Comparative study of the distribution of natural versus artificial drifting Fish Aggregating Devices (FADs) in the Western Indian Ocean

Fauvel Thomas (1), Bez Nicolas (1), Walker Emily(1), Alicia Delgado (2), Murua Hilario (3), Chavance Pierre (1), Dagorn Laurent (4)

(1) IRD, UMR EME, BP 171, 34203 Sète cedex, France
(2) IEO, Centro Oceanográfico de Canarias Apdo. Correos 1373 38080 S/C Tenerife. Islas Canarias, Spain
(3) AZTI - Tecnalia / Unidad de Investigación Marina Herrera kaia portualdea z/g 20110 Pasaia, Spain
(4) IRD, UMR EME, BP 570 Victoria, Seychelles

Abstract

Natural floating objects such as logs or branches have always been a component of the habitat of tropical tunas. However, the introduction of artificial floating objects (fish aggregating devices – FADs) modifies this habitat. In order to quantitatively and qualitatively assess how much those FADs modify the offshore pelagic habitat, we compared the spatial distribution of natural and artificial floating objects. We used data from Spanish and French observers onboard tuna purse seiners in the Western Indian Ocean from December 2006 to December 2008 (for a total of 52 fishing trips). Natural and artificial floating objects were compared using different analyses: Global Index of Collocation (GIC), numbers of FADs per area and quarter, K Ripley function. Altough natural objects mainly occupy waters south of 7°S (Mozambique Channel) and FADs waters north of 7°S, all types of FADs are found everywhere. Results from the GIC analyses mainly show an overlap between the two types of FADs, indicating that in the Western Indian Ocean, FADs do not contribute to generate new major areas of floating objects that were free of natural objects before. The K Ripley analysis shows that both natural and artificial FADs exhibit an aggregated distribution. The major change due to the introduction of FADs concerns the number of FADs. Except in the Mozambique Channel and Chagos, the number of FADs is multiplied by 2 at least everywhere, and can reach up to 20 and 40 (Somalia area). These results are discussed in relation to the Ecological Trap hypothesis.

Introduction

Objects such as logs, parts of trees or drift algae commonly drift at the surface of the ocean and they naturally attract various species of fishes (see e.g. Greenblatt 1979 and Castro et al. 2002). In the literature, Castro et al. (2002) found records of 333 species belonging to 96 families which at some time were observed associated with floating sturctures. However, when considering only species that are commonly found around drifting floating objects in tropical waters, this number drops to 30 to 40 species (Romanov 2002, Taquet et al. 2007a), including tropical tunas such as skipjack (Katsuwonus pelamis), yellowfin (Thunnus albacares) and bigeye (T. Obesus) tunas. This frequent association of tunas with floating structures was the reason for the development of log-fishing by industrial purse seiners. They rapidly started to construct and release man-made Fish Aggregating Devices (FADs) to increase the numbers of floating objects in the oceans and help them fishing tunas. In this paper, we will use the term log to refer to any natural floating object, and the term FAD to refer to any man-made floating object, released by fishermen for the purpose of fishing. Fishing around logs and FADs has been responsible every year since the 90's for about half of the catch of tropical tunas in each ocean (Fonteneau et al. 2000).

Logs usually originate from large rivers or mangrove regions into tropical coastal waters and then drift with the currents. Those objects have therefore always been a part of the habitat of those species that naturally associate with any floating objects. These floating structures play some role in the ecology of those species, even if the exact role has not been elucidated yet for most of them, in particular tunas (Fréon and Dagorn 2000, Castro et al. 2002). However, the influence of floating objects on fish movement behavior has been proven by several studies. Fish can stay up to several days around drifting (Dagorn et al. 2007a, Taquet et al. 2007b) or anchored objects (Ohta and Kakuma 2005, Dagorn et al. 2007b), and fish (e.g. yellowfin tuna) can orient towards anchored FADs from long distances, about 10 km (Girard et al. 2004).

Since the 80's, but mainly the 90's, industrial purse seiners have been releasing large numbers of artificial FADs in the ocean to increase their catch of tropical tunas. Most of those FADs are bamboo rafts with nets hanging underwater, equipped with positionning buoys to locate them (Moreno et al. 2007). Thousands of such FADs are regularly released in the ocean which obviously represents a change in the natural habitat of tropical tunas and other species that associate with floating objects. Some scientists have considered that this habitat modification could lead to major changes in the behavior and biology of tunas. Marsac et al. (2000) considered that tunas could be trapped within networks of artificial drifting FADs. These networks of FADs could take fish associated with them to areas where they would not have been without these FADs. Those areas could be biologically poor and the biology (e.g. growth) of tunas would then be affected by these changes in the migration routes. This corresponds to the ecological trap hypothesis, which is supported by the recent results from Hallier and Gaertner (2008).

In fact, the release of FADs in the ocean can modify the natural environment in two ways. First, FADs can generate in or drift to areas where there is no natural floating object. FADs therefore create new areas of floating objects. This mainly corresponds to the basis of the ecological trap hypothesis (see above) if FADs are in non profitable areas. Second, FADs can increase the numbers of floating objects in areas where logs naturally occur. Before studying the effects of the release of FADs on the ecology of tropical tunas and other species, it is necessary to assess qualitatively and quantitatively how much these artificial FADs have modified the tunas habitat.

This study addresses the question of modifications of the tropical pelagic habitat due to the release of FADs by industrial tuna purse seiners. We consider that the population of logs represent the natural situation (without the introduction of FADs) and therefore base our analyses on the comparison between the log populations and either the FAD populations (for the qualitative assessment) or the populations of all floating objects together (for the quantitative assessment). We focus our research on the Western Indian Ocean where log- and FAD-fishing has always been very important since the beginning of the fishery in the early 80's. Two hypotheses are tested to assess the habitat modifications due to FADs:

1. FADs occupy areas that are free of natural floating objects (creating new floating objects areas)
2. FADs have drastically increased the density (or numbers) of floating objects in areas where natural objects already occur.

Materials and Methods

Data

The tuna purse seine fleet operating in the Western Indian Ocean is mainly composed of Spanish and French vessels. European observers embark onboard those vessels for 50-day trips to monitor by-catch, discards and all activities linked to floating objects. Only data from December 2006 could be used as it corresponds to the period when about 10% of the fleet started to be regularly surveyed. By the time of the analysis, data until December 2008 were available for both fleets, for a total of 52 fishing trips over 2 years. Observers note the type of floating objects encountered by the vessels: FADs (man-made), objects from human pollution (man-made), natural, others (Fig. 1). FADs and logs were encountered in all the fishing zones exploited by the fishery (Fig. 2). In order to be more in phase with fishing seasons and areas, and to get spatio-temporal windows with enough data, we decided to pool data by quarters delayed by one month: 1st quarter corresponds to December, January, February; 2nd quarter corresponds to March, April, May, and so on.

Comparison of the global areas of distribution using the Global Index of Collocation

In order to compare the areas of distribution of logs and FADs, we calculated the Global Index of Collocation (GIC) (Bez and Rivoirard, 2000) between both types of objects for each quarter. The GIC is a tool for testing spatial association between several distributions of populations (in our case natural versus artificial objects). First, the distributions of each of the studied populations are summarized by their centre of gravity (CG) and their inertia (I_{Z1} and I_{Z2} respectively for the first and the second population). Then, for testing the geographical difference between the two populations, the index is calculated in order to compare the distance between the CGs (ΔCG) to the mean distance between individuals taken at random and independently from each population: $GIC = 1 - \frac{\Delta CG^2}{\Delta CG^2 + I_{Z1} + I_{Z2}}$.

The index has been calculated in order to account for the anisotropic distribution of FADs: the inertia I_{Z1} and I_{Z2} taken for the calculation correspond to the dispersion of the FADs in the direction of the axis defined by the CGs.

For the second quarters (main fishing season for the Mozambique Channel), this index has been calculated separately in the southern part (Mozambique Channel) and in the northern part, considering that those two subpopulations of floating objects have very different characteristics (logs dominate in the Mozambique channel).

Quantitative comparison

For a quantitative assessment of how much the FADs modify the population of floating objects, we divided the Western Indian Ocean into a few zones following the Indian Ocean Tuna Commission zones for fisheries data: Somalia, East South Seychelles, North West Seychelles, Mozambique Channel, Chagos (Fig. 2). Those zones appear to be quite homogeneous in terms of populations of floating objects. Then, one can count the number of objects of each type into each of these zones and tell how much this number has been increased compared to a situation where there would only be logs. We also calculated the mean minimal distance between the floating objects, ie the distance from one to its closest neighbour.

Comparison of the distribution at small scale using Ripley's K function

The Ripley's K function (Ripley, 1976) has been calculated in order to characterize the spatial distribution of the floating objects at a smaller scale and analyses if they are randomly (according to a Poisson process), aggregated or regularly distributed. In our case, the Ripley's K function is also appropriate to study if at small scales the natural and artificial objects show the same aggregation patterns. Indeed, this function could not be used on a broad area which has not been fully and homogeneously sampled. At small scales, one can access to the intrinsic characteristics of the distribution of the two types of floating objects, independently of the sampling. The Ripley's K function has been calculated on the trajectories of the boats in one dimension, for each quarter. A trajectory is set to belong to a given quarter if at least 30% was performed in this quarter. All trajectories were then pooled together.

Results

Logs are dominant in waters south of 7°S, and in particular in the Mozambique Channel, while FADs are much more abundant in the northern part (north of 7°S). As fishermen only go in the Mozambique Channel during a limited period of time (mainly 2nd quarter), we miss information about FAD densities and distribution in that area during the three other quarters.

Comparison of the global areas of distribution using the Global Index of Collocation

We arbitrarily considered that a GIC less than 0.8 corresponds to a poor overlap between populations. The GIC (Fig. 3) reveals a rather good overlap between the two populations of floating objects for more than half of the quarters studied: 1st quarter, 2nd quarter Mozambique Channel, and 3rd quarter of 2007, 2nd quarter Mozambique Channel, 3rd and 4th quarter of 2008. There was a poor overlap for the equatorial zone in the 2nd quarters of 2007 and 2008, but the areas occupied by each type are quite small as compared to the other quarters. There was also a medium overlap (GIC=0.8) for the 4th quarter 2007 and 1st quarter of 2008. For the 4th quarter of 2007, the major difference is due to a large dispersion of logs (in particular in the South), rather than new areas occupied by FADs. During the 1st quarter of 2008, FADs are located northern than the natural ones.

Quantitative comparison

The increase of the total number of floating objects due to the presence of FADs is very low for the Mozambique Channel and the Chagos (Table I). FADs in the SE Seychelles multiply the number of objects by an average of 2 to 4. The effects of FADs in NW Seychelles is larger, in particular during the 3rd and the 4th quarters. By the end of the year, FADs contribute to multiply the numbers of floating objects in the area by about 10. Finally, the Somalia area is certainly the area that experienced most of the changes in terms of numbers of floating objects. The multiplication factor can reach up to 20 (4th quarter of 2008) or 40 (4th quarter of 2007). We consider that the increase of the number of floating objects in the northern part of the ocean occurs all year long.

For all quarters except the 2nd quarters, FADs contribute to decrease the average minimal distance between two objects (Fig. 4). The average minimal distance between all objects (logs and FADs together) is quite constant (mean 30.1 km, std 4.3 km), while the average minimal distance between logs is quite variable among quarters and ranges in average from 33.9 to 105.1 km (mean 69.9 km, std 26.6 km).

Comparison of the distribution at small scale using the Ripley's K function

Results of the Ripley's K function for logs and FADs (Fig. 5) demonstrate differences in the type of distribution of the two types of floating objects at small scale. Both show an aggregated distribution (K(r) values are higher than those from a theoretical Poisson random distribution), but for some quarters (2nd quarter 2007, 1st quarter 2008) logs appear to be more aggregated than FADs, while FADs are more aggregated than logs for the 4th quarter of 2007 and the 2nd and 3rd quarters of 2008 (it is not possible to compare both populations for quarters 1 and 3 of 2007, and quarter 4 of 2008).

Discussion

The GIC analysis revealed a rather good overlap between the distributions of logs and FADs. The major difference was only observed for the 2nd quarters of 2007 and 2008, but it is attenuated by the fact that at this period, the areas occupied by each types of floating objects are relatively small. The early years of the fishery help us understand this result. When the tuna purse seiners started to fish in this ocean in the early 80's, they rapidly found many floating objects, more than what was found in the other oceans. Rapidly, a large portion of the catch was coming from fish associated to natural objects. The current major fishing grounds with floating objects (Mozambique Channel and Somalia area) were already major fishing zones but with natural objects. The density of objects in the Mozambique Channel is naturally high as the area is quite small at the scale of industrial tuna purse seiners and fishermen do not seed a lot of new FADs in this area. However, because they knew that tunas naturally aggregate around objects in the Somalia area (a bigger area), they progressively released more and more FADs in this area, as well as around the Seychelles. Our results therefore show that in the Western Indian Ocean, FADs do not contribute to generate new major areas of floating objects. This means that there is no area without logs that FADs colonize. In other words, if FADs are sometimes located in biologically poor areas, logs also appear in such biologically poor areas.

In the Mozambique Channel and in the Chagos, the increase in numbers of floating objects due to FADs is quite low (from 10% to 40% maximum). However, FADs at least double the numbers of floating objects almost everywhere north of 7°S at any period. The biggest change appears in the Somalia area in the 4th quarters, with number of floating objects being multiplied from 20 to 40. The minimal distance between objects also reflects the densification of the FADs network: due to their highest densities, floating objects are found closer to each other due to the presence of FADs. The Ripley's K results (both types of floating objects are over aggregated compared to a theoretical Poisson distribution) are explained by the fact that both types of floating objects are not randomly generated in the ocean. Natural objects usually come from rivers and mangrove regions after storms. Fishermen do not usually deploy artificial FADs at random, but seed them in batches so that they have high probabilities to find them a few weeks after in a known fishing ground.

We could only analyze 2 years of data and it would be useful to conduct the same analysis on a longer period to see if our results are consistent over years. Moreover, fishermen tend to deploy more and more FADs, which could change the distribution of FADs very rapidly. It is therefore very important to maintain observers programs to permanently monitor the changes of habitats due to FADs. We only used data collected by observers as fishermen do not note in their logbooks all floating objects they encounter. They only report the objects on which they set. For our study, it is essential to collect information on all objects found in the ocean and this is currently only available from observers data. However, it is noteworthy that if fishermen could note all encounters of floating objects (indicating at least the type of the object), this would considerably increase the amount of data. In terms of spatio-temporal coverage of the ocean, it is worth noting that our sampling is limited to fishermen's strategy.

For instance, purse seiners never visit the Mozambique Channel out of the 2nd quarter so we cannot have any information on floating objects in this area at the other periods of the year. There might also be some areas which are never visited by purse seiners (out of their fishing grounds) and where artificial FADs and/or natural objects might drift.

What do our results bring to the study of the ecological trap hypothesis? Many hypotheses have been advanced to understand why tropical tunas associate to FADs (see review in Fréon and Dagorn 2000, Castro et al. 2002). One of them is the indicator log hypothesis (Hall 1992). It stipulates that natural floating objects could be indicators of productive areas, either because most natural floating objects originate in rich areas (e.g. river mouth, mangrove swamp) and remain within these rich bodies of water, or because they aggregate in rich frontal zones. The association of tunas with any floating object may then result from an evolutionary process where tunas use these indicators to stay in contact with rich waters. In this hypothesis, artificial floating objects can mislead tunas (i) if fish do not make any distinction between natural objects and man-made FADs and if (ii) FADs occur or drift to biologically poor areas, being away from the common paths of the natural objects. This corresponds to FADs acting as ecological traps (Marsac et al. 2000). In other words, FADs would act as ecological traps (Marsac et al. 2000, Hallier and Gaertner 2008) if the indicator log hypothesis (Hall 1992) is the reason for which tunas developed their association to floating objects. This would imply that logs are located in rich areas while FADs occupy (sometimes) poor areas. If FADs and logs are found in the same areas (which is what we found in the Western Indian Ocean), it would mean that the conditions that could lead to an ecological trap are not respected. However, this qualitative result should actually be balanced with the major changes in terms of numbers of FADs due to the release of FADs. We have seen that north of 7°S, FADs considerably increase the numbers of floating objects (in particular in Somalia). One consequence is also the decrease of the distances between FADs. It is therefore possible that before the use of artificial FADs, natural floating objects in those areas would not form some dense networks of floating objects. Although no study could show the effects of different densities of FADs on tuna movements (e.g. we do not know if time residency of tunas is higher in dense networks as opposed to loose ones), it is possible that tuna would behave differently in such different densities of floating objects. This was advanced for instance by Marsac et al. (2000), considering that the high densities of FADs could trap the fish, while the low densities of logs would not. Behavioral studies have provided estimates of residence times of fish at drifting FADs (Dagorn et al. 2007a), but it is necessary to conduct in depth studies to determine how much dense networks of floating objects increase the residency time of fish.

Hallier and Gaertner (2008) found an effect of FADs on the large-scale movements of tunas when analysing conventional tagging data from the Atlantic ocean. Tunas recaptured under floating objects exhibited different movement patterns than tunas recaptured in free-swimming schools. However, the authors did not indicate if the objects where fish were recaptured were artificial or natural. Knowledge on the distribution and densities of both types of floating objects in those areas would help interpreting those movement data. Although a westward extension of the tuna surface fishery has been observed (Ariz et al. 1999, Marsac et al. 2000), the spatial distributions of logs and FADs in the Atlantic Ocean from fishermen logbooks look quite similar, and the main changes seem to be in terms of numbers of floating objects (see Marsac et al. 2000) rather than new areas. The Eastern Pacific Ocean seem to experience major changes in terms of new areas colonized by FADs. The purse seine fishery has extended its fishing grounds westward thanks to the FADs (like in the Atlantic Ocean) but apparently, no natural floating object is found in these western areas (Hall et al. 1999). Because the relative distribution of natural floating objects and FADs could be different from one ocean to the other, a comparative approach would be very helpful. The consequences of the release of FADs (e.g. if FADs act as ecological traps) could therefore be different among the oceans. In some cases (e.g. Eastern Pacific Ocean), FADs could drift to areas where there was no natural object. In all cases, FADs have contributed to drastic increases of the numbers of floating objects. This could have different effects on the populations of tunas. Because fishermen tend to release more and more FADs in the ocean, it is urgent (i) to assess qualitatively and quantitatively the changes of the environment due to FADs in each ocean, (ii) in parallel conduct studies on the spatial dynamics of tunas from conventional or electronic tags, and (iii) model the behavior of fish to assess the effects of different densities of FADs on their movements. This is necessary to define the respective roles of (i) floating objects and (ii) biological environment (prey) on the determinisms of the spatial dynamics of tunas.

Acknowledgements

This study has been carried out with financial support from the Commission of the European Communities, specific RTD programme of Framework Programme 7, Theme 2 (Food, Agriculture, Fisheries and Biotechonology), through the research project # 210496 MADE (Mitigating adverse ecological impacts of open ocean fisheries). It does not necesarily reflect its views and in no way anticipates the Commission's future policy in this area.

References

Ariz J, Delgado A, Fonteneau A, Gonzalez Costas F, Pallares P, 1999. Logs and tunas in the Eastern Tropical Atlantic. A review of present knowledge and uncertainties. In: Scott MD, Bayliff WH, Lennert-Cody CE, Schaefer KM (eds) Proceedings of the International Workshop on Fishing for Tunas Associated with Floating Objects, La Jolla, CA, February 11–13, 1992. Inter-Am Trop Tuna Comm Spec Rep 11:21–65

Bez N., and J. Rivoirard, 2000. Indices of collocation between populations. In : Checkley, D.M., J.R. Hunter, L. Motos, and C.D. van der Lingen (eds). Report of a workshop on the use of Continuous Underway Fish Egg Sampler (CUFES) for mapping spawning habitat of pelagic fish. GLOBEC Report 14, 1-65 pp.

Castro J.J., Santiago J.A., Santana-Ortega, A.T., 2002, A general theory on fish aggregation to floating objects: an alternative to the meeting point hypothesis. Rev. Fish. Biol. Fisheries 11(3), 255-277.

Dagorn L, Pincock D, Girard C, Holland K, Taquet M, Sancho G, Itano D, Aumeeruddy R, 2007a. Satellite-linked acoustic receivers to observe behavior of fish in remote areas. Aquatic Living Resources, 20(4): 307-312.

Dagorn L, Holland KN, Itano DG, 2007b. Behavior of yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna in a network of fish aggregating devices (FADs). Marine Biology, 151:595-606.

Fonteneau A., Pallares P., Pianet R., 2000, A worldwide review of purse seine fisheries on FADs. *In*: Le Gall J.-Y., Cayre P. and Taquet M. (eds), *Peche thoniere et dispositifs de concentration de poisons*. Ed. Ifremer, Actes Colloq. 28, 15-34.

Fréon P., Dagorn L., 2000. Review of fish associative behaviour: toward a generalisation of the meeting point hypothesis. Rev. Fish. Biol. Fisheries 10, 183-207.

Girard C, Benhamou S, Dagorn L, 2004. FAD: Fish Aggregating Device or Fish Attracting Device? A new analysis of yellowfin tuna movements around floating objects. Animal Behaviour, 67:319-326.

Greenblatt P.R., 1979. Associations of tuna with flotsam in the eastern tropical Pacific. Fish. Bull. US 77(1), 147–155.

Hall M.,1992. The association of tunas with floating objects and dolphins in the Eastern Pacific ocean: VII. Some hypotheses on the mechanisms governing the association of tunas with floating objects and dolphins. Backgound document for the International. Workshop on the Ecology and Fisheries for Tunas Associated with Floating Objects, February 11–13 1992, La Jolla, CA, Available from Inter-American Tropical Tuna Commission, 8604 La Jolla Shores Dr, La Jolla, CA 92037 (mimeo) pp. 6.

Hall M., Garcia M., Lennert-Cody C., Arenas P. and Miller F., 1999. The association of tunas with floating objects and dolphins in the eastern Pacific Ocean: A review of the current purse-seine fishery. In: Scott M.D., Bayliff W.H., Lennert-Cody C.E. and Schaefer K.M. (eds.), Proceedings of the International Workshop on the Ecology and Fisheries for Tunas Associated with Floating Objects, February 11–13, 1992. Inter-American Tropical Tuna Commission Special Report 11, La Jolla, California, pp. 87–194.

Hallier JP, Gaertner D, 2008. Drifting fish aggregation devices could act as an ecological trap for tropical tuna species. Mar. Ecol. Prog. Ser. 353: 255–264

Marsac F, Fonteneau A, Ménard F, 2000. Drifting FADs used in tuna fisheries: an ecological trap? In: Le Gall JY, Cayré P, Taquet M (eds) Pêche thonière et dispositifs de concentration de poissons. Edition Ifremer. Actes Colloq 28:36–54.

Moreno G, Dagorn L, Sancho G, Itano D, 2007, Fish behaviour from fishers´ knowledge: the case study of tropical tuna around drifting fish aggregating devices (DFADs). Can. J. Fish. Aquat. Sci. 64: 1517-1528

Ohta I, Kakuma S, 2005. Periodic behavior and residence time of yellowfin and bigeye tuna associated with fish aggregating devices around Okinawa Islands, as identified with automated listening stations. Mar Biol 146:581–594.

Ripley, B. D., 1976. The second-order analysis of stationary point processes. Journal of Applied Probability 13, 255-266.

Romanov E.V., 2002. By-catch in the tuna purse-seine fisheries of the Western Indian Ocean. Fish. Bull., 100(1), 90-105.

Romanov, E.V., 2002. Bycatch in the tuna purse-seine fisheries of the western Indian Ocean. Fish. Bull. 100(1), 90–105.

Taquet M, Sancho G, Dagorn L, Gaertner JC, Itano D, Aumeeruddy R, Wendling B, Peignon C, 2007a. Characterizing fish communities associated with drifting fish aggregating devices (FADs) in the Western Indian Ocean using underwater visual surveys. Aquatic Living Resources, 20(4): 331-342.

Taquet M, Dagorn L, Gaertner JC, Girard C, Aumerruddy R, Sancho G, Itano D, 2007b. Behaviour of dolphinfish (*Coryphaena hippurus*) around drifting FADs as observed from automated acoustic receivers. Aquatic Living Resources, 323-330.

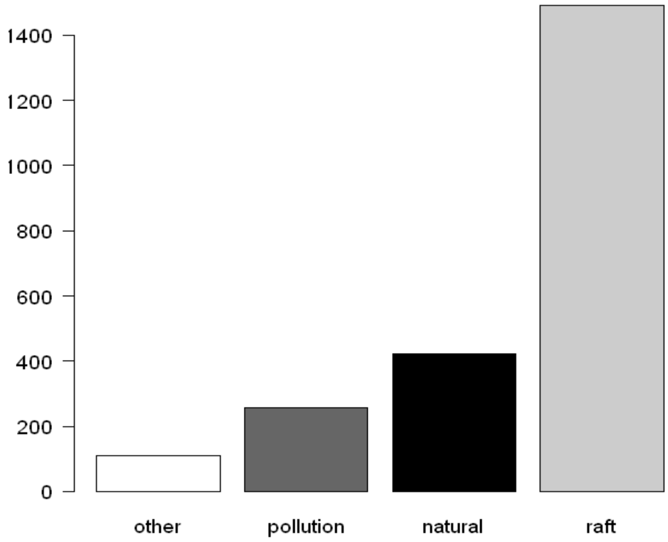


Figure 1: Number of floating objects recorded per category (rafts means FADs) from December 2006 to December 2008.

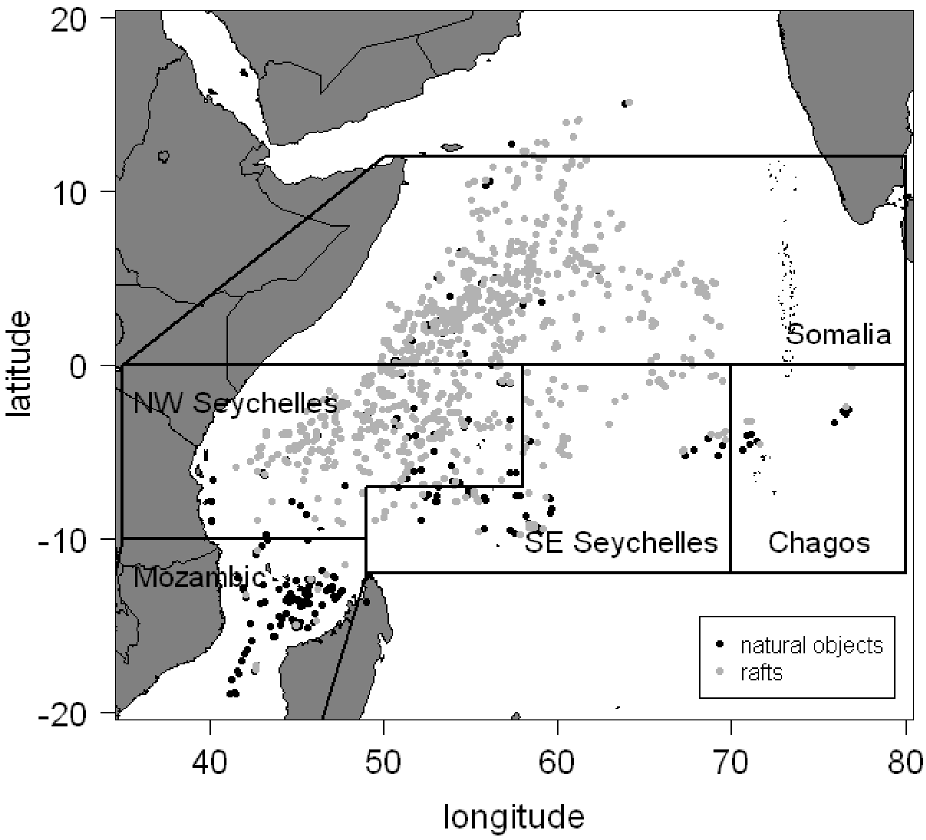
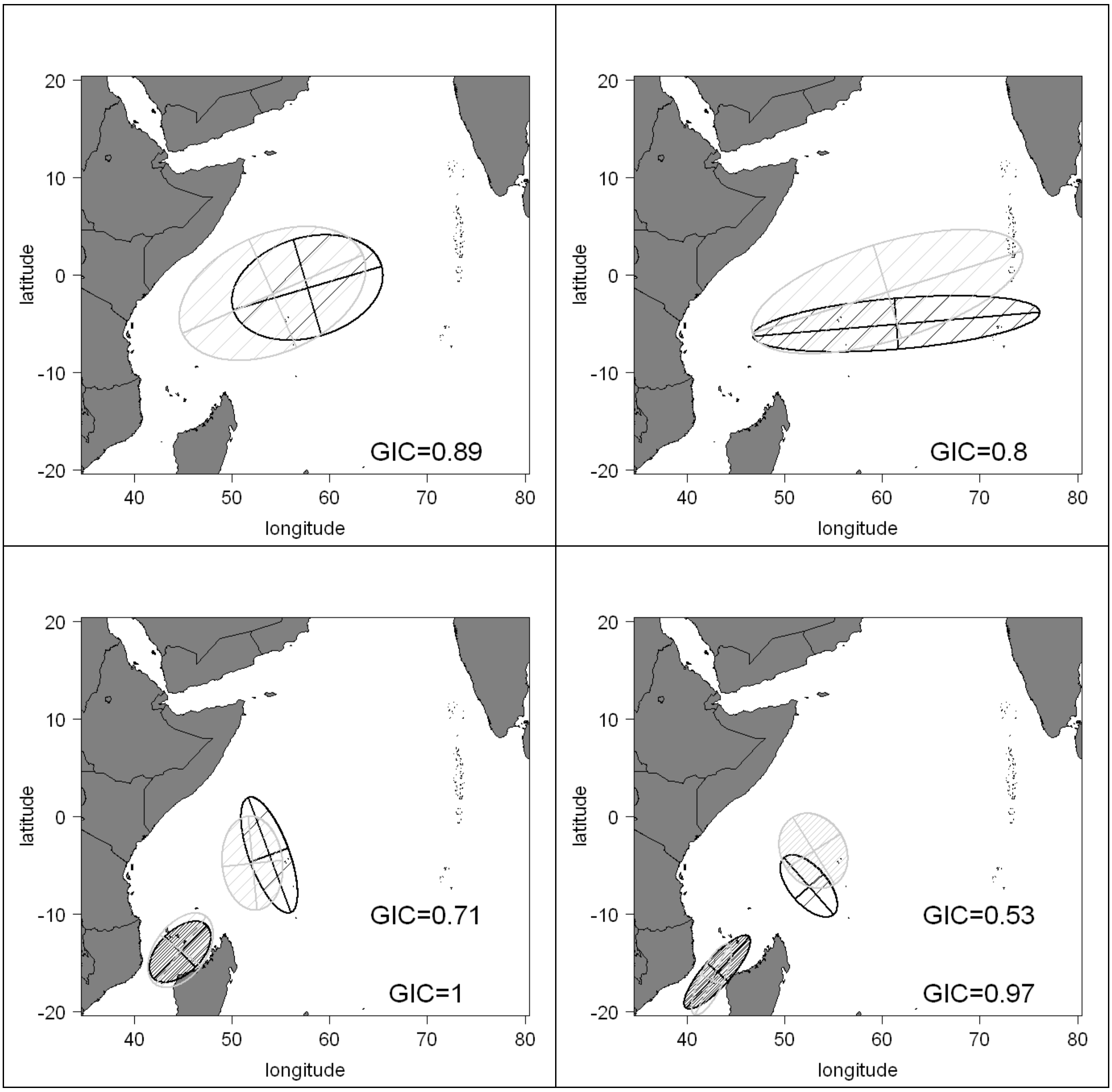


Figure 2: Map representing all FADs and natural objects seen by observers over year 2007.



latitude
longitude
GIC=0.89
GIC=0.8
GIC=0.71
GIC=1
GIC=0.53
GIC=0.97

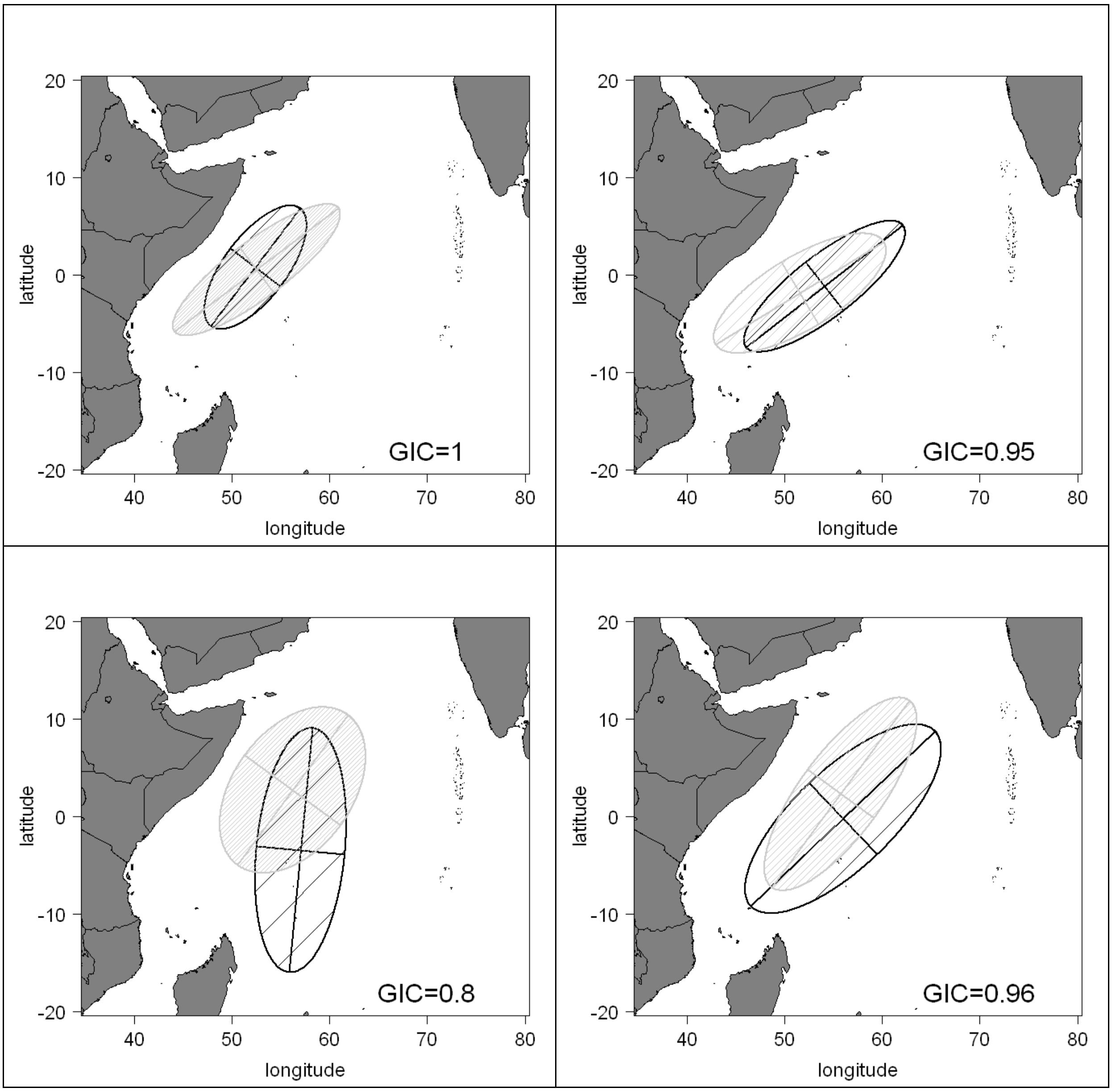


Figure 3: Global Index of Collocation (GIC) calculated at each quarter (first (a), second (b), third (c), fourth (d) of 2007 and first (e), second (f), third (g), fourth (h) of 2008): GIC values represented with their distribution of natural (black) and artificial (grey) FADs summarized by their centre of gravity and their inertia. Density is also represented (hatching) and is calculated here as the ratio between the number of FADs over the area of their convex hull.

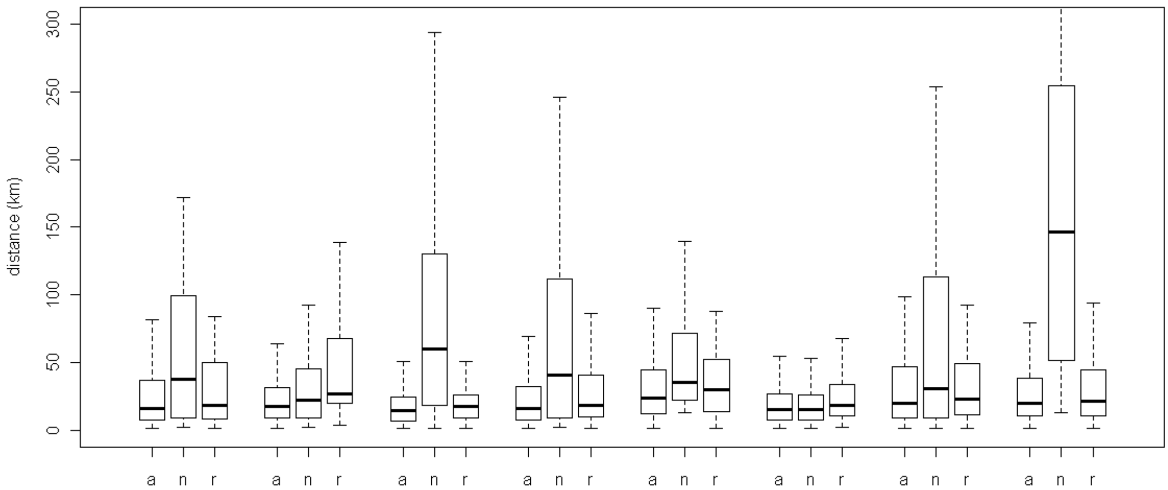


Figure 4: Boxplots representing the mean distance between one FAD to the closest one, for all types (a), natural objects (n) and FADs (r) at each quarter.

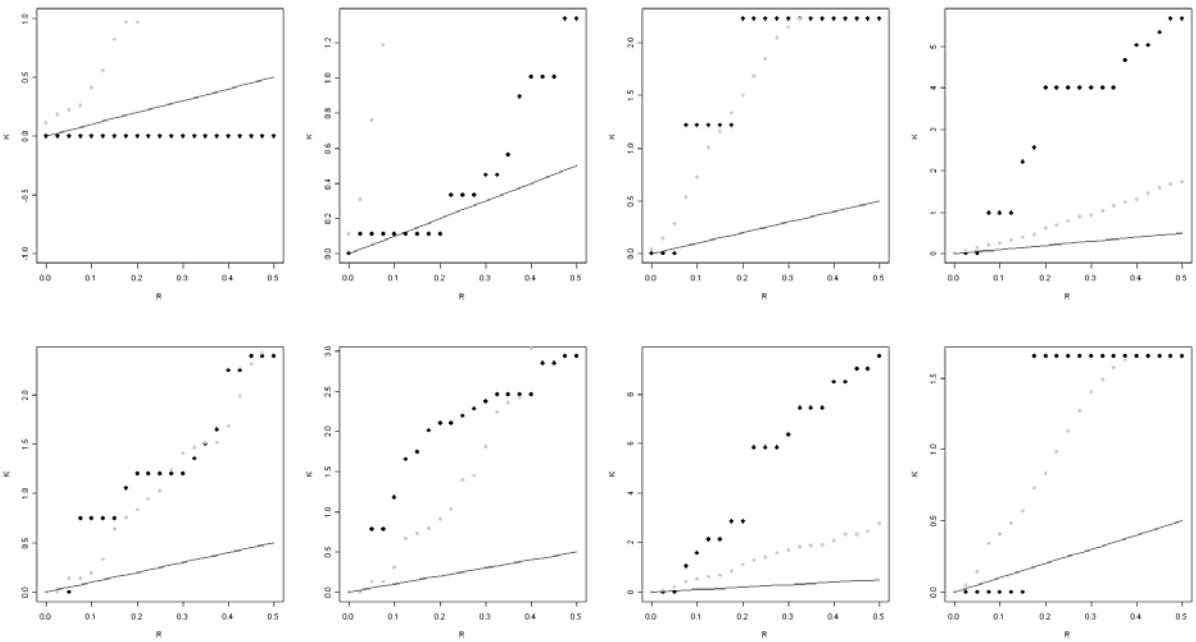


Figure 5: Experimental Ripley's K functions represented at the close distances (points) for natural (black) and artificial objects (grey), with the random Poisson distribution (line), for each quarter (first (a), second (b), third (c), fourth (d) of 2007 and first (e), second (f), third (g), fourth (h) of 2008)

Table I: Ratio between the number of FADs and the number of logs for each zone per quarter.

Quarter	Somalia	NW Seychelles	SE Seychelles	Mozambic	Chagos
Dec 06 - Feb 07	3.4	5.4	2.8	NA	NA
Mar 07 - May 07	1.5	2.4	4	0.1	NA
Jun 07 - Aug 07	8.6	10.3	0	NA	NA
Sep 07 - Nov 07	39.4	13.2	1.6	NA	NA
Dec 07 - Feb 08	Inf	2.4	1.3	NA	0.4
Mar 08 - May 08	Inf	3.8	2.3	0.1	NA
Jun 08 - Aug 08	2.6	4	4	NA	NA
Sep 08 - Nov 08	18.4	12.3	4	NA	NA
Total 2007 - 2008	12.3	5.3	1.9	0.1	0.4