:42	/turtle/docs/turtlebook_eng_lowres.pdf
12	0.05%	31/Oct/07 12:12	/turtle/contacts.htm
11	0.05%	31/Oct/07 12:12	/turtle/index.htm
4	1.38%	31/Oct/07 10:34	/turtle/docs/turtle_handling_placard_en.pdf
3	0.66%	24/Oct/07 11:42	/turtle/docs/turtle_handling_placard_es.pdf
1		22/Oct/07 12:57	/turtle/reports.htm
1	4.17%	31/Oct/07 12:12	/turtle/docs/noaa_release_protocols_es.pdf

This analysis was produced by analog 6.0.
Running time: Less than 1 second.

14 Appendix 6: Fisher Questionnaire

Questionnaire:
EU Surface Longline Swordfish Fisheries

Experimental fishing trials will be carried out in 2007 to test the effectiveness of different types of hooks and bait in EU swordfish longline fisheries in the Mediterranean and the Atlantic, to reduce the bycatch of turtles whilst maintaining or improving target catch rates.

The aim of this questionnaire is to gather information about current swordfish fishing practices in the Mediterranean and Atlantic, in particular to identify the commonly used gear and bait configurations used by the different fleets. It also aims to explore the disturbances to fishing activities caused by turtles and fishermen's ideas for minimising the accidental catch of turtles.

For questionnaires completed by an interview with a fisherman:
This interview should be carried out with a fishing boat owner or fishing master involved in surface longline fisheries in the Mediterranean or Atlantic. Only one interview should be carried out per fishing vessel. The interviewee should be allowed to consult with his crew to respond to the questions, if this is feasible.

For interviews:

Name of interviewer:………………………………………………Interview number ……….

(For interview number use the following format: 3-digit code starting 1xx for Greece, 2xx for Spain)

Date of interview:……………………………

Place of interview (e.g. name of fishing port)……………………………….

Fishery: Atlantic ☐ Western Mediterranean ☐ Eastern Mediterranean ☐

1. General information

1. Name (optional):………………………………………………....
2. How many years have you been fishing? ……………years
3. Which are the main fisheries you are involved in?

(mark up to three, from 1=most important, 2=second most important, 3=least important)

☐ Swordfish
☐ Tuna
☐ Albacore
☐ Other – Please specify:……………………………………
……………………………………

4. In each month, roughly how many days do you fish for swordfish?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

N.b. if the respondent finds it easier, they can give an average number of days for summer and winter. You should then ask which months would be 'summer' and which months would be 'winter' and fill in the average number of days for the relevant months.

The next questions relate to when you are fishing for swordfish.

For the vessel you use to fish for swordfish:

5. What is the name / registration of the vessel? …………………………………………
(This is for us to check we only carry out one interview per vessel)

6. Which port and country is it registered in?
Port: ………………………………………
Country:…………………………….…….

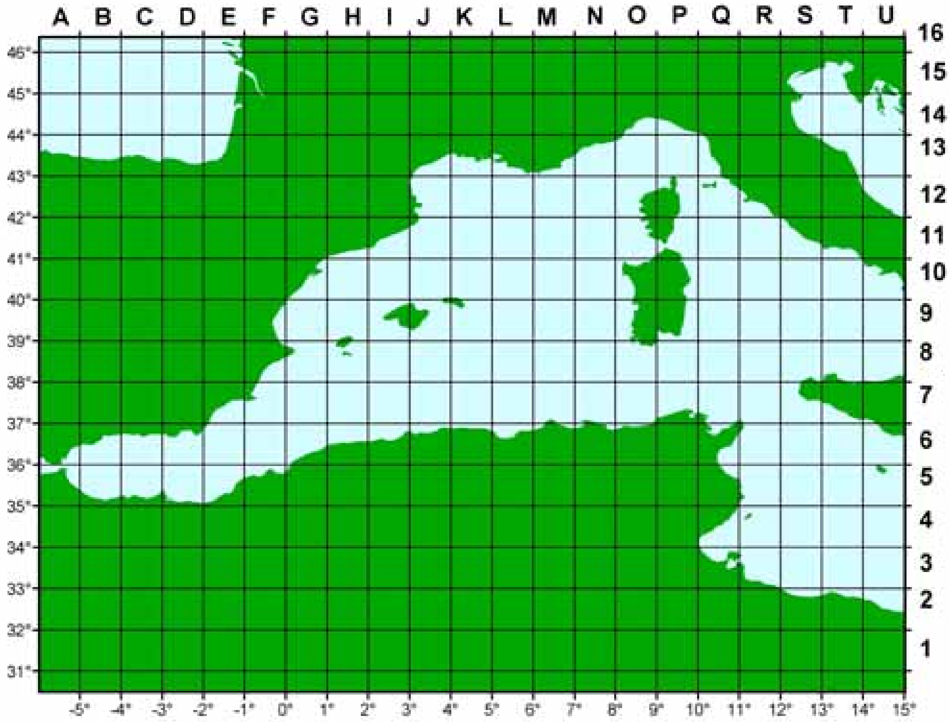
7. What is its length? ………………..metres

8. What is the power of the engine on the vessel? ……………………………hp

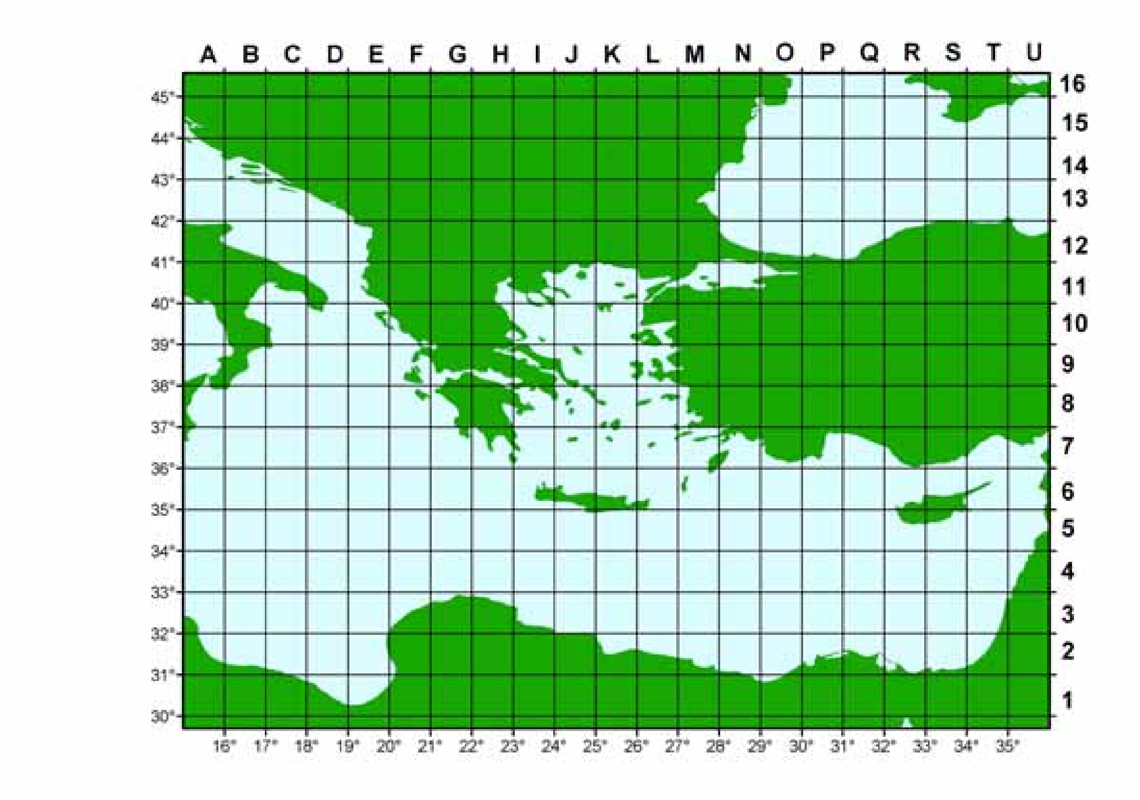
9. In which areas do you usually fish for swordfish?
[Indicate on the relevant map – mark an **X** in each box where you fish for swordfish]

Please mark with an **X** the areas where you fish for swordfish using surface longlines.

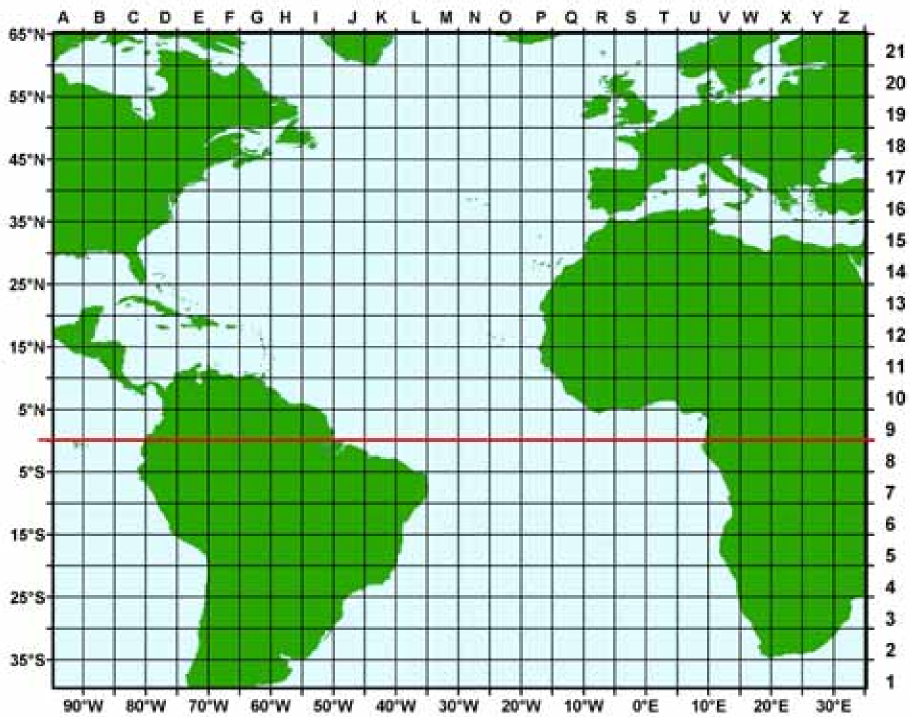
Western Mediterranean:



Eastern Mediterranean:



Atlantic:



2. Gear used in surface swordfish fishing

10. When fishing for swordfish, what type of pelagic longline do you usually use?
    - ☐ Traditional
    - ☐ American/Florian type

The following questions are for the <u>Traditional gear</u>. If you wish to give details on gear configuration for American type longlines as well, please use separate sheets.

11. What kind of hooks do you use?
(please tick the type and specify brand, size and ° offset, if known)

☐ J-hooks Brand/reference: ………………………….
Size: ..……………………………………
°Offset: ……………………………………..

☐ Circle-hooks Brand/reference: ………………………….
Size: ..……………………………………
°Offset: ……………………………………..

☐ Other Brand/reference: ………………………….
Size: ………….……………………………
°Offset: ……………………………………..

12. How long is the main line? …………………….metres

13. How many hooks do you use on each main line? ……………………….hooks

14. Do you use the same hooks on the whole length of the line? **Yes/No**

If No, please give more details on why and what is the configuration / combination of hooks:
…………………………………………………………………………………………………….
…………………………………………………………………………………………………….

15. a. Do you use other attractant devices during swordfish fishing?
☐ Yes ☐ No ☐ Sometimes
If No, go to question 16.

15.b. What sort of attractant devices do you use?
- ☐ Lightsticks
- ☐ Other (please specify)………………………………………………..

15. c. If they are lightsticks, are they chemical or electrical?
☐ Chemical ☐ Electrical

16. d. What colour are they?
- ☐ White
- ☐ Yellow
- ☐ Green
- ☐ Red
- ☐ Blue
- ☐ Other (please specify): …………………..

15. e. How are they spaced?

☐ Random

☐ Regularly spaced (please specify): 1 device every ……hooks/branchlines

17. a. How many lines do you set at one time?..............................line/s

16. b. If 2 or more, how far apart are lines set?............................metres / km / miles *

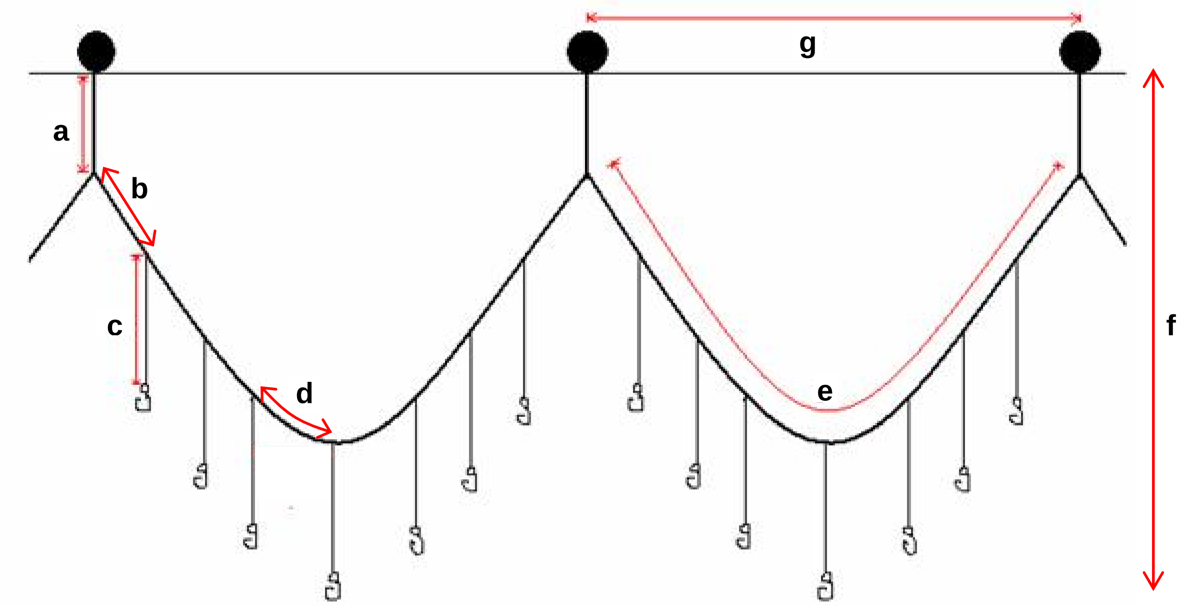
please delete as appropriate

16.c. When using several lines, how many lines and hooks do you use on each line?

Number of lines: ……..…………………………………….

Number of hooks on each line: ...…………………………

18. Please complete the table below for the measurements a, b, c, d, e, f and g if possible, in the diagram below, based on your usual gear configuation.



Key:

a = length of floatline
b = distance between floatline and first branchline
c = length of branchline

d = distance between branchlines
e = number of hooks between floats
f = depth of hooks
g = horizontal distance between floats (if known)

Code	Measurement	Units*
a =		metres / fathoms / …………………..
b =		metres / …………………..
c =		metres / fathoms / …………………..
d =		metres / …………………..
e =		(number of hooks)
f =		metres / fathoms / …………………..
g =		metres / …………………..

**please delete as applicable, or specify other measurement unit used.*
*When entering data into the database, please convert all measurements to **metres**.*

19. How long do you leave the lines in to soak? ……………………..hours

If they have difficulty answering this, you can go through this 'normal working timetable when operating the gear' and use it to estimate soak time:

SETTING TIME OF THE GEAR		HAULING OF THE GEAR	
Starting time	Ending time	Starting time	Ending time
Setting Midpoint =		Hauling Midpoint =	
Hauling midpoint – Setting midpoint = soak time:			

20. Leaving aside the issue of cost, do you think it would be possible to use a different type of hook (e.g. circle hook instead of J-hook) to fish for swordfish?

☐ Yes
☐ No
☐ Maybe

Why? Please explain:……………………………………………………………………………
……………………………………………………………………………………………………
…..

Bait used

21. What kind of bait do you most commonly use in summer and in winter (please tick)?

	Summer	Comment (e.g. species)
Fish	☐	
Squid	☐	
Other (please specify)	☐	

	Winter	Comment (e.g. species)
Fish	☐	
Squid	☐	
Other (please specify)	☐	

22. Do you use the same bait on the whole line, or do you mix it?

☐ same bait on whole line
☐ mixed bait on same line
☐ depends (please give more details, e.g. depends on season, fishing area etc):……………………………………………………………………………………..

23. What percentage of thawed and fresh bait do you use? (Total should = 100)

Thawed………….%
Fresh…………….%

24. What type and size of bait do you use?

Fish	**Squid**	**Other**
☐ whole ☐ pieces	☐ whole ☐ pieces	☐ whole ☐ pieces

25. Do you think it would be possible change the type of bait you use to fish for swordfish?

☐ Yes
☐ No
☐ Maybe

Why? Please explain:………………………………………………………………………………
……
…..

Fishery interactions with turtles

We would like to get an idea of how often you have accidental catches of turtles on your lines, which areas cause the most frequent accidental catches problems, and whether any support can be given to fishers to reduce level of those accidental catches.

26. Do turtles disrupt your fishing activity? **Yes / No**

If yes, what disturbance do they cause? (tick all that apply)

☐ steal bait from the lines
☐ reduces time fishing due to slowing of hauling procedures
☐ damage fish on the line
☐ damage fishing gear
☐ other, please detail………………………………………………………….
……
……

27. Last season, roughly how many turtles became accidentally caught on your lines? Please indicate approximate numbers each month:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

28. In which areas are these disturbances most frequent? Please indicate on the maps overleaf, with an **X** in the boxes where disturbances occur most frequently.

Add any other comments/detail here: ………………………………………………………….
……
……
..……………………………………………………..…………………………………………….

29. What proportion of turtles caught on the lines do you find alive?

☐ 0-25%
☐ 26% to 50%
☐ 51% to 75%
☐ 75% to 100%

29. What percentage of turtles are caught in the following ways:

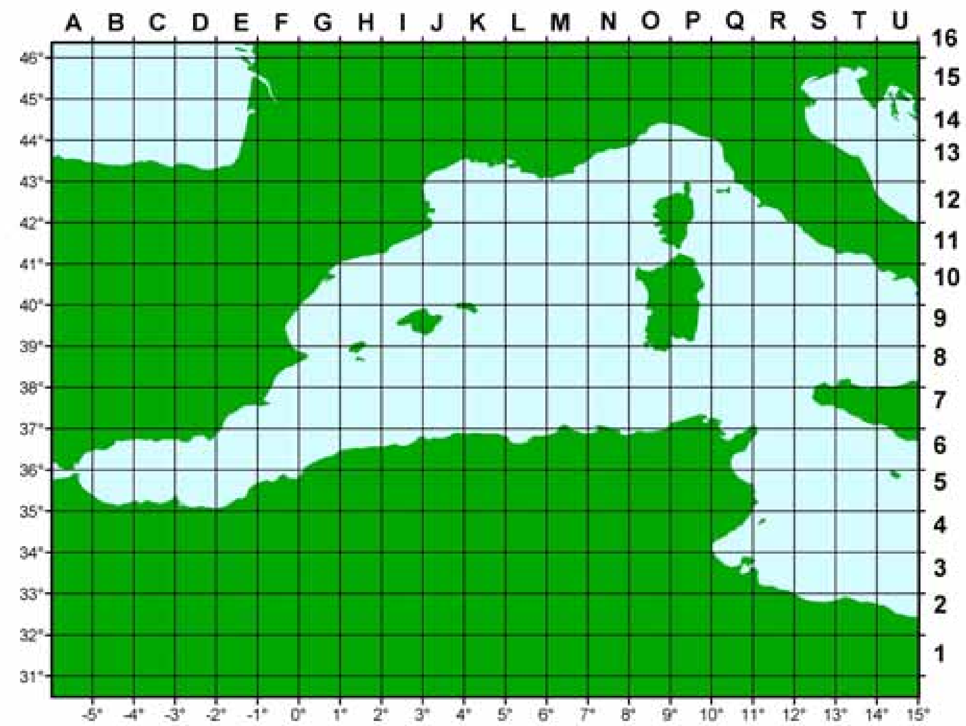
Hooked in mouth	%
Hooked in stomach / hook swallowed	%
Hooked on flipper / other body part	%
Entangled in line	%

30. Do you think anything should be/needs to be done to reduce number of turtles caught? Yes/No

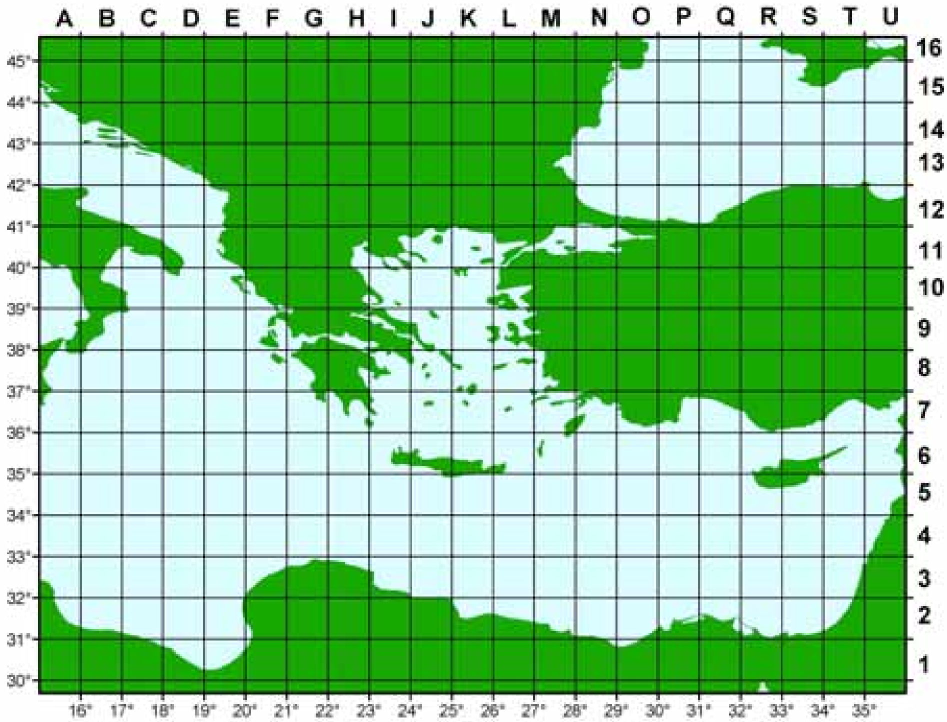
If yes, how do you think this could be achieved?
……
……
……
………

Please mark with an **X** the boxes where interactions with turtles occur most frequently:

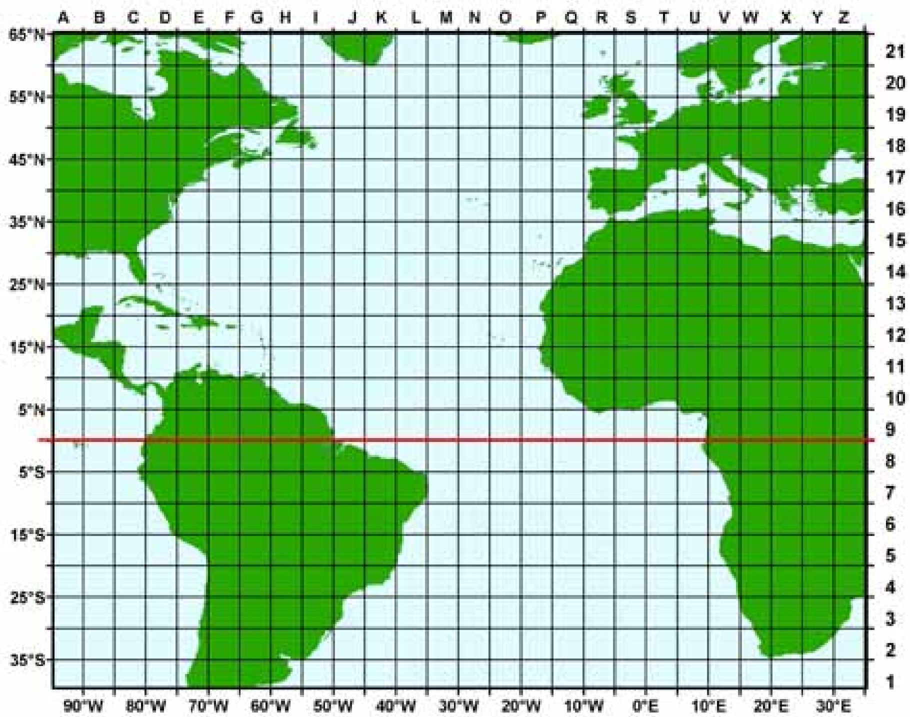
Western Mediterranean:



Eastern Mediterranean:



Atlantic:



15 Appendix 7: Raw Data

Press F11 to open Access Database.