FRONT PAGE

PROJECT FINAL REPORT

Grant Agreement number: 210496

Project acronym: MADE

Project title: Mitigating adverse ecological impacts of open ocean fisheries

Funding Scheme: Small collaborative project

Period covered: from 01/05/2008 to 31/12/2012

Name of the scientific representative of the project's co-ordinator[1],

Dr Laurent DAGORN, IRD (Institut de Recherche pour le Développement)

Tel: +33 499 57 32 02

Fax: +33 499 57 32 95

E-mail: laurent.dagorn@ird.fr

Project website address: www.made-project.eu

[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

4.1 Final publishable summary report

This section must be of suitable quality to enable direct publication by the Commission and should preferably not exceed 40 pages. This report should address a wide audience, including the general public.

The publishable summary has to include **5 distinct parts** described below:

- An executive summary (not exceeding 1 page).
- A summary description of project context and objectives (not exceeding 4 pages).
- A description of the main S&T results/foregrounds (not exceeding 25 pages),
- The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results (not exceeding 10 pages).
- The address of the project public website, if applicable as well as relevant contact details.

Furthermore, project logo, diagrams or photographs illustrating and promoting the work of the project (including videos, etc…), as well as the list of all beneficiaries with the corresponding contact names can be submitted without any restriction.

EXECUTIVE SUMMARY

Collaborative Project n°210496
MADE: MITIGATING ADVERSE ECOLOGIAL IMPACTS OF OPEN OCEAN FISHERIES

Web site: www.made-project.eu

GENERAL OBJECTIVES OF THE PROJECT

The objective of the project was to propose measures that can mitigate the adverse impacts of fisheries targeting large pelagic fishes in the open ocean (purse seiners using fish aggregating devices and longliners), through appropriate knowledge on the ecology of species and the fisheries.

MITIGATE BYCATCH BY PELAGIC LONGLINERS (LL)

- For LL targeting tunas (tropical areas), the most effective technical mitigation measure to reduce shark and turtle bycatch is to fish only at deeper layers and remove the hooks in the shallower mixed layer. Deeper hooks could also reduce the catches of juvenile swordfish in the Mediterranean Sea. For LL targeting adult swordfish and (mostly in the temperate areas of the Atlantic) blueshark, the most effective measure to reduce shark bycatch would be to replace wire leader by monofilament leader (up to 4 times less shark bycatch). Time of day could also be used as a technical measure for swordfish fisheries: limiting the fishing period to nighttime (up to 5 a.m.) could allow to reduce 65% of total bycatch and 40-50% of shark bycatch.
- The artificial bait "EBAB" (Ecological-based artificial bait) was preliminarily tested and patented. Jaw hooking of J hooks with EBAB is similar to that obtained with circle hooks, thus possibly reducing post-release mortality of by-catch, and EBAB are highly reusable.
- Some areas in the central north Atlantic and south Atlantic appear to show increased pelagic predator biodiversity, including sensitive shark species currently subjected to EU fishery banning regulations. In the southwest Indian Ocean this also occurs in some areas of the Mozambique Channel and off the Horn of Africa. In the Mediterranean Sea, first results suggest that spatial fisheries closures could be used to protect juvenile swordfish. These areas can be targeted as pelagic Marine Reserves (MRs) but that will have the major caveat that their location changes across seasons, thus requiring a dynamic designation of MRs.

MITIGATE BYCATCH BY PURSE SEINERS USING FADS

- A major, previously unknown source of shark mortality was quantified: entanglement in drifting FADs. Using satellite tagging and underwater observations, a total of 480 000 – 960 000 sharks was estimated to die through entanglement. The solution is very simple: using non entangling or ecological FADs without any nets, a change already in progress in the EU purse seine fleet. Such non entangling FADs would also eliminate the entanglement of turtles in FADs.
- A guide of good practices to reduce the mortality of sharks and rays caught incidentally by purse seiners was produced. Following these practices, it was estimated that 10-20% of sharks encircled by purse seiners could be saved.
- Noting that the bycatch-to-catch ratios were always highest when catches were small, a practice consisting in avoiding setting on small schools of tuna (e.g. < 10 tons) could reduce the amount of bycatch by 23-43% and the number of bycaught silky sharks by 21-41%.

ASSESSING THE EFFECTS OF FADS ON THE BEHAVIOUR AND ECOLOGY OF PELAGIC FISH

- Tunas exhibit behavioral variability, switching between short and long residence times at FADs. The social behaviour of tunas is likely to play a role in the dynamics of tuna at FADs.
- In an area naturally enriched with logs (Mozambique Channel), condition indices of tunas associated with logs were lower than those measured from free-swimming schools. This study highlights the need for baselines to assess the impacts of FADs on the ecology of tunas and other associated species.

SUMMARY DESCRIPTION OF PROJECT CONTEXT AND OBJECTIVES

This last decade, an increasing number of scientists, politicians, fishers and conservationists clamoured for action to be carried out to resolve the problem of by-catch and discard in fisheries. However, the reality is that, for fisheries catching large pelagic fishes such as purse seiners using fish aggregating devices (FADs) and pelagic longliners, more investigations must be done to reduce by-catch and, more generally, the adverse impacts of these fisheries. This is key to ensure the sustainability of these fisheries.

A particular attention has been paid worldwide on pelagic longline fisheries, as they catch large amounts of by-catch (seabirds, turtles, sharks, etc.). Seabird by-catch mitigation methods have now been established in many fisheries worldwide (Hall and Mainprize 2005), and several projects have been conducted to reduce the by-catch and mortality of turtles (Swimmer et al 2006), all being species protected by international conventions. Synthesis of these past and current studies and their application must be done in order to integrate these outcomes, but similar research efforts must also be developed on the other major longline by-catch groups that remain largely unaddressed by research and technological development: pelagic sharks and juvenile (undersized) swordfish. Sharks are long-lived, low fecundity, top predators. These characteristics reduce resilience of shark populations and make them highly susceptible to overexploitation, and concerns regarding this possibility have been increasing due to their progressive importance in the catches and to signs of population collapse worldwide. Catch of juvenile swordfish is considered a major problem in the Mediterranean and Atlantic longline fisheries, and the imposition of a size limit (approx. 25 kg) has not had satisfactory effects.
In the same ecosystems, another issue attracts the attention of international tuna commissions, scientists, fishers and conservationists: the use of drifting fish aggregating devices (FADs) which are floating objects used by fishers to attract pelagic fish. In the last years, 60-80% of the global catch of tropical tuna purse seiners was made on tunas associated with floating objects (Dagorn et al. 2013, Fonteneau et al. 2013, Leroy et al. 2013). The use of drifting FADs by the purse seine fishery raises the possibility of three potential negative impacts (Dagorn et al. 2013): (i) reduction in yield per recruit of target species (tunas), as fishing on FADs increases the catches of juvenile bigeye and yellowfin tunas, (ii) increased by-catch and perturbation of pelagic ecosystem balance (as compared with fishing on free-swimming schools), with a particular concern on sharks, and (iii) deleterious alteration of the normal movements of the species associated with FADs. This last point concerns the possible ecological impacts of the changes of the environment caused by the deployment of FADs, which represent a different impact from fishing. In the recent years, FADs have received particular attention by environmental groups and scientists, with discussions going from complete ban of FADs to new practices to ensure the sustainable use of these fishing devices.

The European open ocean pelagic fishery is one of the main sources of catch, income and employment for the European fishery. Fishing vessels belonging to Spain, France, Portugal, Italy and Greece operate in all tropical oceans (Atlantic, Indian, Pacific) and in the Mediterranean Sea, with interactions with many developing countries.

It is known that some fishing practices can threaten the long-term sustainability of fisheries and the maintenance of marine biodiversity. In the framework of ecosystem approach to fisheries (EAF), there is a major international concern and pressure to find measures that can effectively minimize the adverse impacts of fisheries. Adverse impacts comprise by-catch of non-target species/sizes, habitat modification, and undesirable biological interactions. Moreover, by-catch can generate conflicts between fisheries, as by-catch of some fisheries represents catch of others.

Historically, one of the first by-catch issue generating public attentions was the incidental mortality of dolphins in the tuna purse-seine fishery of the eastern Pacific Ocean during the 1960s. However, more generally, research and actions focused on this topic mainly concerned benthic and demersal

resources exploited by both active and passive gears: otter trawl, beam trawl, demersal seines, dredges, gill-nets, traps, bottom longline (Kaiser and de Groot, 2000). Moreover, several works integrated the habitats in order to mitigate the effects of fishing activities on them and the species (spatial measures).
It is only recently that pelagic fisheries, other than the tuna-dolphin issue in the Eastern Pacific Ocean, started to be concerned with such issues and research, because there was a general belief that the impacts of anthropogenic pressures on fish communities are mainly limited to the coastal zones (Caddy, 1993). While this assumption was probably valid during a great part of the 20th century, human direct and indirect influences on oceanic environments are changing and expanding. Gillnet and then pelagic longlines catching large pelagic fishes such as sharks, turtles, marine mammals, seabirds (Casey and Myers, 1998; Lewison et al., 2004). The massive increase of the use of FADs in tropical oceans (Fonteneau et al., 2000; Dagorn et al. 2013, Fonteneau et al. 2013, Leroy et al. 2013) or the problems induced by the global climate change (Greene and Pershing, 2007) clearly illustrate that the impact of human activities now concerns the whole world Ocean.

Target species of these fisheries (tunas and billfishes) are managed by international tuna commissions such as IOTC (Indian Ocean), ICCAT (Atlantic Ocean), IATTC (Eastern Pacific Ocean) and WCPFC (Western and Central Pacific Ocean). These commissions need integrated information and proposals to mitigate the adverse impacts of these fisheries.

Considering this context, three main objectives were identified for the MADE project:
- to propose mitigation methods to mitigate bycatch by pelagic longliners, with a particular focus on sharks and juvenile swordfish
- to propose mitigation methods to mitigate bycatch of tropical tuna purse seiners, with a particular concern on sharks and turtles
- to assess the effects of the deployment of FADs in the ocean on the ecology of tuna and other associated species

DESCRIPTION OF THE MAIN S&T RESULTS/FOREGROUNDS

The objective of the project is to propose measures to mitigate adverse impacts of fisheries targeting large pelagic fish in the open ocean (purse seiners using fish aggregating devices – FADs - and longliners), through appropriate knowledge on the ecology of species, and of the fisheries. Therefore, the main S&T results/foregrounds are structured into four sections:

- Improved knowledge on the biology of pelagic sharks
- Mitigate bycatch by pelagic longlines (including both spatial and technical measures)
- Mitigate bycatch by purse seiners using FADs (including both spatial and technical measures)
- Assessing the effects of FADs on the behaviour and ecology of pelagic fish

For each study, it is indicated if it has been published or submitted. If there is no indication, it means that the study will be submitted for peer-review publication in the coming months.

Improved knowledge on the biology of pelagic sharks

- Studies on vertical behaviour of pelagic sharks / juvenile swordfish

Combined instrumented longline experiments (with hook-timers and Depth-Temperature Recorders DSTs) deployed in the fishing line), satellite telemetry and acoustic telemetry showed that

a) some sharks (blue shark BSH) can descend to mesopelagic or even bathyal extreme depths (in excess of 100 m) while others (e.g. oceanic white shark OCS) appear to stay within the epipelagic (>200 m) realm;

b) all studied sharks exhibit diel diving behaviour whereby they spend their time at deeper (variable) depths during the day and shallower (within the mixed layer) at night;

c) the same behaviour is shown by juvenile swordfish (SWO) but in a very marked fashion;

d) the nightime period is, therefore, when most of the interaction with the longline gear occurs: limiting the fishing period between dusk (beginning of the setting) and 5 am could reduce 65% of total bycatch and 40% to 50% of shark bycatch.

e) the vertical distributions of shark catches observed from experimental longline fishing with an instrumented longline targeting tuna from the surface to ~450 m shown that the percentage of blue, oceanic white tip and silky sharks caught in the first 100 meters (i.e. on the 6 shallowest of a basket) reached 23%, 62% and 67%, respectively.

- Studies on spatial (horizontal) behaviour of pelagic sharks / juvenile swordfish and hotspots of pelagic biodiversity

Spatial behaviour and habitat use of by-catch species was analyzed using fishery (population) and telemetry (individual) data. Fisheries data was analyzed to present predictions of bycatch rates for key pelagic sharks (BSH, OCS, silky shark FAL) in several ocean basins (north Atlantic, south Atlantic, western Indian, Mediterranean) based on various sources of fishery data (observer, logbooks). Satellite telemetry experiments were deployed in multiple cruises in all the ocean basins by-catch (BSH, FAL, SWO, OCS, over 100 animals tagged). Results of both types of studies were used to identify areas with higher rates of by catch in epipelagic longline fisheries, to evaluate the overlap between fishing effort and (multispecies) bycatch hotspots, and to look at their fine-scale movements, habitat use and residency. Some areas in the central north Atlantic (tens to hundreds of km) and south Atlantic (hundreds to thousands of km) appear to show increased pelagic predator biodiversity, including sensitive shark species currently subjected to EU fishery banning regulations. In the southwest Indian Ocean this also occurs in some areas of the Mozambique Channel and off the Horn of Africa. These areas can be targeted as pelagic Marine Reserves (MRs) but that will have the major caveat that their location changes across seasons, thus requiring a dynamic (temporary) designation of MRs and concomitant compliance enforcement. The exception to the previous rule are some relatively permanent multispecies hotspots associated to seamount complexes (e.g. Corner Rise seamounts NA), proximity to continental shelves (e.g. NE coast of

Brazil) or islands (e.g. Madagascar), or single-species essential habitats (e.g. nurseries in the Azores region for juvenile BSH and in continental NE Brazil for juvenile OCS). Parts of this data were used to evaluate multispecific clustering of large pelagic fishes on LL catches, revealing the existence of previously unknown small-scale biodiversity patchiness in the open ocean, and pointing to the possibility that areas of higher clustering may be avoided to maximize target catch and minimize bycatch.

- Filmalter J, Forget F, Poisson F, Vernet AL, Bach P, Dagorn L. Vertical and horizontal behaviour of silky, oceanic white tip and blue sharks in the western Indian Ocean. IOTC-2012-WPEB08-23

The vertical and horizontal behaviour of silky, oceanic whitetip and blue sharks in the western Indian Ocean was investigated through the use of pop•up archival tags (PATs) and smaller miniPATs. Tags were deployed from 2009 to 2012 under the MADE, ISSF bycatch research projects and the project Contrat Avenir from the French fleet organization ORTHONGEL. Data from 35 silky sharks (87 – 235 cm TL), 2 oceanic whitetip sharks (170 – 183 cm TL) and 7 blue sharks (142 – 220 cm TL) were analysed. Strong differences were found between the vertical behaviour of juvenile silky sharks tagged around drifting FADs and larger individuals caught on pelagic longlines. Small sharks typically used shallower depths (>20 m) while larger individuals the majority of their time between 50 -150 m. Oceanic whitetips displayed similar vertical behaviour to large silky sharks (typically staying between 50-150 m) while blue sharks spent far more time at greater depths (50-400 m). All three species displayed large horizontal movements (Figure 1).

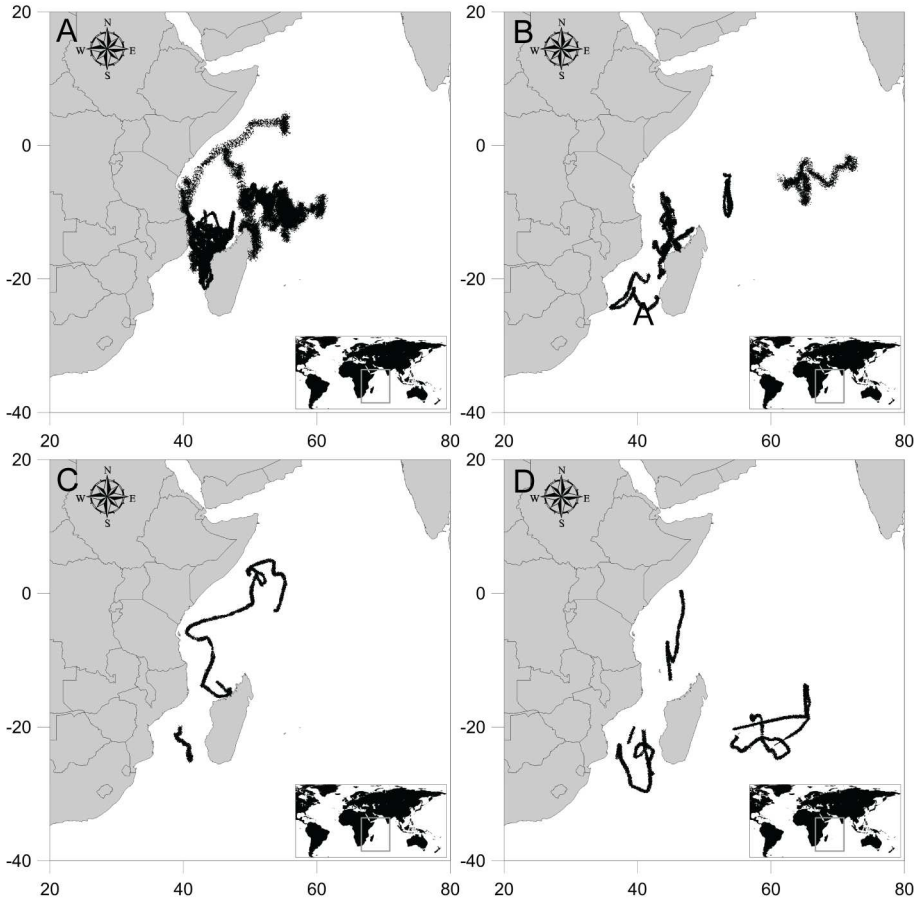

Figure 1. All geolocation estimates for A) 26 juvenile silky sharks *Carcharhinus falciformis* tagged at drifting FADs, B) for seven large silky sharks tagged with PATs C) oceanic white tip sharks *Carcharhinus longimanus*

(n = 2) tagged with PAT and MiniPAT's and D) blue sharks *Prionace Glauca* tagged with PATs in the western Indian Ocean.

- Travassos Tolotti M, Travassos P, Lucena Frédou F, Wor C, Agrelli Andrade H, Hazin F. Size, distribution and catch rates of the oceanic whitetip shark caught by the Brazilian tuna longline fleet. Fish Res 143: 136-142.

Catch and effort data from 14,835 longline sets conducted by foreign tuna longline vessels chartered by Brazil, from 2004 to 2010, were analyzed aiming at assessing the size, distribution and the relative abundance of the oceanic whitetip shark (Carcharhinus longimanus) in the southwestern and equatorial Atlantic Ocean. The nominal catch per unit of effort (CPUE) exhibited a gradual increase, from 0.04 sharks/1000 hooks, in 2004, the first year of the time series, up to 0.13, in 2007. In 2008, however, the CPUE increased sharply, reaching 0.43, dropping, then, back to 0.15, in 2010. A CPUE standardization was performed using a delta-GLM approach, but the standardized index of abundance did not differ significantly from the nominal CPUE. The models indicated that the catches of oceanic whitetip sharks are higher for the Spanish fishing strategy, which is characterized by the deployment of hooks at shallower depths. These results indicate that the use of deep longline hooks (>100 m) may help to mitigate the bycatch of this species.

- Martins, L. 2013. Juvenile swordfish (Xiphias gladius) and blue shark (Prionace glauca) bycatch in surface longlining. MSc thesis, University of the Azores.

The pelagic longline fishery faces severe management and conservation problems related to its high levels of by-catch, juvenile swordfish (Xiphias gladius), the target species, and blue shark (Prionace glauca), the main accessory species. This project aimed at contributing with relevant ecological information to evaluate possible technological measures that could reduce this juvenile by-catch, namely type of leader (steel wire versus monofilament), hour and depth of hook setting. 163 sets were made onboard three commercial vessels around the Azores and mainland Portugal areas. 42 sets were partially instrumented with hook timers (7494 hooks) and Temperature Depth Recorders to study the hooking time and depth. Juveniles of both species were always above 50% of the catches per species, regardless of area and leader type. However, 901 swordfish (CPUE 8.1/1000 hooks) and 6365 blue shark (56.0/1000 hooks) were caught in 106 wire leader sets in the Azores area whereas the 28 monofilament sets caught 590 swordfish (19.3/1000 hooks) and 754 blue shark (24.9/1000 hooks). Proportion of juveniles was comparable between wire and mono sets for both species (57.2% vs. 58.4% and 84.7% vs. 92.8%, respectively). These results show that the use of mono leader allows significantly larger (2.4 times) catches of swordfish, the target species, whereas those of blue shark are significantly (0.4 times) lower than wire leader catches. Comparison between areas (mono leaders only) showed substantially higher catches of blue shark (avg. CPUE 24.9 vs. 3.1) and slightly higher catches of swordfish (CPUE 19.3 vs. 15.6) in the Azores for comparable proportions of juveniles in both species (swordfish 92.8 vs. 84.9%; blue shark 58.4 vs. 47.8%). The instrumented line showed a common preference o bite the hook in the first hours of the nightime period. However, swordfish bites the hook at night only whereas blue shark also bites during the day. Both species bitten the hooks at 30 to 80 meters depth. However, there were no significant differences between juvenile and adult in relation to depth or time of day. These results show that 1) using mono leader can be an effective measure to reduce juvenile (and adult) by-catch of blue shark while increasing swordfish catches but at the cost of also increasing juvenile swordfish by-catch, and that 2) time of day or depth of line setting don't seem to be effective measures to reduce juvenile by-catch of both species. This work also supports previous findings that the Azores region is an important nursery for blue shark in the North Atlantic.

- Vandeperre F, A Aires-da-Silva, M Santos, R Ferreira, A B Bolten, R S Santos, P Afonso (in review). Demography and ecology of blue shark (Prionace glauca) in the central North Atlantic. Fisheries research.

In the North Atlantic, blue shark has become an important by-catch for the pelagic swordfish fisheries, and even the target species of the fishery when swordfish abundance is low. Still, their complex life cycle and population structure remain poorly understood, limiting current management and conservation efforts for this species. This study provides information on the population structure and seasonal abundance of blue shark around the Azores Archipelago, in the central North Atlantic, based on detailed analyses of fishery independent and observer data for the area. A total of 23119 blue sharks were sampled during 388 research longline fishing sets conducted between 1993 and 2004. Standardised catch rates varied greatly over the year, reflecting the changing presence of different sex and life stages in the area, and were strongly influenced by environmental factors, namely sea surface temperature (SST), sea surface height anomalies (SSHa) and lunar cycle. In general, the catches were strongly dominated by juvenile blue sharks, with higher catch rates during winter months. Young-of-the-year (YOY) juveniles of both sexes were present throughout the year. While older juvenile and sub-adult females dominated during winter, juvenile males dominated during the rest of the year, indicating that different juvenile life stages of both sexes alternate in using the area. The presence of mature females in advanced stages of pregnancy during spring and the appearance of the smallest size-classes of YOY in early summer also suggest that the area is used as a pupping ground. Mature males appear mainly during summer, probably for feeding. The periodic presence of all these life stages emphasises the central role of the area, as some of these population components are seasonally associated with one of either sides of the North Atlantic.

- Capello M., P. Bach and E. Romanov (in press). Fine-scale catch data reveal clusters of large predators in the pelagic realm. Canadian Journal Fisheries Aquatic Sciences

The management and conservation of large pelagic fish commonly rely on fisheries data and thus crucially depend on our understanding of the fish response to the fishing gear. Stock assessment of both tropical and temperate tuna strongly leans on the catch statistics derived from pelagic longline fisheries. However, the role of the spatial distribution of catches of tuna and bycatch species over the gear, that can affect the estimated tuna abundance, is still neglected. In this study, we analyzed data obtained from 147 instrumented pelagic longline sets equipped with hook timers and temperature depth recorders to characterize the distribution of hooking contacts and success at a fine temporal and spatial scale. Scientific surveys were carried out in the Central-South Pacific Ocean (French Polynesia), targeting tropical (Thunnus albacares, T. obesus) and temperate (T. alalunga) tuna. Data analysis based on spatial point processes and stochastic modeling demonstrate the presence of spatio-temporal clusters for both hooking contacts and hooking success from the surface to deep waters (~ 450 m on average). The comparative analysis of the observed spatio-temporal patterns for different oceanographic zones revealed the persistent structure of the clusters, suggesting that they are neither related to local environmental conditions nor to the spatial distribution of prey. As clusters include both target and bycatch species, the mitigation of bycatch have to consider a modification of the gear such as the elimination of hooks in depth layers where bycatch species occur.

- N. Rabehagasoa, A. Lorrain, P. Bach, M. Potier, S. Jaquemet, P. Richard, F. Ménard, 2012 - Isotopic niches of the blue shark Prionace glauca and the silky shark Carcharhinus falciformis in the southwestern Indian Ocean. Endangered Species Research, Vol. 17: 83–92 (doi: 10.3354/esr00418).

In the Indian Ocean, the blue shark Prionace glauca and the silky shark Carcharhinus falciformis represent the 2 main shark bycatch species in pelagic longline and purse seine fisheries, respectively. With the increasing market demand for fins, catches may increase in the future, with potential effects on ecosystem trophic functioning through top-down cascading effects. Knowledge of the species' trophic ecology is therefore crucial but is limited by the lack of data from the Indian Ocean. Stable isotope analysis was therefore performed on muscle tissues (δ15N and δ13C) of these 2 shark species from the western Indian Ocean. Our study showed that body length, season, and zone effects were relatively small for the 2 species. However, significant δ13C differences between the 2 species suggest niche partitioning, with silky sharks having a more inshore foraging

habitat than blue sharks. Finally, lower muscle δ15N values were observed in juvenile silky sharks caught by purse seiners around fish aggregating devices (FADs) compared to juveniles caught by longliners. One hypothesis is that FADs could act as an ecological trap for juvenile silky sharks, leading to a position at lowest trophic level for these individuals. However, different foraging habitats could also explain the observed patterns between juveniles. Although preliminary, our results provide a basis for the implementation of species-specific protection and management strategies.

- N. Rabehagasoa, A. Lorrain, J. Kiszka, P. Bach (in prep.) - Ontogenetic trophic shifts of the blue shark (Prionace glauca): insights through vertebrae and muscle stable isotope analysis

Ontogenetic variation in the trophic ecology of blue shark (Prionace glauca) was investigated using stable isotope analysis (δ15N and δ13C) in vertebrae (adults) and muscle (mother and embryos) tissues. δ15N values decreased significantly with increasing mean BCFL (Back Calculated Fork Length, from 43 to 148 cm), and then increased. Mean values of δ13C values also increased undergo three step of rapid increase (between 40-80 cm, 140-160 cm and 200-240 cm BCFL) before reaching a plateau between each increase (80-140 cm, 160-200 cm and after 240 cm BCFL). Muscle δ15N values were higher in embryos than in adults, reflecting maternal effects. Patterns of δ15N and δ13C values in vertebrae were consistent among individuals.

- N. Rabehagasoa, P. Bach, E.V. Romanov, S.E. Campana, A. Lorrain, J.H. Bruggemann (submitted, Journal of Fish Biology) – Age determination, age validation ands growth of the blue shark (Prionace glauca) in the South West Indian Ocean.

Blue sharks (n=110; 49 males and 61 females) were collected in the south-west Indian Ocean and aged by replicate counts of growth bands on both whole vertebrae and freshly sectioned vertebra. Bomb radiocarbon dating of two blue sharks, aged 17 and 22 yr, provided a preliminary validation of the accuracy of the ages. There was no systematic difference in age estimation from whole vertebrae (1-13 years) and sectioned vertebrae (2-14 years); the precision of age estimates was high for both methods (CV <8 %, APE <7 %). Sexual dimorphism was apparent with both the 2-parameter and 3-parameter von Bertalanffy growth models.

- N. Rabehagasoa, L. Vigliola, A. Lorrain, E. Romanov, S. Campana, J. H. Bruggemann, P. Bach (in prep) – Growth of two oceanic sharks, Prionace glauca (Blue shark) and Carcharhinus falciformis (Silky shark) assessed by back-calculation from vertebrae in the Southwest Indian Ocean

The blue shark, Prionace glauca and the silky shark, Carcharhinus falciformis are the main shark species taken as bycatch in pelagic longline and purse seine fisheries in the Indian Ocean, respectively. Because of the paucity of the basic biological information and fishery statistics, population trends in this oceanographic region cannot be assessed. Growth parameters unknown for the Indian Ocean so far are necessary for predicting population responses to fishing pressure and are therefore crucial both for management and conservation purposes. Between 2009 and 2010, 188 blue sharks, P. glauca (36cm – 276cm LF) and 197 silky sharks, C. falciformis (51cm - 264cm LF) were collected in the southwest Indian Ocean by observers and during scientific surveys. Of these samples, vertebrae were aged and analyzed. For both species, the relationship between fish length (L) and vertebrae radius (R) was best modeled by the allometric L-R model, with significant negative allometry for P. glauca (F-test, $P<0.001$) and significant positive allometry for C. falciformis (F-test, $P<0.05$). Back calculation length data with a NLME approach fitted to the von Bertallanffy equation revealed that both shark species had a relatively slow growth, attaining an average size of about 200-250 cm LF at an age of 15-20 years. No effect of sex on growth was detected. Final models indicated growth parameters of -0.89 ±0.03 years for t0, 0.161 ±0.003 y-1 for

k, 258 ±3 cm LF for ♂ for P. glauca, and -2.38±0.06 years for t0, 0.095±0.006 y-1 for k, 230±9 cm LF for ♂for C. falciformis.

- Filmalter J, Seret B, Dagorn L. Length and length / weight relationships for the silky shark Carcharhinus falciformis, in the western Indian Ocean. IOTC-2012-WPEB08-19

Meristic relationships between total length (TL), fork length (FL) and pre-caudal length (PCL) as well as between total length and whole weight are described for silky sharks *Carcharhinus falciformis* from the western Indian Ocean. In total 265 individuals were sampled between 2010 and 2012. TL: FL relationship for both sexes was TL = 1.20FL + 2.90 (n = 265, r^2 = 0.99). TL : PCL relationship was TL = 1.34PCL + 1.78 (n = 214, r^2 = 0.99). FL : PCL relationship was FL = 1.10PCL - 0.44 (n = 214, r^2 = 0.99). Whole weight : TL relationship was $W = 1.48 \times 10^{-6}$ $TL^{3.29}$ (n = 208). Observed relationships compared well with those found for the species from other areas of its cosmopolitan distribution.

- Dietary analysis of silky sharks at FADs

Silky sharks (*Carcharhinus falciformis*) that were incidentally captured and died during purse seine operations at FADs in the western Indian Ocean were collected and their stomachs sampled for dietary analysis. The objective of this work was to assess whether silky sharks associated with FADs were feeding on fish from the aggregation. This information is critical for a better understanding of the motivation for silky sharks to associate with FADs. In total the stomachs from 288 silky sharks were collected, of which 129 (45%) contained contents. Preliminary results suggest that slightly more than half of the diet in term of weight consists of species from within the aggregation. When looked at in terms of numbers, prey items that do not aggregate at FADs were slightly dominant. These results suggest that silky sharks may use FADs for more complex reasons that just feeding sights. Both social interactions and predator avoidance may well play a key role in the manifestation of this aggregative behaviour.

Mitigate bycatch by pelagic longliners

- EBAB : Bait innovation as a new challenge in pelagic longlining

Development of artificial baits is likely one of the major challenges for pelagic longline fisheries in the nearest future. Such an innovation might alternate extremely negative perception of longline gear by: i) decrease of volume of capture fisheries yields directed to bait, ii) decrease of discards by transformation of wastes produced by tuna fishing industry into by-products, iii) improves the selectivity and performance of the longline gear both in the size of targeted fish and species caught. For the pelagic longline fisheries, knowledge of both behaviour and distribution of fish for target species (mainly tunas and swordfish) are not sufficient to mitigate: i) non-sustainable fisheries interactions with endangered, protected and threatened marine top predators and ii) the impact of the fishing pressure on non-managed bycatch species. The ecological-based artificial bait (EBAB) patented during the project was tested during fishing operations targeting swordfish. The use of EBAB significantly reduced the bycatch of pelagic stingrays and dolphinfish. EBAB successfully caught target species (tuna and swordfish) but at lower catch rates than the control baits. Species-selectivity of the baits proved to be sub-optimal, but overall the trials were promising. Jaw hooking of J hooks with EBAB is similar to that obtained with circle hooks, thus possibly reducing post-release mortality of bycatch, particularly sharks. With a lost rate of 12 EBAB for 1000 hooks EBAB was proved as highly reusable.

Figure 2 : Left: EBAB prototype (total length = 23 cm) before deployment at sea. Right: Jaw hooked bigeye caught with EBAB showing the liberation of the mould on the branchline to avoid its damage

- The fishing time as a bycatch mitigation measure in swordfish-targeting longline fisheries

While swordfish is the target species for some pelagic longline fisheries during nightime fishing, this fishery yields numerous species of epipelagic predatory community such as scombrids, billfish, sharks and rays, other teleost fish, reptiles, and birds, even if not in all oceans. Many of these non-target species are susceptible to fishing pressure and cannot sustain current level of exploitation. Fishing surveys with a longline equipped with time depth recorders and hook timers were carried out in the South West Indian Ocean to explore the fishing time as a mitigation measure to reduce bycatch in swordfish fisheries. Capture time for swordfish and non-target species were analysed to investigate potential time difference in the hooking contacts among different species. Moreover, an optimal time window optimizing the Catch per Unit Effort (CPUE) for the target species with respect to the ratio between bycatch groups and the target species was identified. Swordfish captures occurred only after sunset while bycatch ocurred earlier and reached 100% at sunrise when the number of bycaught individuals attained 68%. By stopping fishing operations (i.e. hauling) at 5 a.m., the percentage of swordfish caught was 80% while the percentage of total bycatch was only 35% and 50% for the shark group. Other experiments were carried out in the Mediterranean Sea, where a pelagic deep-sea longline is used, getting no catches of any sea bird or turtle and very low by-catch rates.

- Remove shallowest hook for longline daytime fishing while targeting tunas

Results on the vertical behavior of different species (see previous section on Improved knowledge on the biology of pelagic sharks) have shown that adjusting the fishing depth during daytime could have significant impacts on the bycatch of longline fisheries targeting tunas. For longline targeting tunas (essentially in tropical areas) the most effective *technical mitigation measure* (gear type and deployment style) to reduce shark and turtle bycatch is to fish only **at deeper layers** and remove the hooks in the shallower mixed layer.

By analyzing data obtained from 147 historical instrumented pelagic longline sets equipped with hook timers and temperature depth recorders we characterized the distribution of pelagic fishing capture during daytime fishing at a fine temporal and spatial scale. Data analysis based on spatial point processes and stochastic modeling demonstrates the presence of spatio-temporal clusters of capture extended from the surface to deep layers (~ 450 m) independent of both the species composition and oceanographic characteristics.

The vertical distribution of catches revealed that ~15% of tunas were caught on hooks (#1, #2, #3, #23, #24, #25) deployed in the shallowest layer (< 100 m depth) while ~27% of bycatch species were caught on the same hooks. By removing these shallowest hooks, the reduction of blue, oceanic white tip and silky sharks would reach 23%, 62% and 67%, respectively.

- Spatial measures for juvenile swordfish in the Mediterranean Sea

Juvenile swordfish constitute a large part of the Mediterranean swordfish fisheries and through the analysis of past fisheries, it has been attempted to identify measures that could reduce their catch rates. Analysis of a time series of CPUE rates from commercial fisheries operating in the eastern Mediterranean indicated that the distribution pattern of juvenile swordfish varies in space and time and although some abundance ”hot spots” can be identified they do not seem to be persistent. Consideration of these findings together with past studies support the hypothesis of spatial disaggregation among juvenile and adult population parts. This suggests that spatial fisheries closures for the protection of juveniles that take into consideration the dynamics of species movements may be feasible.

- Deeper hooks to reduce catches of juvenile swordfish in the Mediterranean Sea

A series of experimental fishing operations that were monitored through hook-timers and time-depth recorders provided useful information on the dynamics of the longline gear that is summarized below. All findings refer to night fishing which is the common practice for the large pelagic surface longline fisheries in the Mediterranean.

- Independently of season, the setting depth of the longline seems to affect the size of the captured swordfish individuals.
- The size of the captured swordfish is positively related to the setting depth of the longline.
- The probability of capturing swordfish juveniles is inversely related to the setting depth of the gear, being generally lower in depths over 20m.

These findings, although still preliminary due to the low number and the seasonality of the experimental operations, suggest that fishing exclusively in deeper layers (over 20m from the surface) could favor the decrease of juvenile catch rates.

- Economic impacts of different mitigation measures for pelagic longline fisheries

Economic impacts of different mitigation measures have been studied. In particular the EBAB for longline French fleet (LL) in La Reunión has been analyzed. Risk analysis methodology is used for analyzing the EBAB for LL. EBAB with identical CPUE would be profitable for fleets since bait costs are divided by a factor 2 with artificial bait. But current tests show that yields are a great deal lower than those with natural bait. Experimental tests have been developed. In particular, the Monte Carlo analysis has been implemented with the ratio of CPUE between natural and EBAB to show different situations regarding CPUE yields in several cases of longline fisheries.

Mitigate bycatch by purse seiners using FADs

INTRODUCTION

Higher levels of bycatch taken during fishing operations at FADs as compared to those when fishing on free swimming tuna schools is a cause for concern for RFMOs. Particular concern surrounds species that are poorly suited to high levels of exploitation such as sharks. Their inherent life history traits of slow growth, late maturation and low reproductive output mean that increased fishing pressure will lead to rapid population declines. As such the MADE project set out (i) to seek practical measures that could be adopted to reduce the mortality of these species during fishing operations at FADs and (ii) to investigate the potential effects of time-area closures to reduce bycatch. This section is structured into 5 sub-sections:

- Non-entangling FADs (or ecological FADs), including the assessment of the shark mortality due to the entanglement of sharks in FAD netting
- Setting on bigger aggregations
- Attracting sharks away from FADs
- Releasing sharks from the decks
- Spatial measures

NON-ENTANGLING FADS (OR ECOLOGICAL FADS)

- Filmalter JD, Capello M, Deneubourg JL, Cowley PD, Dagorn L, 2013. Looking behind the curtain: quantifying massive shark mortality in fish aggregating devices. Frontiers in Ecology and the Environment, 11(6): 291-296 (doi:10.1890/130045).

Increasing catch rates are considered the main impact of dynamic fisheries practices on marine ecosystems, but other effects can be equally important and are often ignored. Here we quantify a major, previously unknown source of shark mortality: entanglement in drifting fish aggregating devices, now widely used in the global tropical tuna purse-seine fishery. Using satellite tagging and underwater observational data, we developed two novel, independent, and complementary approaches, which quantify and highlight the scale of this problem. Entanglement mortality of silky sharks (Carcharhinus falciformis) in the Indian Ocean was 5–10 times that of the known bycatch of this imperiled species from the region's purse-seine fleet. More importantly, these estimates from a single ocean (480 000–960 000 silky sharks) mirror those from all world fisheries combined (400 000–2 million silky sharks), a situation that clearly requires immediate management intervention and extensive monitoring.

- Design of ecological FADs

The solution to this problem is simple. Only FADs designed to have a zero probability of entangling animals should be deployed. That is, the use of netting should be completely discontinued. Different designs of ecoFADs were initially proposed by the project (D6.1), some of them including the use of nets wrapped up into "sausages" to avoir having large panels of nets underneath the FADs. Even if such designs of FADs would considerably decrease the probability of sharks getting entangled, we strongly suggest to avoid the use of any netting to reach a zero probability to entangle animals. Materials like ropes could be promoted. A very strong recommendation by the project is the use of non-entangling FADs to eliminate any ghost fishing.

SETTING ON BIGGER AGREGATIONS TO REDUCE TOTAL BYCATCH

- Dagorn L, Filmalter JD, Forget F, Amandè MJ, Hall MA, Williams P, Murua H, Ariz J, Chavance P, Bez N, 2012. Targeting bigger schools can reduce ecosystem impacts of fisheries. Canadian Journal of Fisheries and Aquatic Sciences, 69: 1463-1467.

Sustainability of living resource exploitation relies on an ecosystem management approach. Within tropical tuna purse seine fisheries using fish aggregating devices (FADs), such an approach incorporates the reduction of bycatch, in particular vulnerable species such as elasmobranchs. The levels of total bycatch (in mass) from fishing operations using FADs is known to be five times higher than when tuna are caught in free-swimming schools. We intend to find practical solutions to reduce bycatch in FAD sets through the investigation of the relationships between the ratio of bycatch to target catch across different set size classes in all oceans. Ratios were always highest when catches were small, with the smallest class of catches responsible for the highest total portion of bycatch (23%–43%) while only contributing negligibly to the total target catch (3%–10%). Reducing the number of fishing sets (a part of the total effort) while maintaining the same total yield could contribute to a substantial reduction in the impacts of human activities.

ATTRACTING SHARKS AWAY FROM THE FAD

A scientific cruise was jointly organized in June 2011 by ISSF and MADE. Shark attraction experiments were conducted on 5 different FADs. The scientific protocol consisted of (i) assessing the numbers of sharks around the FAD at the start of the experiment (snorkeling), (ii) using a small tender to drift slowly away from the FAD with a bag full of fish chum (bait), (iii) assessing the number of sharks attracted and maximum distance of attraction using underwater GoPro cameras and a handheld GPS. Each experiment was terminated when either the tender reached a distance of 500 m from the FAD or when no more sharks were observed for several minutes.

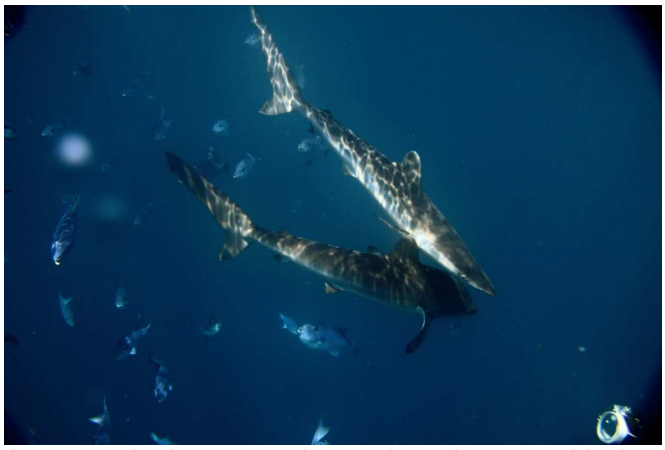

Figure 3 : Sharks attracted away from the FAD with chum

FAD	Number of sharks at start	Number of sharks attracted	Maximum distance (m)
1	9	3	500
2	2	1	120
3	3	2	80
4	2	1	80
5	2	2	250

This study provided key information:

- sharks can be attracted hundreds of meters away from FADs by simply towing a bag of bait away from the FAD
- reactions of sharks varied greatly between the experiments ranging from almost no reaction to attraction up to 500 m. It appears that many factors could be responsible for the success of the attraction: if the FAD was fished a few days before (probably affecting the natural behavior of sharks), the size of the multispecies fish aggregation, feeding motivation, etc. The small dataset does not allow conclusions to be drawn on the respective effects of each parameter.

RELEASING SHARKS FROM THE DECKS

- Poisson F, Vernet AL, Séret B, Dagorn L, 2012. Good practices to reduce the mortality of sharks and rays caught incidentally by tropical tuna purse seiners
- Poisson F, Séret B, Vernet AL, Goujon M, Dagorn L., 2013. Collaborative research: Development of a manual on elasmobranch handling and release best practices in tropical tuna purse-seine fisheries. Marine Policy, in press.
- Filmalter JD, Forget F, Poisson F, Vernet AL, Dagorn L, 2012. An update on the post-release survival of silky sharks incidentally captured by tuna purse seine vessels in the Indian Ocean. IOTC-2012-WPEB08-20, Indian Ocean Tuna Commission, Working Party on Ecosystem and Bycatch, Victoria, 3 p. multigr.
- Poisson F, Vernet AL, Filmalter JD, Goujon M, Dagorn L, 2011. Survival rate of silky sharks (Carcharhinus falciformis) caught incidentally onboard french tropical purse

seiners. IOTC-2011-WPEB-07, Indian Ocean Tuna Commission, Working Party on Ecosystem and Bycatch, Victoria, 6 p. multigr.

This work was done jointly with the French fleet represented by its association ORTHONGEL. D7.2 is a guide dedicated to fishers to describe best fishing practices to optimize survival of sharks released by crew, and is also a part of a peer-reviewed publication:
In addition, the survival of sharks released by purse seiners, following the above good practices, was estimated. Although purse seine vessels in the Indian Ocean may not retain sharks onboard, before the MADE project, little was known regarding the percentage that actually survive the capture process after being discarded. To overcome this important knowledge gap, sharks caught during purse seine operations were tagged with pop-up satellite tags (miniPATs, Wildlife Computers, USA), by scientists onboard. Only sharks that showed signs of life were tagged and released. A total of 33 sharks were tagged, 29 of which provided useful data. All sharks but one were silky sharks (C. falciformis) with the other being a shortfin mako (Isurus oxyrinchus). Of these 29 sharks 48% survived beyond 2 weeks. This represented an overall survival of 15-20% of all sharks caught during fishing operations. As sharks tagged during these operations generally represented those handled in the best possible manner and released as soon as possible (see D6.2 Guide on Good practices to reduce the mortality of sharks and rays caught incidentally by tropical tuna purse seiners), the results obtained though this study likely represent the maximal survival rate possible under standard fishing procedures. Nonetheless, this research shows that if sharks are released as rapidly as possible and handled in a good manner, bycatch mortality of silky sharks can be reduced by 15-20% in the fishery.

SPATIAL MEASURES

- Amandè J.M., Bez Nicolas, Konan N'Da, Murua H., Delgado de Molina A., Chavance Pierre, Dagorn L, 2011. Areas with high bycatch of silky sharks (Carcharhinus falciformis) in the Western Indian Ocean purse seine fishery. IOTC-2011-WPEB-07, Indian Ocean Tuna Commission, Working Party on Ecosystem and Bycatch, Victoria, 9 p. multigr.

Catch per unit of effort (number of individuals per fishing set) and numbers of silky sharks (Carcharhinus falciformis) caught accidentally by the European tuna purse seine fishery (France and Spain) around floating objects in the Indian Ocean were estimated and mapped for the period 2003--•2009. Data were collected by the French and Spanish observer programmes representing a total of 3052 observed fishing sets (1548 on free swimming schools and 1504 on FADs, the term FADs representing here all floating objects, natural and artificial). Kriging interpolations allowed estimating the total FAD--•catches of silky sharks at any set performed by the European tuna purse seine fishery (sets declared in the logbooks). The largest catch of silky sharks per unit of effort (mean numbers of silky sharks/FAD set) was observed north off the fishing grounds (centered on 12°N and 60° E). Due to the uneven spatial distribu tion of the fishing effort, the largest amount of silky sharks caught around FADs did not occur in the area with the highest catch per unit of effort, but in an area centered on 2°N and 53°E. The spatia l distribution of silky shark catches was quite constant among years. Effects of potential mitigation measures are discussed.
These results may be used to determine key areas to protect in order to reduce the catches of silky sharks around FADs by purse seiners. The area centered on 12°N and 60°E appears to be particularly abundant in small juvenile silky sharks around FADs. Increasing the fishing effort on FADs in this area could then result in a large increase of catches of small silky sharks. This area is right outside the time--•area closure (0--•10°N, African Coast-- •60°E) adpoted by the IOTC for purse seiners during the month of November. If the effort of purse seiners moves outside this closed area, in particular in its northern part, this could have very detrimental effects on the silky shark populations. The maps of the total catches of silky sharks clearly shows that the largest catches are not done in the area with the highest catch per unit of effort. This demonstrates that in order to

control the total numbers of sharks accidentally caught by purse seiners around FADs, it is important to consider both the catch per unit of effort and the distribution of effort.

ECONOMIC CONSIDERATIONS

- A cost-benefit analysis of eco-FADs, application to the real option theory.

A cost-benefit analysis, CBA, of different mitigation measures, MM, has been developed with special emphasis on the deployed of eco-FADs by purse seiners. The first step in a CBA is to identify and quantify all relevant costs (incl. opportunity costs) and benefits of the different MM. The NPV is then found as the sum of the discounted flows of costs and benefits over the lifespan of the MM. The risk or uncertainty of the variables entering a CBA will affect the precision of the estimated expected NPV. It is therefore important to consider the effects of risk and uncertainty. Real Option Theory has been used with this aim.

- A Socio-economic Sustainability Indicator for the Basque tropical tuna purse-seine fleet with a FAD fishing strategy", presented and accepted for publication at the review: Agricultural and Resource Economics. In Press, 2013.

An analysis of the different contribution to the economic sustainability when fishing is around Fish Aggregation Devices (FADs) instead of free-swimming schools has been developed. FADs are increasingly used by tuna purse-seine fleets all around the world and the contribution or not to the economic sustainability could be considered to be an important determinant factor for policy makers and fishers.

- Guillotreau P., Salladarré F., Dewals P., Dagorn L. (2011), Fishing tuna around Fish Aggregating Devices (FADs) vs free swimming schools: skipper decision and other determining factors, Fisheries Research, vol. 109(2-3), p. 234-242

Exploiting variability in the managerial dimension, this piece of research presents firm management through firm and time effects in a production function that uses a three-way fixed effect model and a unique panel dataset that tracks multiple managers for each firm from 1980–2007. We allow for time-varying firm management through learning. The model is applied to the French purse-seine fleet harvesting tuna in the Indian Ocean.We find that skippers' learning-by-doing as measured by experience and job tenure plays no significant role, meaning that managerial ability is time-invariant.

CONCLUSIONS

The work conducted during the MADE project has shown that through slight modifications to fishing practices significant reductions in tropical tuna purse seine bycatch can be achieved. Although the extent of the issue of shark entanglement was previously unknown, and has resulted in a dramatic increase in the ecosystem impacts of this fishery, these effects can be mitigated both rapidly and efficiently. Through the adoption of the best handling practices for bycatch once it is brought onboard (see D 6.2), the post-release survival can be maximised. Following these methods the number of silky sharks killed can be reduced by 15-20%. Additionally, through the avoidance of setting on small aggregations a further 25-40% of silky shark catch can be avoided. Similarly, overall bycatch of all non-target species can simultaneously be reduced by up to 40%. As such through the combination of the simple measures described here, significant progress towards the sustainable use of FADs can be achieved.

Assessing the effects of FADs on the behaviour and ecology of pelagic fish

INTRODUCTION

Fish aggregating devices (FADs) are used throughout the world's tropical and subtropical oceans and represent important fishery enhancement tools for both artisanal and industrial fisheries

targeting pelagic fishes. Artisanal fisheries generally utilize anchored FAD arrays moored in deep waters surrounding islands while industrial tuna fleets more regularly use drifting FADs, but in certain areas (e.g. Papua New Guinea) extensive arrays of anchored FADs are also employed. The main scientific objective of this WP was to characterize the behaviour of fish at FADs and assess the impacts of FADs on the ecology of associated species. This document is structured by species, with a short summary of every paper when it has been published, or an extended summary when the publication is on-going.

HABITAT MODIFICATION

- Dagorn L, Bez N, Fauvel T, Walker E, 2013. How much do Fish Aggregating Devices (FADs) modify the floating object environment in the ocean? Fisheries Oceanography, 22(3): 147–153.

Natural floating objects (e.g., logs) have always been a component of the habitat of tropical tunas. However, the introduction of fish aggregating devices (FADs) modifies this environment. To assess the changes due to the deployment of FADs, we compared the spatial distribution of natural and artificial floating objects (FADs), using data from observers onboard tuna purse seine vessels in the Indian Ocean from December 2006 to December 2008. Although natural objects occur more commonly in waters south of 7°S and FADs are more c ommon in waters north of 7°S, all types of floating objects can be found everywhere. Using different spatial scales (quadrats of size 1° x 1°, 2° x 2°, 5° x 5°, and 10° x 10°), we computed the prop ortion of FADs observed in quadrats without natural objects. The scale of 2° 9 2° quadrats repr esented a threshold: distributions of the two types of objects were different at scales smaller than this threshold. The strongest change that has occurred since the introduction of FADs (besides the increased catches) has been the dramatic increase in the total number of floating objects. Since the introduction of FADs, the number of objects has at least doubled everywhere (except in the Mozambique Channel and Chagos) and in some areas (e.g., Somalia area) the multiplication factor has reached as high as 20 or 40. Our study sets the ranges of values of key parameters of the floating object environment, which are crucial in the design of future experimental studies aimed at investigating the impacts of FADs on the ecology of tunas.

MODELING (ALL SPECIES)

- Sempo G, Dagorn L, Robert M, Deneubourg JL, 2013. Impact of increasing deployment of artificial floating objects on the spatial distribution of social fish species. Journal of Applied Ecology, in press.

Approximately 300 pelagic fish species naturally aggregate around floating objects (FOBs) at the surface of the oceans. Currently, more than 50% of the world catch of tropical tuna comes from the industrial tuna fisheries around drifting FOBs. Greater understanding of the complex decision-making processes leading to this aggregation pattern and the impact of the massive release of artificial FOBs by fishermen on the spatial distribution and management of tuna is needed. We analyse how the interplay between social (relationships between individuals) and non-social (responses to the environment) behaviours may affect the spatial distribution of a population in a multi-FOB environment. Taking the example of tropical tunas associating with FOBs and using differential equations and stochastic simulations, we examine how, when increasing the number of FOBs, fish aggregation dynamics and the distribution of the population among patches are affected by the population size, level of sociality and the natural retentive and/or attractive forces of FOBs on individual tuna. Our model predicts that, depending on the species' level of sociality, fish will be scattered among FOBs or aggregated around a single FOB based on the number of FOBs deployed in a homogeneous oceanic region. For social species, we demonstrated that the total fish catch is reduced with increasing FOBs number. Indeed, For each size of population, there is a number of FOBs minimizing the total population of fish associated with FOBs and another number of FOBs maximizing the total population of associated fish.

Synthesis and applications. In terms of fisheries management, the total catch volume is directly linked to the total number of floating objects (FOBs) for non-social species, and any limit on the number of sets would then result in a limit on the total catch. For social species (e.g. tuna), however, increasing the number of FOBs does not necessarily lead to an increase in the total catch, which is a non-intuitive result. Indeed, our model shows that, for specific values of the parameters, deploying a greater number of FOBs in the water (all other parameters being constant) does not necessarily help fishermen to catch more tuna but does increase the level of fishing effort and bycatch.

TUNAS

- Robert M, Dagorn L, Deneubourg J-L, Itano D, Holland K, 2012. Size-dependent behavior of tuna in an array of fish aggregating devices (FADs). Marine Biology, 159: 907-914.

Several lines of evidence indicate that aggregations of yellowfin tuna associated with floating objects are more frequently comprised of small animals than larger ones. Also, the diet of small yellowfin tuna caught at anchored FADs around Oahu, Hawaii was found to shift quite rapidly when these fish reached approximately 50 cm FL. In order to test for ontogenetic changes in aggregation behavior, we tagged and released two distinct size classes of yellowfin tuna in an array of anchored FADs around Oahu, Hawaii. Twenty four yellowfin tuna 30-39 cm FL and 16 yellowfin tuna 67-83 cm FL were tagged with acoustic transmitters and released near anchored FADs equipped with automated acoustic receivers. Fish in the smaller size class stayed about 2.5 times longer at individual FADs than the larger fish (mean 4.05 days vs 1.65 days), and displayed larger horizontal movements within the array. However, the durations of unassociated phases, residence times in the entire FAD array, percentage of time spent associated with FADs and numbers of movements between FADs did not show any difference between the two size groups. The observed size-dependent behavior is discussed in terms of physiological abilities, diet segregation and anti-predator behavior.

- Robert M, Dagorn L, Filmalter JD, Deneubourg J-L, Itano D, Holland K, 2013. Intra-individual behavioral variability displayed by tuna at fish aggregating devices (FADs). Marine Ecology Progress Series, 484: 239–247.

Fishers have exploited the associative behavior displayed by several pelagic fish species with floating objects for decades, through the use of man-made fish aggregating devices (FADs), which facilitate the capture of such species. However, our understanding of this associative behavior and its adaptive value is poor and the scientific community is ill-equipped to provide fishery managers with science-based recommendations on the impacts of FADs on ecosystems. In an array of 13 anchored FADs around Oahu, Hawaii, USA, 72 yellowfin tuna Thunnus albacares were equipped with internal acoustic tags, which facilitated the continuous monitored of their presence and absence around each FAD using automated acoustic receivers. Data were analyzed using survival curves with the objective of determining the behavioral dynamics of fish joining and leaving the FADs. Residence times at FADs were characterized by 4 behavioral modes: briefly passing near a FAD (average 13.1 min), short association (average 2.9 d), and 2 long association behaviors (13.8 and 23.2 d, respectively). Statistical analyses suggest that different behavioral modes were likely dependent upon local conditions around the FAD at a given time (environmental factors or social interactions). We observed 2 behavioral modes for absence times from FADs: short (2.8 d) and long (infinite). More importantly, individuals exhibited behavioral variability, switching between short and long residence times at FADs. This suggests that large pelagic fish can display a range of behavioral responses while in an array of FADs, challenging the common hypothesis of a single behavioral pattern, which could ultimately lead to an ecological trap. Survival curves were best fitted with exponential models, suggesting that underlying behavioral processes were time independent.

- Govinden R, Jauhary R, Filmalter JD, Forget F, Soria M, Adam S, Dagorn L, 2012. Movement behaviour of skipjack (Katsuwonus pelamis) and yellowfin (Thunnus albacares) tuna at anchored fish aggregating devices (FADs) in the Maldives investigated using acoustic telemetry. Aquatic Living Resources, 26: 69–77.

The pole and line tuna fishery in the Maldives relies heavily on an array of 45 anchored fish aggregating devices (FADs), making it one of the largest anchored FAD-based tuna fisheries in the world. We examined the behaviour of skipjack (Katsuwonus pelamis) and yellowfin (Thunnus albacares) tuna around anchored FADs (1 000 to 2 000 m deep) in the Maldives using passive acoustic telemetry. Eight neighbouring FADs (distance range: 30 to 95 km, average: 50 km) were equipped with automated acoustic receivers in January 2009, for a period of 13 months. A total of 40 skipjack (37−54 cm FL) and 21 yellowfin (35−53 cm FL) tuna were tagged with Vemco V13 transmitters in January (start of the northeast monsoon, dry season) and November (end of the southwest monsoon, wet season) 2009 and released at the two central FADs within this instrumented array. No movement between FADs was observed for any acoustically-tagged tuna in the instrumented FAD array. These results suggest that FADs in the Maldives may act independently. The maximum time a tagged skipjack remained associated with a FAD was 12.8 days in January but only one day in November. In addition, residence times at FADs were found to differ with time (month) and space (FAD location) for skipjack tuna, suggesting that external biotic factors (e.g., prey, conspecifics or predators) might influence the time this species spends at FADs. In November, the residence times of yellowfin tuna (maximum observed time: 2.8 days) were three times greater than those of skipjack tuna at the same FADs. This specific difference could be explained either by the two species responding to different factors or by the species' responses being dependent on the same factor but with different thresholds. No particular preference for time of departure from the FADs was observed. Some monospecific and multispecific pairs of acoustically-tagged individuals were observed leaving the FADs simultaneously. Thus, this study indicates a high degree of complexity in the behavioural processes driving FAD associations.

- Robert M, Dagorn L, Lopez J, Moreno G, Deneubourg J-L, 2013. Does social behavior influence the dynamics of aggregations formed by tropical tunas around floating objects? An experimental approach. Journal of Experimental Marine Biology and Ecology, 440: 238–243.

Tropical tunas associate with objects floating at the surface of the ocean, a behavior widely exploited by fishers. However, the respective roles played by environmental variables and behavioral processes (e.g., social behavior) in the formation of these aggregations remain elusive. To investigate the role of social behavior in the dynamics of such aggregations, we used the binary choice approach. The experimental design comprised two close and identical anchored fish aggregating devices (FADs) equipped with an echo sounder buoy to monitor the aggregated biomass of tuna under each device. Analysis of the results entailed characterizing whether the aggregated biomass is distributed asymmetrically (indicative of social behavior playing a role in the dynamics) or symmetrically between the two close and identical FADs, and comparing the results with theoretical distributions based on different definitions of basic units (individual fish or small schools). The results suggest that social interactions underlie aggregation processes, which represents a major advance in our understanding of these aggregations, a priority for science-based fishery management. While recognizing the logistical and technical constraints, we encourage the development of experimental studies (e.g., in which animals are presented with controlled situations) to enhance our understanding of the behavior of large pelagic fish.

- Stehfest KM, Patterson TA, Dagorn L, Holland KN, Itano D, Semmens JM, 2013. Network analysis of acoustic tracking data reveals the structure and stability of fish aggregations in the ocean. Animal behaviour, 85: 839-848.

Aggregations in the distribution of individuals are an almost universal phenomenon in living organisms. Groups of animals that display collective coordinated movement without forming stable social bonds such as fish schools are a special type of aggregation. In tropical tuna fisheries, aggregating behaviour is directly exploited through the use of artificial fish aggregating devices (FADs). Hence, understanding the dynamics of schooling behaviour and the potential impacts of FADs upon it may have ramifications for tuna management. As a novel way of quantifying spatiotemporal co-occurrences of animals, we applied network statistics to acoustic tracking data to identify the co-occurrences of individual yellowfin tuna, Thunnus albacares, in an array of FADs and determine the frequency and temporal dynamics of these co-occurrences. We observed large interannual variation in movement rates of tuna between FADs, and corresponding interannual variability in the mean number of spatiotemporal associates for each individual as well as the temporal stability of associations. When movement rates were high, associations within FAD aggregations decayed to randomness three times faster than when movement rates were lower. This raises the possibility that if FADs are sufficiently close for fish to perform frequent between-FAD movements, school mixing may be increased and cohesion reduced.

- Robert M, Dagorn L, Deneubourg JL, 2010. Comparing condition factors of skipjack tuna associated with natural floating objects and those from free swimming schools in the Mozambique Channel. IOTC-2010-WPTT-24, Indian Ocean Tuna Commission, Working Party on Tropical Tuna.

The objective of this study is to compare condition indices of skipjack tuna (Katsuwonus pelamis) (plumpness, bioelectrical impedance) caught in schools associated to natural floating objects with fish caught in free-swimming schools. All samples were collected in the Mozambique Channel within 3 weeks (April 2010) assuming that all skipjack tuna were experiencing the same environmental conditions. The Mozambique Channel was chosen as it is a major fishing area that has not been hardly modified by the introduction of FADs (artificial floating objects), then representing the natural habitat of tuna before the use of FADs. All samples come from 6 free-swimming schools and 21 logassociated schools. For both indices, skipjack tuna around logs revealed lower conditions than in free-swimming schools. We propose two possible interpretations of our results that can help better understand the reason why tuna aggregate under floating object. Differences could come from different feeding success (foraging strategies) between fish around logs and those in free-swimming schools. Considering that in average, tuna stay associated to floating objects for a few days only, it would mean 1) that condition indices rapidly change (within a week) and 2) that the reason for which skipjack tuna has developed this associative behavior is not linked to feeding behavior but to other major component of their behavior, such as schooling (see the meeting point hypothesis). The other interpretation is that the observed difference is not the consequence of the association but the cause why tuna aggregate under logs. Skipjack tuna would associate to floating objects after some bad feeding success in free-swimming schools. Associating to floating objects could be a behavioral strategy for fish in free-swimming schools that are in low conditions to save energy, form larger schools that could be more efficient when foraging, etc. Our results are not in favor of the ecological trap hypothesis as they tend to represent the conditions of tuna before the introduction of FADs and it is difficult to assume that animals could have developed a behavior that would lead to lower fitness. However, before concluding, further analyses are needed to better understand what the absolute values of condition indices represent and to measure the differences of condition indices in areas that are highly modified by FADs.

- Dagorn L, Holland KH, Filmalter J, 2010. Are drifting FADs essential for testing the ecological trap hypothesis? Fisheries Research, 106: 60-63.

Because tropical tunas are known to aggregate around floating objects, it has been suggested that the large number of drifting fish aggregating devices (FADs) built and deployed by purse seiners could act as an 'ecological trap'. This hypothesis states that these networks of drifting FADs could take fish to areas where they would not normally go or retain them in places that they would otherwise leave. Because the ecological trap hypothesis was first advanced for drifting FADs, some

have argued that only studies using drifting FADs can test this hypothesis. However, because working with drifting FADs is difficult, accepting this precept would preclude the scientific community from providing urgently needed information to organizations charged with management of fisheries that exploit drifting FADs. We argue that because both anchored and drifting FADs alter the natural environment, the more easily accessible anchored FADs can be used to test the ecological trap hypothesis. Also, based on a comparative scientific approach, we argue that understanding the behaviour of tunas around anchored FADs can improve our general understanding of tunas around all types of floating objects and help design new, well focused studies for drifting FADs. As anchored FADs are easier to access and offer a greater potential for research, we encourage scientists to design and conduct studies (in particular on the behaviour of fish at FADs) around the moored structures.

- Stehfest K.M. and Dagorn L, 2010. Differences in large scale movement between free swimming and fish aggregating device (FAD) caught tuna. IOTC-2010-WPTT-06, Indian Ocean Tuna Commission, Working Party on Tropical Tuna.

Tropical tuna are amongst a number of pelagic fish species that are known to aggregate around floating objects. While the ecological or evolutionary advantage of this behaviour is still unclear, tuna fishermen have been exploiting it for decades by actively seeding artificial FADs, modifying the physical habitat of tuna. There are growing concerns over the ecological impact of this phenomenon, especially the potential of FADs to act as an ecological trap. We used the Indian Ocean Tuna Commission mark recapture database to determine whether there are differences in movement characteristics between tuna caught in free schools and those caught under FADs that might be indicative of an impact of FADs on large-scale tuna movement. We found that there were some differences in displacement rates between individuals caught at FADs and those caught in freeswimming schools, as well as differences in movement angles. We suggest, however, that this is not necessarily an indication of a FAD effect on tuna movement, but might be an artefact of the nonuniform distribution of FAD fishing effort. We furthermore show that movement characteristics did not differ between fish tagged during periods of high and those tagged during periods of low FAD density and suggest that this might indicate the absence of an ecological trap effect. We conclude that school type at recapture might not be representative of a tuna's movement history and therefore not suitable for detecting an ecological trap effect of FADs. Hence we propose the use of a more sophisticated statistical model of the mark-recapture data to address the question of whether FADs have the potential to alter large-scale tuna movements.

- Robert M, Dagorn L, Deneubourg JL, 2010. Comparing condition factors of skipjack tuna associated with natural floating objects and those from free swimming schools in the Mozambique Channel. IOTC-2010-WPTT-24, Indian Ocean Tuna Commission, Working Party on Tropical Tuna.

The objective of this study is to compare condition indices of skipjack tuna (Katsuwonus pelamis) (plumpness, bioelectrical impedance) caught in schools associated to natural floating objects with fish caught in free-swimming schools. All samples were collected in the Mozambique Channel within 3 weeks (April 2010) assuming that all skipjack tuna were experiencing the same environmental conditions. The Mozambique Channel was chosen as it is a major fishing area that has not been hardly modified by the introduction of FADs (artificial floating objects), then representing the natural habitat of tuna before the use of FADs. All samples come from 6 free-swimming schools and 21 logassociated schools. For both indices, skipjack tuna around logs revealed lower conditions than in free-swimming schools. We propose two possible interpretations of our results that can help better understand the reason why tuna aggregate under floating object. Differences could come from different feeding success (foraging strategies) between fish around logs and those in free-swimming schools. Considering that in average, tuna stay associated to floating objects for a few days only, it would mean 1) that condition indices rapidly change (within a week) and 2) that the reason for which skipjack tuna has developed this associative behavior is not linked to feeding behavior but to other

major component of their behavior, such as schooling (see the meeting point hypothesis). The other interpretation is that the observed difference is not the consequence of the association but the cause why tuna aggregate under logs. Skipjack tuna would associate to floating objects after some bad feeding success in free-swimming schools. Associating to floating objects could be a behavioral strategy for fish in free-swimming schools that are in low conditions to save energy, form larger schools that could be more efficient when foraging, etc. Our results are not in favor of the ecological trap hypothesis as they tend to represent the conditions of tuna before the introduction of FADs and it is difficult to assume that animals could have developed a behavior that would lead to lower fitness. However, before concluding, further analyses are needed to better understand what the absolute values of condition indices represent and to measure the differences of condition indices in areas that are highly modified by FADs.

- Govinden R,©Dagorn L, Soria M, Filmalter JD, 2010. Behaviour of Tuna associated with Drifting FADs in the Mozambique Channel. IOTC-2010-WPTT-25, Indian Ocean Tuna Commission, Working Party on Tropical Tuna.

To study the behaviour of yellowfin (Thunnus albacores), skipjack (Katsuwonus pelamis) and bigeye tuna (Thunnus obesus) around Drifting Fish Aggregating Devices (DFADs), we tagged individuals with long-lived, coded sonic transmitters and attached automated sonic receivers to DFADs in the Mozambique Chanel, Western Indian Ocean. Two different methods were used to estimate residency times of tunas associated with DFADs; the continuous residence time (CRT) and fine-scale residence time (FCRT). The median CRTs of yellowfin, skipjack and bigeye tuna were 9.98, 4.47 and 3.89 days respectively with no interspecific differences observed. However, for all species combined the median CRTs at DFAD34 were significantly higher than those at DFAD31, indicating that the tunas were more resident at DFAD34. In contrast, the median FCRT of yellowfin, skipjack and bigeye tuna were 0.59, 0.12 and 0.10 days respectively. There was a significant difference between the FCRT of yellowfin and skipjack tuna whilst, there was no differences in FCRTs between bigeye and yellowfin and skipjack tuna. Moreover, the FCRT of yellowfin tuna was significantly higher than the sum of its absence time (AT), whilst that of skipjack was not significant. This indicates that yellowfin tuna were more associated to DFAD than the two other species. The arrival and departure events were significantly higher during nightime compared to daytime for all three species of tuna. For both DFAD combined, the median number of excursions per day of skipjack tuna (2.13) was significantly higher than that of yellowfin tuna (1.08). However, the median total time of excursions of skipjack (2.30) and yellowfin tuna (1.80) was not significantly different. This shows that skipjack tuna made more excursions of more than one hour away from the DFAD than yellowfin tuna but spent almost the same amount of time away from the DFAD as yellowfin tunas. All three species of tuna exhibited diel patterns in their vertical distribution, with deeper median depths encountered during the day than during the night. The median depth of bigeye tuna was significantly deeper than that of yellowfin and skipjack tuna during daytime and nightime. In addition, that of skipjack tuna was significantly deeper than that of yellowfin tuna. More studies of this nature on DFADs are needed to establish if there are any temporal and spatial effects on the behaviour of tunas.

ALL SPECIES

- Dagorn L, Holland K, Restrepo V, Moreno G, 2013. Is it good or bad to fish with FADs ? What are the real impacts of the use of drifting FADs on pelagic marine ecosystems? Fish and Fisheries, 14: 391-415 (DOI: 10.1111/j.1467-2979.2012.00478.x.)

The use of fish aggregating devices (FADs) by purse seine fisheries has come under increasing criticism for its potential deleterious impacts on tuna stocks, for high levels of by-catch and threats to the biodiversity of tropical pelagic ecosystems. Here, we review the current state of scientific knowledge of this fishing technique and current management strategies. Our intent is to encourage objective discussion of the topic and highlight areas worthy of future research. We show that

catching juvenile tuna around FADs does not necessarily result in overfishing of stocks, although more selective fishing techniques would likely help obtain higher yield. Levels of non-tuna by-catch are comparable to or less than in other commercial tuna fisheries and are primarily comprised of species that are not considered threatened. Accordingly, to minimize impacts on ecosystem balance, there is merit in considering that all species captured in purse seine fisheries (excluding vulnerable species such as turtles and sharks) should be retained, but the consequences of such a measure should be carefully examined before implementation. The take of vulnerable species could be further reduced by introduction of additional mitigation measures, but their potential benefits would be limited without parallel efforts with other gears. Finally, there is no unequivocal empirical evidence that FADs represent an 'ecological trap' that inherently disrupts tuna biology although further research should focus on this issue. We encourage RFMOs to expand and improve their FAD management plans. Under appropriate management regimes, FAD fishing could be an ecologically and economically sensible fishing method.

SILKY SHARKS AND OTHER BYCATCH SPECIES

- Filmalter JD, Dagorn L, Cowley P, Taquet M, 2011. First descriptions of the behavior of silky sharks (Carcharhinus falciformis) around drifting fish aggregating devices, in the Indian Ocean. Bulletin of Marine Science, 87(3): 325-337.

Silky sharks, Carcharhinus falciformis (Mu□ller and Henle, 1839), are the primary elasmobranch bycatch species in tuna purse seine fisheries throughout the world's major oceans. Juveniles of this species commonly associate with drifting fish aggregating devices (FAD s) deployed to enhance tuna catches in these fisheries. Here we present results from the first investigation into the behavior of juvenile silky sharks associated with drifting FAD s in the western Indian Ocean. A total of 10 silky sharks were tagged with coded acoustic transmitters around drifting FAD s equipped with acoustic receivers. Following release, all sharks undertook an excursion away from the FAD with which they were associated. Two individuals were subsequently never detected, while the initial absence period of the eight detected sharks ranged between 0.1 and 3.5 d. After returning, total association times averaged 5.19 d (SD = 3.15 d) and related horizontal movement rates ranged from 8 to 50 km d−1. Short excursions away from the FAD were undertaken by some individuals, all of which lasted a few hours and were made at night. During periods of association, silky sharks typically occupied the upper 35 m of the water column for the majority of the observation period. These results provide new insights into our understanding of associative behaviors. Further studies are needed to improve assessment of the impacts of FAD s on the ecology of this species, a major concern considering the large number of FAD s deployed.

- Filmalter JD, Dagorn L, Soria M, 2010. Double tagging of juvenile silky sharks to improve our understanding of their behavioral ecology : preliminary results. IOTC-2010-WPEB-10, Indian Ocean Tuna Commission, Working Party on Ecosystem and Bycatch.

The behaviour of two juvenile silky sharks Carcharhinus falciformis, both while they were associated with drifting FADs and while not associated, was investigated through double tagging with acoustic transmitters and miniaturized PAT tags. Sharks were caught and tagged around drifting FADs in the Mozambique Channel. Drifting FADs were equipped with satellite-linked acoustic receivers, to monitor the fine scale behaviour of sharks while at FADs. Both sharks remained associated with the drifting FADs for several days (at least 7.8 and 10.0 d respectively). During their association both sharks undertook nocturnal excursions away from the FAD, during which deep dives were often observed. Vertical behaviour was found to change once the sharks were believed to have left the FAD, with the depth of the nocturnal dives increasing considerably.

- Forget F, Dagorn L, Filmalter JD, Soria M, Govinden R, 2010. Behaviour of two major bycatch species of tuna purse seiners at FADs: oceanic triggerfish and rainbow runner. IOTC-2010-WPEB-11, Indian Ocean Tuna Commission, Working Party on Ecosystem and Bycatch.

Elagatis bipinnulata (Bennet, 1840) and Canthidermis maculatus (Bloch, 1786) are widely distributed species and are two of the main bycatch species of tuna purse seiner fisheries. To date, very little information is available of the biology and behaviour of those two species. The increasing importance of Fish Aggregating Devices (FADs) within the fishery has raised concern over the impacts of these devices on the pelagic ecology and populations of those bycatch species. In this study, acoustic telemetry was used to investigate the behavioural ecology of these two species around FADs. Three tuna purse seine FADs in the northern Mozambique channel were equipped with satellite linked acoustic receivers. Two E. bipinnulata and 13 C. maculatus were equipped with coded acoustic tags some of which had pressure sensors. The average Total Time of Association (TTA) with the FAD for E. bipinnulata was of 67 days and 21.5 days for C. maculatus. No departures lasting more than 24 hours were observed for both species. The diel pattern in vertical distribution of E. bipinnulata and C. maculatus where similar averaging 9.9 m (SD ± 11.7m) and 5.1 m (SD ± 9.2 m) during the night, 19.7 m (SD ± 14.1 m) and 10.1 m (SD ± 12.5 m) during the day, respectively. The high fidelity and limited vertical distribution of the two bycatch species studied confirms the high catchability by the FAD based purse seiner fishery.

- Results on silky sharks that are under the process of peer-reviewed publications:

A total of 39 silky sharks (69 - 116 cm TL) were tagged with acoustic tags at 9 drifting FADs between 2009 and 2012. Data were obtained using the same VR4 global acoustic receivers described above for tunas. Information on the residency and behaviour were obtained for 21 sharks and covered a total observation period of 329.5 days. All sharks were observed to leave the immediate vicinity of the FAD (i.e. the reception range of the receiver, approximately 500 m) directly after tagging and release and returned between 43 min – 3.65 days later. Several observations were truncated as purse seine vessels set their nets on FADs where tagged sharks were still present. In fact, of the 21 sharks for which data was obtained, only 7 were observed leaving the FAD of their own accord. As such, the residence times observed in this study were certainly shorter than they would be under undisturbed conditions but likely represent the real conditions of the fishery. The average total association time was 15.69 days and ranged between 2.84 and 30.63 days. Highly regular patterns were observed across many individuals, where sharks would leave the FAD shortly after sunset for several hours (mean ± SD = 3h45min ± 3h13min) and return in the early hours of the morning. The continuous residence times (CRTs) observed between these excursions averaged 6h59 min and ranged between 1 min and 5.85 days (5 days 20 hours and 24 min).

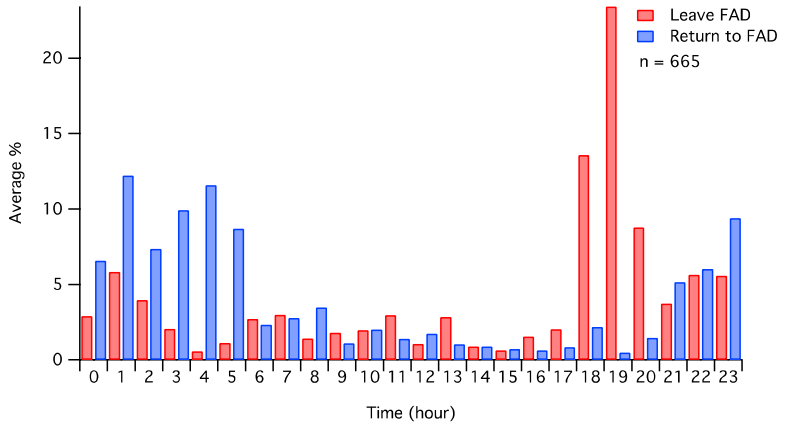

Figure 4: Timing of arrival and departures of silky sharks at drifting FADs.

The regularity of these excursions, coupled with a complimentary dietary analysis from silky sharks caught at FADs, suggests that this behaviour likely represents foraging forays into the areas surrounding the FAD but beyond the receiver's reception range. During the periods within which the sharks were associated, the monitored FADs drifted between 50 and 850 km, moving between 9.2 and 45.1 km.day-1.

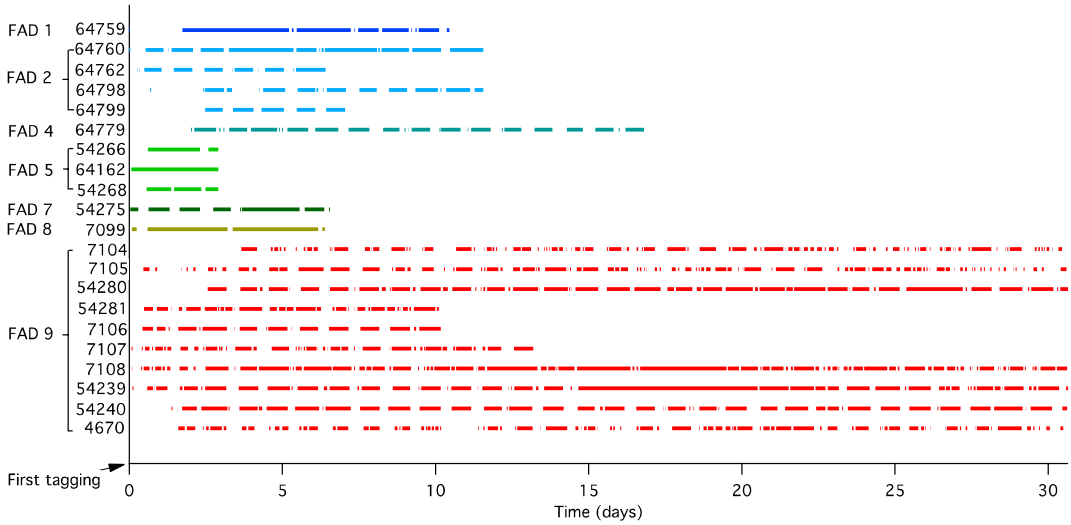

Figure 5 : Residency behaviour of all silky sharks monitored during the MADE project. Tag ID's are shown on the y-axis, along with the FAD ID at which the individuals were tagged. Gaps in each bar represents excursions away from the FADs.

In addition to acoustic tagging 13 silky sharks caught at 7 drifting FADs were also fitted with pop-up satellite archival tags (MiniPATs, Wildlife Computers, USA). These tags allowed the observation of their fine scale vertical behaviour as well as their large-scale horizontal behaviour after acoustic monitoring ended. Results obtained from these depth time series data collected by these tags and coupled with that obtained from acoustics tags in the same animals, showed distinct changes in vertical behaviour at night, when individuals were on excursions away from their FAD. This involved much greater vertical movements than were typically observed during the day, with sharks regularly moving between the surface and depths 60 – 100m.

A major constraint with this kind of tagging is ensuring these external tags remain on the shark for as long as possible. In this study tags were programmed to pop up after 100 or 150 days at liberty. Tag retention varied between animals but on average, they remained attached for 47.3 days (range 5 to 121). Straight line displacement between deployment and pop-up locations ranged between 90 and 1720km. Preliminary analysis of the tracking data suggests that the movement patterns observed for many individuals are similar to the drift patterns of FADs in the area. Consequently, distinguishing between the effects of ocean currents as opposed to the FADs themselves on the large-scale movements of these individuals is difficult. Furthermore, the lack of information regarding their movements in the absence of FADs complicates any effort to gain an understanding of how the increased deployment of FAD could affect their biology.

- Results on other bycatch species that are under the process of peer-reviewed publications:

Using the same protocols described above, 50 Oceanic triggerfish and 24 rainbow runners were tagged at drifting FADs. Fine scale behaviour was observed for a total of 650 days for the oceanic

triggerfish and 300 days for the rainbow runner. The total times of association were generally longer than for the tunas and the silky shark; ranging from 9 to 66 days from the oceanic triggerfish and 10 to 85 days for the rainbow runner. As explained above, several of the observations were truncated by fishing activities and it is thus likely that some of the individuals would have remained associated longer. As opposed to the tunas and the sharks, most excursions (>90 %) undertaken by the two species occur during daytime. These excursions were relatively short averaging 1h55min (SD ± 3h18min) for the oceanic triggerfish and 2h28min (SD ± 2h23min) for the rainbow runner. The mean continuous residence time between the excursions was of 14h19min (SD ± 28hr14min) for the oceanic triggerfish and 8hr42min (SD ± 12hr24min). The oceanic triggerfish and the rainbow runner both had a strong diel vertical behaviour. The two species occur close to the surface at night (1-10m) and extent their vertical range during daytime (20 – 80m). The long residence time of the oceanic triggerfish and the rainbow runner, coupled to their limited horizontal and vertical distributions when associated to FADs, make these two species vulnerable to capture with the purse seine.

CONCLUSIONS

From the telemetry studies described above it is clear that FADs have varying degrees of influence on the ecology of the species that commonly associate with them. Triggerfish and rainbow runners appear highly dependent on the presence of floating objects, remaining constantly associated with the same object for extended lengths of time. Juvenile silky sharks also appear to show relatively strong dependence upon these objects, but do appear to break their associations more regularly than the other small teleost species. The three tuna species show the highest degree of independence, with some differences between the species being observed. Skipjack appear to have the fastest turnover rates, with individuals leaving FAD after the shortest amount of time, while yellowfin and bigeye tuna are more resident but still average only a few days. This behaviour has been observed eastern Pacific Ocean through similar studies on yellowfin and bigeye, suggesting that their behavioural response to floating objects is similar in all oceans.

In spite of the relatively short association times that tunas display, the possibility still remains that the increased densities of FADs leads to an increased frequency with which such associations occur. As such these telemetry data do not unequivocally refute the potential of a FADs influencing the ecology or biology of the aggregated species. Addressing this question necessitates the investigation of physiological parameters of associated and non-associated individuals.

The extensive and almost unregulated use of FAD in all tropical oceans is a major concern for management bodies. As such understanding their impacts on fish populations is of critical importance. However, understanding the influence of FADs on fish behaviour is no trivial task. The studies described above represent extensive progress in this poorly studied yet highly important field. Through the combination of behavioural, physiological and modelling approaches the work conducted under the MADE project has revealed significant new information and highlighted specific areas where research attention should be focused in the future. While behavioural studies tend to suggest that FADs are unlikely to trap tunas, the investigation of condition factors suggests that associating with a floating object leads to short term reductions in condition. Despite this, as tunas also aggregate in areas where FADs are seldom used, this observation is certainly not a result of increased FAD deployment. This study, specifically, highlights the need for developing baselines against which current observations can be rigorously tested. Without such comparative benchmarks, the significance of future analyses investigating the influence of FADs on fish ecology will be compromised.

POTENTIAL IMPACT

The potential impact of the project is structured within four categories: fishers, tuna RFMOs, SMEs and general public.

Impact: Fishers

Fishers and Tuna RFMOs were the main targets of the project which aimed at investigating methods to reduce the impacts of pelagic longliners and tropical tuna purse seiners on the pelagic ecosystem. During the project, scientists were in very close contact with fishers and some studies were actually conducted with them. Fishers, but also fish processors (through the International Seafood Sustainability Foundation, gathering the main international tuna processors in the world) co-funded some research with MADE, revealing the strong implication that the MADE project had with fishers and other stakeholders. This is a demonstration of the strong links developed during the project between scientists and fishers, as well as with fish processors.

Purse seiners are now well aware of the need to use only ecological FADs and both the French and the Spanish fleets have moved towards this direction in the Indian Ocean. This is a major change in the fishery as we have shown that in the Indian Ocean, 0.5-1 million silky sharks were killed every year through entanglement in netting underneath FADs. All European purse seiners also received the guide for best practices to reduce the mortality of sharks and rays caught incidentally during their fishing operations (Deliverable D6.2). This guide has also been presented in other oceans and is now available online on the BMIS web site of the SPC, which collates all mitigation methods related to tuna fisheries.

It is noteworthy that all results of the MADE project, related to purse seiners, are being disseminated to skippers from the major purse seine fleets throughout the world through the ISSF skippers' workshops. These workshops, which are held each year in Europe, Africa, Latin America and Asia, present the latest scientific results in terms of mitigation in purse seine fisheries to skippers of purse seiners. This has allowed a wide dissemination of the results of the project to skippers of purse seiners.

Longliners in La Réunion showed good acceptance for the principle of using an artificial bait (EBAB) instead of fish bait. For the Réunion swordfish longline fishery, changing fishing time to reduce catches of sharks was not well accepted. The main reason for this was that, during daytime, they often catch non-target species with commercial interests, such as billfish, dolphinfish and albacore tuna.

Impact: Tuna RFMOs and fishery managers

Scientists of the MADE project have regularly presented their results to the IOTC and the ICCAT. A total of 23 working papers were already presented to the Working Party on Ecosystem and Bycatch (WPEB) of the IOTC, and 3 to the ICCAT. These two Tuna RFMOs are therefore aware of the results of the project.

It is noteworthy that Resolution 13/08 of IOTC and Resolution C-13-04 of IATTC are based on the results of the project on ecological FADs (study performed in conjunction with the ISSF Bycatch project and the Orthongel Bycatch project):

- IOTC Resolution 13/08. Procedures on a fish aggregating devices (FADs) management plan, including more detailed specifications of catch reporting from FAD sets, and the development of improved FAD designs to reduce the incidence of entanglement of non-target species.
- IATTC Resolution C-13-04. Collection and analyses of data on fish aggregating devices

However, the IATTC requirement is not yet firm, calling for more research. The two other RFMOs (ICCAT and WCPFC) have no resolutions on non-entangling FADs. We believe that it is important to conduct research to assess the rate of sharks and turtles entanglement in other oceans, as was done

in the Indian Ocean. However, it is also noteworthy that FAD nets can also cause other damages when they wash up on beaches or reefs. Further work is definitely needed in other oceans, but in the interim, it could be necessary to adopt a precautionary approach and call for the use of non-entangling FADs.

The 4 RFMOs have set a ban on retention on oceanic white tip sharks, and ICCAT has set the same ban on silky sharks. Without good practices when handling and releasing sharks from fishing vessels, or other technical mitigation methods, such bans would have no effect. MADE has produced such a guide for purse seiners that is already distributed to European purse seiners.

Through better knowledge on the behavior of fish at FADs, and the development of behavioral models, it will be possible to provide some information on a theoretical optimal number of FADs in order to avoid major adverse impacts on the ecosystem. Using the same kind of data and models, it will also be possible to derive fishery independent indices of population sizes.

During daytime, oceanic white tip, silky sharks and turtles are usually located in the upper water layer (< 100 m) while the main target species (either bigeye tuna or swordfish) usually occupy deeper waters. One method to reduce interactions with sharks turtles would be to set deep hooks, which should also increase CPUE of target species.

Impact: SMEs
One European patent has been produced on the artificial bait EBAB: EBAB was patented in France in September 2011with the reference number **FR1158054** and in Europe in September 2012 with the reference number **EP12183563**.
The potential to both reduce bycatch and bring other efficiencies to the fishery (e.g. enhanced selectivity, waste reduction, etc.) by using artificial bait exits, however much work remains to be done before artificial baits are a viable alternative to natural baits.
The future research expected to continue will consider the following objectives:

- identifying environmentally friendly material for the mould;
- evaluating mould design with regard to shark cues (e.g., incorporation of electropositive metals in the mould, the colour of the mould);
- evaluating mould design with regard to sink rate to avoid seabird bycatch;
- examining the fish pulp mixture (e.g., considering the inclusion of deterrents such as shark necromones); and
- hook design (diving speed, hook and barb shapes) and position in the mould to reduce negative effects just by contact.

A proposal is currently on-going for the development of this product in the commercial phase.

Impact: General public
MADE also had some impacts on the general public, mainly through the improved knowledge on shark biology and behavior. Sharks are charismatic species and the public constantly demands nformation on their biology and behavior. The project has been working on pelagic species that are not well known by the public: the blue shark, silky shark and the ocanic white tip shark.

Results of the project help tuna fisheries to improve their sustainability. With ever increasing societal demands for sustainably harvesting seafood products, the actions of this project have help to maintain the environmental, economic and social viability of these fisheries. Outreach was achieved through the project's web site as well as through close collaboration with ISSF. This foundation has a strong public awareness campaign and efficient information dissemination systems.

A movie has been made on the project. This movie can be seen at:
http://www.ird.fr/la-mediatheque/videos-en-ligne-canal-ird/mitigating-adverse-ecological-impacts-of-open-ocean-fisheries

This movie has been presented at the following festivals in 2013:

- Handaye France, FILMAR Festival du international du film de la mer
- Hamburg Germany, Beneath the waves
- Falmuth, UK, Beneath the waves
- Santa Cruse, CA,USA, Beneath the waves
- Ventura, CA, USA, Beneath the waves
- Boston, MA, USA, Beneath the waves
- Lima, Peru, Beneath the waves
- Perth, Australia, Beneath the waves
- Galway, Irland, Beneath the waves
- Almada, Portugal, Beneath the waves
- Barcelona, Spain, Beneath the waves
- Hvammstagi, Iceland, Beneath the waves

Information on the project are available at:
Web site: www.made-project.eu

MAIN DISSEMINATION ACTIVITIES

Peer-reviewed publications

A total of 18 peer-reviewed papers have already been published from the MADE project. It is expected that 5-15 more papers be published within the coming two years. The coordinator will make sure that most results obtained during the duration of the project are published, in order to ensure effective dissemination of the results to the scientific community, and through this means, to a wider audience. This also guarantees the scientific quality of the work undertaken during the project.

Working papers at Tuna RFMOs

A total of 26 papers were presented at meetings of the IOTC and the ICCAT. Similarly to the continuing effort in peer-reviewed publications, the coordinator will personally ensure that results, in particular those in future peer-reviewed publications, will be disseminated to the Tuna RFMOs communities. This is one of the main priorities, to ensure that the methods proposed during the project are known by the management bodies of tuna fisheries. A good example is the ecological FADs, but efforts should be undertaken on other results of the project as well.

Conferences and workshops

A total of 26 oral presentations or posters were presented at conferences or workshops. During the following two years, in parallel to the work on peer-reviewed publications, scientists from the MADE project will participate in conferences ensuring further dissemination of the projects results.