Ocean sentinel albatrosses locate illegal vessels and provide the first estimate of the extent of nondeclared fishing

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Henri Weimerskirch, Julien Collet, Alexandre Corbeau, Adrien Pajot, Floran Hoarau, et al.. Ocean sentinel albatrosses locate illegal vessels and provide the first estimate of the extent of nondeclared fishing. Proceedings of the National Academy of Sciences of the United States of America, 2020, 117 (6), pp.3006-3014. 10.1073/pnas.1915499117 . hal-02462482

HAL Id: hal-02462482
https://hal.science/hal-02462482

Submitted on 28 Oct 2021

Albatrosses as Ocean Sentinels: from research to operational monitoring of Southern Ocean's fisheries

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Abstract

Threats to nature becoming increasingly prominent, in order for biodiversity levels to persist, there is a critical need to improve implementation of conservation measures. In the oceans, the surveillance of fisheries is complex and inadequate, such that quantifying and locating non-declared and illegal fisheries is persistently problematic. Given that these activities dramatically impact oceanic ecosystems, through over-exploitation of fish stocks and bycatch of threatened species, innovative ways to monitor the oceans are urgently required. Here, we describe a new concept of 'Ocean Sentinel' using animals equipped with state-of-the-art loggers which monitor fisheries in remote areas. Albatrosses fitted with loggers detecting and locating the presence of vessels, and transmitting the information immediately to authorities, allowed the first estimation of the proportion of non-declared fishing vessels operating in National and International waters of Southern Ocean. We found that in international waters more than one third of vessels had no Automatic Identification System operating; in national Exclusive Economic Zones (EEZ) this proportion was lower on average, but variable according to EEZ. Ocean Sentinel was also able to provide unpreceded information on the attraction of seabirds to vessels, giving access to crucial information for risk assessment plans of threatened species. Attraction differed between species, age and vessels activity. Fishing vessels attracted more birds than other vessels and juveniles both encountering fewer vessels, and showed a lower attraction to vessels, than adults. This study shows that the development of new technologies offers the potential of implementing conservation policies by using wide-ranging seabirds to patrol oceans.

Significance

New technological approaches to improving remote surveillance of the oceans are necessary if we are to implement effective conservation. Of particular concern is locating non-declared and illegal fisheries that dramatically impact oceanic ecosystems. Here we demonstrate that new animal-borne satellite-relayed data loggers both detected and localised fishing vessels over large oceanic sectors. Attraction of albatrosses to fishing vessels differed according to species and age. We found high proportions of non-declared fishing vessels operating in international waters as well as in some remote national seas. Our results demonstrate the potential of using animals as Ocean Sentinels for operational conservation.

INTRODUCTION

The Anthropocene era is associated with increasing threats to nature and biodiversity (1), and as a result, conservation research is becoming increasingly sophisticated, in an attempt to protect ecosystems (2). Today conservation studies often focus on increasing the accuracy of information used to prioritise locations for conservation actions, e.g. delimitation of areas of conservation (3). Yet, it is increasingly recognised that the implementation of conservation measures is inadequate and a major hindrance in global conservation (4). There is a crucial need to improve the implementation of conservation research into practice and policy, beyond specific species or systems studied.

Compared to terrestrial habitats, the surveillance and implementation of conservation measures is considerably more complicated in marine systems. In particular international oceanic waters and remote areas are particularly challenging for political and logistical reasons. Fisheries are operating worldwide over National Economic Exclusive Zones (EEZs) and international waters. They have a profound effect on ecosystems through overexploitation of fish stocks, the removal of key ecosystem components and accidental capture of marine vertebrates (5). As a result, there is an urgent need for in depth reforms to fisheries management to improve fish abundance while increasing food security (6). Today basic knowledge about the distribution of fishing vessels is fundamental for the regulation of fishing activities, as well for the conservation of the oceans (7). Yet information about fishing vessel location is very difficult to obtain. It is eventually made available to authorities or international fisheries organisations through voluntary declaration using Vessel Monitoring Systems (VMS) or indirectly through the use of Automatic Identification Systems (AIS) (8). The former is generally used only in EEZs, the latter should be used both in EEZ and international waters to avoid collisions and may be accessed through dedicated sites (www.marinetraffic.com). However, AIS are not used systematically, and can be switched off from the vessel. In international waters, information on fishing effort and distribution may be completely lacking, or made available by Regional Fisheries Management Organisations (RFMO), such as tuna fisheries, but at a very coarse scale and in an aggregated form, making it impossible to have real time or regular (e.g. daily) information. Recent efforts have been made to improve this, through the use of AIS, allowing visualisation, tracking and sharing of data on global fishing activity (https://globalfishingwatch.org)(9, 10). However, this information is limited as it is complex to access in real time, and, furthermore, at any time AIS can be switched off, which is likely to be particular common by illegal fisheries. Yet information on the location of fishing vessels is critical since in many oceanic sectors non-declared and illegal fisheries are negatively affecting ecosystems through over exploitation and by catch of non-target species (11, 12). Among these species, bycatch of albatrosses and petrels is very high and these are among the most threatened bird species, with 100,000s killed by long line fisheries every year (13).   Thus, there is a need to obtain better information on seabirds-fishery interactions (14).

Estimates of the overlap between seabirds and fisheries activities outside EEZ are at best available at large scale from RFMOs. It is in these international waters that information on seabird-fishery interactions are badly required to estimate global bycatch risks (15, 16). At present, risk assessments are based on the assumption that the co-occurrence of seabirds and fisheries in a large scale sector (generally 5° squares for tuna fisheries) leads to interactions, and therefore mortality risks. This has so far not been documented, and until today real degree of overlap can only be obtained by scaling down the analysis of interactions (17) by using high resolution VMS data and seabird tracking data. However VMS data do not exist in international waters and for most fisheries operating in EEZ VMS are rarely fully available to researchers, especially in real time. Obtaining real interaction information requires having fine scale information simultaneously on fisheries distribution and seabird movements, which is rarely the case, generally restricted to limited EEZ areas (18). More importantly once interactions have been located, if an intervention from authority is required, there is a need for an immediate relay of information on these interactions.

Tracking of marine animals has been used widely to determine sites to protect (19), with the ultimate goal of improving conservation (20). In addition, during recent years, seabirds, marine mammals and turtles, fitted with a variety of loggers, have been used worldwide as oceanic samplers through equipment with bio-logging sensors (21, 22). These loggers have the potential to transmit information instantaneously through satellites, and make them available to agencies or researchers (23, 24). Recently a new logger detecting radar emissions of vessels has been developed, providing locations of interactions between albatrosses and vessels over vast oceanic sectors (25). Building on this new platform, we have developed a new concept of operational conservation based on new loggers that will allow the immediate transmission of vessel location for improving surveillance and enforcement.

By using wide-ranging large seabirds that are attracted to boats, such as albatrosses, petrels and gannets, we have developed the concept of OCEAN SENTINEL. Ocean Sentinels aim to provide more accurate information on the distribution of fisheries in any oceanic sector and to provide instantaneous information to authorities, international fisheries agreements or researchers, on the location of fishing boats. For the first large-scale test of the concept we have used albatrosses. Large albatrosses cover huge areas of the ocean surface (22 million square kilometres with 50 individuals equipped) and are highly attracted to fishing vessels which they can detect from up to 30 km away (26), making them particularly suitable patrollers of the oceans. The concept was tested between November 2018 and May 2019 in the Southern Indian Ocean, at Crozet, Kerguelen and Amsterdam Islands, where valuable and extensive fisheries operate, both in EEZs and in international oceanic waters. Its aim was to provide information on fisheries distribution in oceanic sectors where monitoring information is currently not available. In the Southern Ocean, surveillance of the EEZs is extremely costly, and thus only occasional visits by Navy ships, provide monitoring for these zones. Furthermore, in international waters such surveillance in absent.

Here we present the first results of a six-month large-scale test of the Ocean Sentinel concept carried out in the south-western Indian Ocean. The specific aims of this paper are 1) to test whether it is possible to use animals as platforms to make research operational, especially for large scale surveillance, 2) to compare the efficiency of the concept to the other existing surveillance systems based on VMS, AIS satellite and naval ship-based surveillance, 3) provide for the first time an estimate of the proportion of vessels illegally deactivating their AIS system, by comparing the data made available by AIS system to those provided by the bird-borne radar detectors , 4) obtain more accurate information (occurrence and location) on interactions between fisheries and two threatened species, wandering and Amsterdam albatrosses, and test the assumption that co-occurrence of seabird and fisheries results in real interaction. We also provide a first estimate of the real proportion of birds attending fishing boat after co-occurrence, and how it differs between species and age classes.

Material and methods

Loggers

Since all boast at-sea use radars for safety and operational reasons, the ability to detect radar emissions from geolocating loggers provides accurate information on the location of boats. We have developed, with Sextant Technology, and tested between 2015 and 2017, a logger (XGPS) that provides the GPS location of the fitted animal and simultaneously detects radar emissions (25). From this platform, we developed a new logger that includes this radar detector, a GPS antenna, a processor and memory, but with the additional of an Argos antenna for real time data transmission. It is powered by a lithium rechargeable battery which has a solar panel capable of recharging the device when on the bird. The GPS location can be programmed to record GPS fixes at intervals of 1sec to 1h. The Argos antenna sends this information at a programmable interval. Two models were developed: Centurion and XArgos.

Centurion logger weights 65 g, measures 109 X 30 X 22 mm (see SI Appendix, fig. S1) and records all the information on-board but sends instantaneously through Argos the location of the radar detection as soon as a vessel is detected through its radar emission. Loggers were deployed on actively breeding birds, which alternate foraging trips at-sea with periods on the nest, making recovery simple. For our large scale field deployment test we programmed Centurions so that the GPS recorded fixes every 2 mins and the radar detector recorded the presence of radar emissions every 5 mins, for a duration of 1 min. If the logger received a radar signal, the radar information (location and number of radar detections) was sent in real time through the Argos system, and afterwards continuously during 12h. When no radar signals had been detected after 12h, data was stored on the device but not transmitted through Argos. The complete information, including GPS locations every 2 min and radar detections was then downloaded from the logger when the bird had returned to its nest. The logger must be recovered to download the entire information on the track of the bird.

XArgos loggers (55 g, 109 X 30 X 19 mm) record and send the location of the bird and the summary of the Radar Detector scanning (scan for radar emissions recorded during 1.5 mins every 15 mins) every hour through Argos. They were deployed on juveniles leaving the colony, where they remain at-sea for several years, without returning to land. In addition, they were deployed on immature birds, defined as birds that return to the colony for pair formation but have yet to commence breeding, post-breeding birds, which are either adult birds that have successfully finished breeding or failed breeders, which are adult birds that have attempted to breed but failed to fledge a chick. All birds were captured on the colony but as no birds were actively breeding at deployment, the chance of logger recovery was very low, making these loggers optimal.

Deployments

A total of 169 individuals of wandering (*Diomedea exulans*) and Amsterdam (*Diomedea amsterdamensis*) albatrosses were equipped with Centurion (breeding adults) and XArgos loggers between November 2018 and March 2019 from Crozet, Kerguelen and Amsterdam (Table 1).

The loggers were attached to the back feathers using special tape (Tesa, Germany). For short-term deployment (Centurion loggers on breeding adults), the logger was removed after the bird returned on its nest after one foraging trip. For long-term deployment (XArgos loggers on juveniles, immature and post-breeding adults), the attachment was reinforced by Loctite glue on the contacts between the logger and the tape. XArgos detached from birds through the loss of feathers during moulting process after 3-6 months. The loggers represented 0.46% to 0.93% of the bird body weight (wandering albatrosses weight between 7 and 12 kg, Amsterdam albatross between 6 and 10 kg), i.e. below the recommended maximum 3% of the bird’s body mass for loggers attached (27).

Vessel information and AIS data

AIS data were made available through the Themis interface (CLS Toulouse) for the sector 20-70°S, 10-180°E. Through this system, all AIS emissions in the sector are recorded, and the information was downloaded every day from the CLS server and stored in a database. During the study period, more than 100 million AIS locations were obtained. For each AIS location the following information was available: date, latitude, longitude, Ship Name, IMO number of the vessel (identity of International Marine Organisation), nationality, call sign, speed, heading, type of vessel (fishing, tanker, cargo, pleasure etc.), activity. The densities of AIS were highest along continents, and the distribution of AIS from fishing boats varied throughout the study period (Figure 1).

Data access and accessibility

The information sent by the Centurion/XArgos loggers are received by the Argos satellites, and made available within minutes through the Argos website. Every 10 minutes the data were automatically downloaded, treated and made available through a dedicated Web page of the Terres Australes Françaises National Reserve (http://178.170.56.102/websig/lizmap/www/index.php/view/map/?repository=sentinel&project=ocean_sentinel). Access to this site was given to the researchers, the TAAF Administration and to the Regional Operational Monitoring and Rescue Center based on Réunion Island (CROSS) which controls the movements of boats in the Western Indian Ocean. When a boat was detected by a bird the location appeared immediately on the interface (See SI Appendix, fig. S2).

During the study period, the Ocean Sentinel website was continuously consulted and regularly verified by the TAAF administration and the CROSS Control Centre. All detections of vessels were compared by the CROSS with the AIS data available, as well as with the VMS data from the fishery operating in the Crozet, Kerguelen and Amsterdam EEZ. Thus, the system allowed an alert to any Navy Patrol vessels present in the EEZ for a control in case of a non-declared boat detected within the EEZ (Figure 2).

Data Processing and Analyses

All information received through Argos, were filtered based on Cyclic Redundancy Check (CRC) to remove improperly transmitted locations with failures. We then applied a speed filter of 150 km.h^{-1} to remove all implausible locations of bird movements. These data were then made available on the web site. Data downloaded from Centurion loggers after birds were recovered on the nest, were similarly filtered, and all data filtered were then stored in a database.

All bird data was then merged with AIS data so that to each bird location was associated to AIS information of any vessel occurring within 5 km (considered as the distance of a bird nearby boat and ATTENDING it, and corresponding to the range of radar detection for the logger –(25), and within 30 km (the maximum distance of detection of a boat by an albatross, considered as an ENCOUNTER (26)). To determine bird-boat distance and time spent ATTENDING and in ENCOUNTER we used the linearly interpolated AIS location the closest in time from the bird location. Birds attracted to fishing boats come close and stay for at least a couple of hours (28) so that we are confident that a series of consecutive boat locations recorded within proximity of a bird are not due to inaccurate spatio-temporal matching. All series (at least 2 successive) radar detections associated to GPS locations without gaps of more than 2 h were grouped into Radar Event. A Radar event was considered as an association with a boat.

Then the database was processed to associate to each bird location, each Radar Event, Attending (AIS within 5 km) and Encountering (AIS within 30 km) locations, the following parameters: bathymetry, international or EEZ waters and all information on the associated AIS boat (IMO number or identification number for the International Maritime Organisation, ship name, activity, nationality).

From the data base we calculated, for each individual bird, the number of vessels within 100 km of each bird location, the number encountered (within 30 km) and the number attended (within 5 km or with a radar detection). From this we calculated first the proportion of vessels within 100km that were encountered and attended, and then from the number of vessels encountered, we estimated the proportion of these vessels were attended. We also calculated for all the encounters and attendance the proportion of all vessels that were fishing versus other types of vessels.

All data processing was performed under R environment. Statistical Analyses were performed under Statistica 12. Data will be made available through the online open access repository Figshare (https://figshare.com).

RESULTS

Coverage of Ocean Sentinel

Between the 1st of December 2018 and the 1st of June 2019, 632,333 GPS locations of albatrosses, together with 5108 Radar detections, were received from Argos or downloaded from centurion loggers. The 5108 radar detections, represented interactions with 353 different boats, considered as boat events. Adult and immatures birds had a higher proportion of vessels than juveniles (Table 1). The simultaneous deployment of these loggers gave coverage of a wide area of more than 47 million km^2 (Fig. 3).

Radar detections were found throughout the albatrosses range (Fig. 3) but with high densities within the EEZs on the edge of the Kerguelen-Heard plateau (Fig. 4) and Crozet – Del Cano plateau (Fig. 3). Proportion of time spent in international waters varied according to bird breeding status ($F_{3,133} = 5.1$, P=0.0049) with juveniles and non-breeding adults spending more time in international waters than breeding adults and immatures (Table 1). The proportion of trips spent in the French EEZ differed between stages as well, adults spending more time in EEZ than juveniles ($F_{3,133} = 5.8$, P=0.0024) (Table 1).

For centurion loggers, fitted on breeding adults, the transmission of radar detection through Argos allowed access to the location of boats within 0.2 to 2h of the first contact between a bird and a vessel, and this information was accessible immediately through the Ocean Sentinel website.

Comparison with AIS

Among the 353 detections of vessels, 71.8% had a corresponding AIS signal, but 28.2% had no AIS signal within 30 km. The situation differed between EEZs and international waters. In EEZs 74.2% of radar events had a corresponding AIS signal within 30 km, i.e. 25.8% of boats detected in EEZ had no associated AIS identification. In international waters, this percentage increased to 36.9% (the difference between EEZ and international waters was significant: Fisher Exact test, P= 0.042). The percentage of radar detection events without AIS differed between EEZs (χ^2_5= 105.2, P<0.001) (Table 2).

For the French Crozet-Kerguelen EEZs, most of the radar detections with AIS corresponded to fishing vessels from the Réunion based French fishing fleet. For the Crozet and Kerguelen EEZ most of the radar detections events without AIS corresponded to the detections of surveillance ship from the French Navy (no AIS) and to the detection of declared fishing boats that had their AIS momentarily switched off but were recognised from their VMS position by CROSS. For the Amsterdam EEZ, half of radar detections were non-declared ships. On the border of EEZ several vessels were detected in operation, with AIS irregularly ON (e.g. Fig. 4). This was a Spanish vessel and several Chinese long-liner fishing at the edge of the Kerguelen and Crozet EEZs.

In international waters short encounters corresponded to encounters with vessels transiting in the range zone of albatrosses, with functioning AIS. This was particularly the case for transport ships in the high-density zone of vessels with AIS south east of South Africa (Fig. 1). For long encounters with vessels (several hours of radar detections), half occurred with Asiatic long-liners, but half were not associated with an AIS signals, but occurred in the zone of high densities of Asiatic fishing boats operating, suggesting that within the fleets, a significant proportion of vessels had no AIS working.

77.4% of radar detection events occurred over shelves and shelf edges, with 99 events (28.1%) being not associated with an AIS within 5 km from the bird (Fig. 5). Over oceanic waters, 39.7% of events had no AIS. 28.2% of Radar Detection had no AIS information on the type of ship within 30 km (either no AIS at all or no AIS information on the ship type). 83.3% of ships with radar detection and an AIS signal were fishing vessels, 11.1% Cargo or Tanker and 5.6% other vessels. Time spent attending fishing vessels was longer than for the other vessel types (4.8 h versus 2.4 h respectively; $F_{2, 249} = 3.2$, P=0.045).

In 403 events, where AIS were located within 5 km of birds, 188 (46.6%) had a radar detection with 132 (54.8% of events) for Centurion and 56 (35% of events) for XArgos.

Co-occurrence and attraction

Only 10% of individuals did not have any vessel within a range of 100 km during their trip. For those that had at least one vessel within 100km of their movement, 19.9%±20.4 came within 30 km of at least a vessel, and 6.3±11.9% attended a vessel. These values varied extensively according to the age of individuals with juveniles being less prone to encounter and approach vessels to attend it, than adults ($F_{3,175}$=5.8, P<0.0001 and $F_{3,175}$=7.7, P<0.001 respectively) (Fig. 6a and b).

When birds encountered a vessel (within 30 km), 19.8±20.4% attended the vessel. Again, this value varied extensively according to the status, juveniles having a lower propensity to attend vessels encountered ($F_{1,146}$=8.2, P<0.001) (Fig. 6c).

Attractivity of vessels varied between species, with Amsterdam albatrosses being less attracted to vessels than wandering albatrosses (8.5±13.3% of Amsterdam albatrosses encountering a vessel approached at less than 5 km of the vessel compared to 21.1±22.8% for wanderings, $F_{1,148}$=4.4, P=0.038). Wandering albatrosses were also more likely to approach a fishing vessel if encountered, compared to other vessel type: 40.3% of encounters of fishing vessels resulted in an attendance, compared to 10.9% for other vessels (χ^2_1= 81.2, P<0.001).

DISCUSSION

The ultimate goal of conservation research should be not only to provide ever-improving measures of priority areas to be protected, but to also provide new ways to improve of the implantation of recommendations to conserve biodiversity and sustainable resources of high importance to humans (3). In the oceans, among these processes, there is the need for new methods of surveillance of fisheries, and a way to better quantify and locate non-declared and illegal fisheries, particularly in international waters.

The first results of the Ocean Sentinel program indicate clearly that it is possible to use animals to improve our capacity for surveillance in very isolated oceanic sectors. They also allowed us to estimate the proportion of boats operating without AIS i.e. that were operating in EEZ and in international waters without the capacity to be located via standard monitoring systems. Finally, they provide accurate information on the interactions between two endangered species and fisheries, and differences existing between adults and young individuals.

Capacity of improving prosecution

Our study shows that it is possible to use bird-borne loggers to survey fishing activities over large oceanic sectors. The deployment of loggers on 169 individuals during a 6 month period gave a large coverage of the south-western Indian, extending through to New Zealand. The quasi-immediate transmission of more than 5000 radar detections through the Argos system to a web site, accessible to authorities, confirms that using large albatrosses as indicators of the presence of vessels is an efficient way to survey large areas where direct survey by patrolling vessels is rare and costly.

In the EEZs around Crozet and Kerguelen, where the French fishery targeting Patagonian tooth-fish operates, all vessels present were detected several times by breeding adults on the shelf's edges. In some cases, the declared vessels were detected by birds without associated AIS emissions: however, the identity of the vessel was confirmed by the CROSS through the VMS system. For this declared fishery, absence of AIS during radar detections was relatively rare. During the study period, no non-declared fishing vessel was detected in the EEZs of Crozet and Kerguelen, two in the EEZ around Amsterdam, and all detections in the EEZ around the Prince Edward Islands had no AIS. In addition, several vessels were detected with no AIS at the edges of the Kerguelen-Heard EEZ and of the Crozet and Prince Edward EEZ. For at least two cases, some boats had their AIS regularly switched off for long periods. In the EEZ around Crozet and Kerguelen the fishery is strictly controlled today by authorities using mitigation measure to reduce seabird mortality to very low numbers (29, 30).

In the CCAMLR zone and in international waters, at least half of the radar detections over several hours, corresponding to typical vessels in fishing operation, had no AIS associated. Most detections occurred in subtropical waters, where large Asiatic fisheries operate targeting tuna (31). Typically, the fleets are located through clusters of vessels with AIS but with irregular AIS transmissions and incomplete information on the identity of vessels. It is in these areas of tuna fisheries where AIS are often not transmitted that a significant number of radar detection occurred with no AIS (Fig. 5). Although the Indian Ocean Tuna Commission (IOTC) requires that fishing boats targeting tuna use at least two seabird mitigation methods selected from a range of methods (32), and that best practice to reduce mortality in these fisheries is well established (33), most tuna fisheries do not use mitigation measures apart for some countries which have adopted to use them voluntarily (31, 34, 35). Thus, it is in these waters that mortality risks in long-line fisheries are the highest and hence seabirds are at the highest risk.

The Ocean Sentinel (OS) concept appears offer a way forward to help develop new tools for surveillance and improved enforcement. First, OS provides researchers or international agreements for Fisheries Management (such as Tuna Commissions, IOTC, CCSBT etc.) or for Conservation (such as CCAMLR), unprecedented information on the distribution of fisheries in remote areas, where conventional methods are not available. We have shown that Ocean Sentinel was able to provide to national and regional authorities direct information about the presence of fishing boats in the region they manage. This is critical information for regions where surveillance by maritime or aerial patrols is not possible because of their remoteness and/or because of the extensive cost of surveillance. The Radar-Sat system (www.asc-csa.gc.ca/fra/satellites/radarsat2) can provide information on the potential presence of boats in a particular region through the detection of metallic masses. However, the cost for obtaining images is extremely high (for example 1.4M€/year for the TAAF area), and the information depends on the coverage by the satellite bands. More importantly, the detections provide only 'potential' signals of boat presence. Our preliminary examination shows that satellite images are available irregularly and when available, not all boats are detected by the system.

The only open access system providing information on fisheries is the Global Fishing Watch (globalfishingwatch.org) that potentially enables anyone with an internet connection to see fishing activity anywhere in the ocean, with a two-day delay. The system is based on the detection of AIS signals sent by boats. We have shown that a significant proportion of vessels detected by our birds had no AIS. Since AIS can be switched off, and this probably occurs in illegal fisheries, full coverage of fishing activity using AIS is not possible. Ocean Sentinel appear to be a complementary tool for surveying fisheries in remote areas.

Apart from these two systems based on satellites, surveillance can be made by patrol boats or airplane, but the more remote the area, the more difficult and costly the surveillance. For example, in the Kerguelen and Crozet EEZs, airplane cannot be used, and Naval or surveillance vessels are infrequently present in these remote areas. When present in the zone, they had access to Ocean Sentinel information. The CROSS used the Ocean Sentinel data to survey the zone indicating that the program has the potential to improve surveillance, and in case of the detection of illegal activities within EEZ, to improve enforcement efficiency.

Co-occurrence, attraction and risk assessment

Tracking of marine animals has been used extensively to delineate hot-spots of biodiversity (19, 36-38), with the ultimate goal of improving conservation through the setting of marine protected areas or the enforcement of conservation measures (20). In this context, overlapping seabird or turtle distribution with fisheries activities (when available, at various spatial scales) allows the estimation of interaction and estimate risks of bycatch (7, 39). However, this risk assessment is generally based on the strong assumption that the co-occurrence of seabirds and fisheries leads to interaction and mortality risks. This assumption may be correct when overlapping fine scale fishery activities but these are rarely available (28), especially in international waters where the information on fisheries distribution is at best available at large scales from RFMOs (15, 16). Based on the results of Ocean Sentinel, our study is the first to test the hypothesis that co co-occurrence at various scale leads to interaction. This hypothesis has been tested previously using vessels equipped with VMS in EEZ (14, 17, 26), whereas our study uses a system detecting not only vessels in EEZ, but also in international waters. Several seabird species, such as albatrosses, are well known to be attracted to fishing vessels. However, the attractivity of vessels to seabirds is difficult to study (14), and generally examined indirectly through the comparison of numbers of seabirds in co-occurrence with vessels at different spatial scales (40). Attraction of seabirds to fishing vessels is believed to be mainly the result of local, small scaled, co-occurrence (41). Our new loggers have allowed us for the first time to estimate co-occurrence at various scales and attraction to vessels for two different species and different age classes. Juvenile individuals, during their first months at-sea, encountered fewer boats than adults or immature birds, and when co-occurring within 100km of a vessel had almost a zero probability of attending the vessel,whereas for adults 10% of birds attended such vessels. The low attendance rate of juvenile was the result of the low density of vessels in the range of juveniles, but also because juveniles were less attracted to vessels than adults. Amsterdam albatrosses forage in a sector with high boat densities, especially large tuna fisheries, compared to wandering albatrosses, yet the population is increasing with very low mortality rates at all ages (42, 43). Examination of encounter rates followed by attendance at the boat suggests that Amsterdam albatrosses attend fewer fishing boats compared to wandering albatrosses, despite encountering more boats. These results have strong implications for future risk assessment plans since it provides the first figure for the attraction of albatrosses to fishing boats and shows that attraction differs extensively between age classes and species.

Our data are also the first to indicate that adult albatrosses are more attracted to fishing vessels than to other type of boat. Short encounters at vessels in international waters generally correspond to birds crossing the route of large transport ships within the range of albatrosses. Birds never follow these boats for long periods (maximum two hours). Conversely, for fishing boats in operation, encounters are followed by long attendance periods. In the EEZ, attendance can last several hours on the shelf edge, corresponding to long-liners, targeting Patagonian tooth-fish (28).

Conclusions

The concept of Ocean Sentinel is flexible and can be applied to many other systems. According to the area and requests of local authorities, the accessibility of the data can be fully open-access through the web (for example in the case of international waters), or with limited access restricted to authorities through a password system (for example in EEZs where regulated fisheries operate). The system can be exploited in any situation where large seabirds attracted by boat (for example albatrosses are attracted by boat at distance of up to 30 km and cover millions of square kilometres during foraging trips) can be fitted with the Ocean Sentinel concept. Preliminary tests have been made with our loggers on other albatross populations in Hawaii and in the New Zealand region. The loggers can be deployed on smaller seabird size species such as gannets to detect fishing boats (44). However, our results show that the species and age class have to be selected carefully: in our case, adult wandering albatrosses appear to be excellent sentinel species, since they are very attracted by fishing vessels, and can detect them at 30 km distance. In addition, the system has the potential to provide unpreceded information on the attraction and attendance of seabirds to vessels, opening new perspectives for the study of behaviour of seabirds in relation to vessels, but also giving access to crucial information for risk assessment plans. The concept of Ocean Sentinel is complementary to other efforts aiming at providing independent information on fisheries distribution (9). It is a good example of how the development of new technologies applied to conservation make operational conservation possible, and could be used in other animal taxa such as sea turtle or sharks, where conservation actions and independent by-catch locations are critically required (45, 46).

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Acknowledgments

The study is a contribution to the Program EARLYLIFE funded by a European Research Council Advanced Grant under the European Community's Seven Framework Program FP7/2007–2013 (Grant Agreement ERC-2012-ADG_20120314 to Henri Weimerskirch) and to the Program Ocean Sentinel funded by the ERC under European Community's H2020 Program (Grant Agreement ERC-2017-PoC_780058 to HW). The field work was also funded by IPEV program n°109, and was only possible thanks to the help of field workers, especially Jeremy Dechartre, Aude Schreiber, Tobie Getti, Yuseke Goto, Yoshi Yonehara and Florent Lacoste. The field procedures and manipulations on Crozet, Kerguelen and Amsterdam were given permission by the 'Préfet of Terres Australes et Antarctiques Françaises'. We thank the Reserve Nationale des TAAF for help with the development of the web site and for funding loggers deployed on Amsterdam Island and Florient Orgeret for comments on the manuscript.

Legends of figures

Figure 1 - Distribution of AIS locations (for all vessels, left, and fishing vessels only, right) in the study sector – south Indian Ocean between Africa and New Zealand) recorded in January, February and March 2019. Number of vessels over 4 days randomly selected every week through each month, for squares of 125 km.

Figure 2 - Schematisation of OCEAN SENTINEL concept: detection by Centurion loggers fitted on foraging albatross, immediate transmission by Argos system, analysis of data, provision of data on the TAAF/OCEAN SENTINEL website, comparison with VMS and AIS data, and alert in case of detection of undeclared activity, with potential control by Navy ship.

Figure 3 – Southern Indian Ocean with the tracks of Crozet wandering albatrosses (green), Kerguelen wandering albatrosses (orange) and Amsterdam albatrosses (blue). Radar detections in yellow. EEZ limits in the yellow line.

Figure 4 – Tracks of wandering albatrosses (as in Figure 3) and location of radar detections (yellow and black points) in the sector of the Kerguelen-Heard plateau. Star indicates location of the colony. EEZ limits in the yellow line.

Figure 5 – a) Study area showing the overall range (blue line, kernel 90% of all birds), core area (blue zone, kernel 50%) and the location of radar detection with AIS associated (green dots) and no AIS associated (red dots). Limit of EEZ in yellow. **b)** eastern part of the range.

Figure 6 – Average (± one S.E.) percentages of albatrosses of different age classes that (a) encountered (within 30 km from a vessel) and (b) attended (within 5 km from a vessel) after being in a 100 km range from a vessel, and average percentage of albatrosses attending a vessel after encountering it.