Collect. Vol. Sci. Pap. ICCAT, 76(9): 84-96 (2020)

INDICATORS OF *ORCINUS ORCA* INTERACTIONS WITH PELAGIC LONGLINE GEAR IN THE ICCAT CONVENTION AREA

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SUMMARY

Longline fishery interactions with Orcas constitute both a loss of the target species due to depredation and a potential for hooking or entanglement. The potential for Orcinus orca interactions with pelagic longline gear was estimated using computer generated habitat suitability maps and estimates of overall Atlantic fishing effort by time-area strata (EFFDIS). Depredation estimates of Swordfish and Albacore catch was based on the estimated longline catch by time-area strata (CATDIS). Annual trends in vulnerability, depredation and depredation per unit effort are provided by area across all seasons and fleets.

RÉSUMÉ

*Les interactions des pêcheries palangrières avec les orques entraînent la perte des espèces cibles en raison de la déprédation et représentent un risque d'hameçonnage ou d'enchevêtrement. Le risque d'interactions d'*Orcinus orca *avec les palangriers pélagiques a été estimé sur la base de cartes de l'adéquation de l'habitat générées par ordinateur et d'estimations de l'effort de pêche global de l'Atlantique par strates spatio-temporelles (EFFDIS). Les estimations de la déprédation des prises d'espadon et de germon étaient basées sur les prises palangrières estimées par strates spatio-temporelles (CATDIS). Les tendances annuelles de la vulnérabilité, de la déprédation et de la déprédation par unité d'effort sont fournies par zone, toutes saisons et flottilles confondues.*

RESUMEN

Las interacciones de la pesca con palangre con las orcas constituyen tanto una pérdida de la especie objetivo debido a la depredación como una posibilidad de enganche en el anzuelo o enmallamiento. El potencial de interacción de Orcinus orca *con los artes de palangre pelágico se estimó utilizando mapas de idoneidad de hábitat generados por ordenador y estimaciones del esfuerzo de pesca general en el Atlántico por estratos espacio-temporales (EFFDIS). Las estimaciones de depredación de la captura de pez espada y atún blanco se basaron en la captura estimada de palangre por estratos espacio-temporales (CATDIS). Las tendencias anuales de vulnerabilidad, depredación y depredación por unidad de esfuerzo se presentan por zonas en todas las estaciones y flotas.*

KEYWORDS

Orcinus orca, depredation, vulnerability, by-catch, ICCAT

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1. Introduction

In 2017, the ICCAT Sub-committee on Ecosystems developed a work plan that included a proposal to develop a prototype Ecosystem report card for the ICCAT Commission to review in 2018. The report card was intended to inform on fishery impacts for 11 key components of the ecosystem. One of these components provided an indicator for the impact of ICCAT fisheries on marine mammals (Hanke and De Bruyn 2018). Upon review of this document the Subcommittee recommended that further development of the indicator was necessary. It was recommended that impacts also be reported for purse seine and gill net gears and that the indictors be developed for more regions. Furthermore, it was suggested that consideration be given for the potential impacts of marine mammals on ICCAT fisheries particularly in the case of *Orcinus orca* which has a circumglobal distribution and is well known for its depredation of both pelagic and ground fish catch around the world (Secchi and Vaske Júnior 1998, Dalla Rosa and Secchi 2007, Williams *et al.* 2009, Passadore *et al.* 2012, Samarra *et al.* 2018, Söffker *et al.* 2015, Peterson *et al.* 2013).

The purpose of this report is to address the issues identified by the subcommittee by providing indicators of the potential interaction rate of *Orcinus orca* with longline gear for 5 sub regions of the ICCAT convention area as well as to produce indicators of the depredation by *Orcinus orca* of Swordfish and Albacore catches. This report also demonstrates a method for developing an indicator in situations where direct evidence is scare or not available.

2. Methods

2.1. Orca distribution

The basis for the habitat suitability information used in the current analysis was obtained from AquaMaps (Anon. 2016). The native range map was developed from a model that estimated the environmental envelope for the species using true and estimated environmental covariates associated with 1581 observed locations of killer whales. The environmental variables and the estimated preferred range in the habitat model are provided in **Table 1**.

The NetCDF format of the native range map (**Figure 1**, top) was filtered to exclude all habitat suitability values less than 0.8 (**Figure 1**, bottom). The degree of suitability of habitat can be interpreted as a relative probability of occurrence.

AquaMaps also provides a native range map for the year 2100 which uses the same constraints on the habitat variables for estimating the environmental envelop and applies them to environmental data generated based on an IPCC A2 emissions scenario. This distribution map could be used to show the expected distribution of killer whales under climate change.

2.2 Longline effort and catch distribution

ICCAT provides Task II monthly catch and fishing effort statistics by species, gear and flag. CATDIS is a dataset that represents the Task II catch data raised to the total landings by species quarter, flag, gear and 5x5 degree grid cells. This exercise made use of the cdis5016_SWO.csv and cdis5016_ALB.csv files which are specific to catch of Swordfish and Albacore respectively. Online access to the data can be found here: https://www.iccat.int/Data/Catdis/cdis5016_bySpecies.7z . Other species are depredated by killer whales however Swordfish and Albacore were observed to be depredated on a regular basis.

ICCAT also provides spatial-temporal estimates of overall Atlantic fishing effort for longline and purse seine fleets, termed EFFDIs. EFFDIS has the same spatial and temporal resolution as CATDIS. The effdis_ll.1950.2015.csv file for longline can be accessed here: https://www.iccat.int/Data/effdis_ll.1950.2015.csv.zip . EFFDIS offers the user access to both the observed fishing effort as well as overall Atlantic fishing effort as estimated by the modeling approach outlined by Beare (2015). This exercise made use of the estimated values in the calculation of the indicators.

2.3 Vulnerability and depredation scores

The R-packages *sp* (Pebesma and Bivand, 2005) and *raster* (Hijmans, 2018) were used to grid and create a raster from the EFFDIS data (**Figure 2,** top left) and then rasterize the *Orcinus orca* habitat suitability data (**Figure 2**, top right). These operations essentially associate the killer whale habitat suitability data with the appropriate 5x5 degree grid square from EFFDIS. Given the higher resolution of the killer whale data, the associated habitat suitability value for a given grid square was represented by the median.

The vulnerability score for a 5x5 grid square was the product of the total hooks (observed or expected) and the median habitat suitability (**Figure 2**, bottom left).

In order to determine *Orcinus orca* depredation of longline caught Swordfish and Albacore, the total catch of these species from CATDIS was merged with the EFFDIS and median habitat suitability data. This was facilitated by the common structure of the EFFDIS and CATDIS data bases. Passadore *et al.* (2015b) estimate the total proportion of depredation cumulated for the period 1998–2007 for Swordfish and Albacore in the Southwest Atlantic to be 0.0117and 0.0088, respectively. It was assumed that the Swordfish and Albacore catches in CATDIS were the totals reported after depredation. Consequently, total removals of these species was the CATDIS amounts plus a depredation amount consistent with the proportions reported by Passadore *et al.* (2015b).

The depredation amounts are a function of both the probability of occurrence of killer whales and the amounts of Swordfish and Albacore catch reported but do not account for effort. These estimates were relativized using the total longline effort on a per grid square basis resulting in a depredation per unit effort (DPUE) for both Swordfish and Albacore.

2.4 Area definitions and indicators

Reporting of the vulnerability of killer whales to gear and their depredation of Swordfish and Albacore catch was based on ICCAT’s stock area boundaries. Collectively, the stock boundaries describe 6 regions; namely, the CarGom (Caribbean Sea and Gulf of Mexico), SWATL (southwest Atlantic), SEATL (southeast Atlantic), NWATL (northwest Atlantic), NEATL (northeast Atlantic) and MED (Mediterranean Sea). See **Figure 3** which represents the **Figure 2** vulnerability by area.

Indicator plots were developed for vulnerability, depredation and DPUE according to the method suggested by the subcommittee. This method involves a centering and scaling of indicator metrics so that the visualization of indicator trends and thresholds is standardized for all components of the ecosystem report card.

3. Results

The trend in the vulnerability of *Orcinus orca* to the observed and estimated fish hooks deployed per region is shown in **Figure 4** (top) and **Figure 5.** Since 2010, all regions show a decline in the vulnerability of the whales to longline gear and **Figure 4** (top) shows relatively similar trends for both observed and estimated hook amounts.

Depredation of Swordfish is estimated to be rarely more than 50 MT per year (**Figure 4**, bottom) and is highest in the northwest, southwest and northeast Atlantic Ocean. Depredation of Albacore is highest in the SEATL region where it rarely exceeds an estimated 75 MT in a year.

Since 2010, the depredation of Swordfish catch has been gradually increasing in the southwest, southeast and northeast Atlantic Ocean while in the northwest Atlantic Ocean and Caribbean Sea there has been a rapid decrease (**Figure 5**, top). Depredation of Albacore (**Figure 6,** top) shows no trend in either the northeast Atlantic or Caribbean, gradual increase in the northwest and southwest Atlantic and a rapid decline in the southeast Atlantic.

The effort adjusted depredation of Swordfish (DPUE) shown in **Figure 5** (bottom) is different from the unadjusted depredation described above. Relative to the effort, the depredation of Swordfish is increasing rapidly in the southwest Atlantic, not decreasing at all in the northwest Atlantic, showing a gradual decrease in the Caribbean and rather more rapid increases in the southeast and northeast Atlantic. In contrast, the DPUE trends for Albacore (**Figure 6,** bottom) are consistent with the depredation trends. It should be noted that the regional time series for Albacore all include a period of high DPUE in the 1960s which affects interpretation of the more recent trends.

4. Discussion

4.1 Vulnerability

The vulnerability of *Orcinus orca* to longline gear was shown for 5 regions within ICCAT's convention area, however these trends are only meaningful if it can be demonstrated that bycatch of these whales occurs frequently. Dalla Rosa and Secchi 2007 describe a single incidental capture of a female killer whale during a 3 year study where the individual was hooked and escaped alive. Passadore *et al.* (2015a) report that 2 Orcas were entangled in Uruguayan pelagic longline between 1996 to 2013 and that they were both released alive. Consequently, there is little published evidence to suggest that the whales are vulnerable to hooking. A potentially a more serious issue is the fishermen's efforts to deter depredation of their catch by shooting at the whales (Secchi and Vaske Jr. 1998).

Given the lack of evidence of an impact of the longline fishery, we conclude that rather than reflecting harm to the species, the indicator of vulnerability merely reflects the potential for depredation of the catch without any perception of danger.

4.2 Depredation and DPUE

Between 1987 and 1992, Secchi and Vaske Jr. (1998) reported that Orcas preferentially depredated Swordfish caught in the Brazilian longline fishery and that in the southern region of the Brazilian fishery, more than 50% and up to 100% of a fisherman's catch may be lost to killer whale depredation. Dalla Rosa and Secchi (2007) estimated that the Swordfish depredation from 1993 to 1995 for Brazilian longline sets targeted by killer whales was 47.4% and 0.25% for tuna. Passadore *et al.* (2015b) estimated the total proportion of depredation cumulated for the period 1998–2007 in the Uruguayan longline fishery at no more than 1.17% for Swordfish and 0.88% for Albcaore. Much older estimates of depredation of tuna longline catch by killer whales and sharks in the Indian Ocean during the 1950s are as high as 4% of the annual catch (Sivasubramanian 1965).

In the South African fishery, overall killer whales depredated at a rate of 0.5% of total catch and took swordfish *Xiphias gladius* in preference to tunas *Thunnus spp*. They were seldom reported from vessels fishing for hake *Merluccius spp*. Skippers reported killer whale depredation on sharks, notably mako sharks *Isurus oxyrinchus*, with some sharks bitten and others removed completely (Williams *et al.* 2009).

Significant depredation events have also been reported in Iceland were several hundred killer whales sighted on the halibut fishing grounds consumed all the catch of longliners leading fishermen to abandon fishing (Samarra *et al.* 2018). Peterson *et al.* (2013) noted that when killer whales were present during Alaskan survey gear retrieval, that they removed an estimated 54–72% of sablefish (*Anoplopoma fimbria*), 41–84% of arrowtooth flounder (*Atheresthes stomias*), 73% of Bering Sea Greenland turbot (*Reinhardtius hippoglossoides*), 51% of Western Gulf Pacific halibut (*Hippoglossus stenolepis*) and 46% of Western Gulf Pacific cod (Gadus macrocephalus).

This analysis is based on depredation estimates provided by Passadore *et al.* (2015b) and, given the context provided above, may be conservative. It is also important to recognize that the analysis did not capture potentially important temporal and spatial dynamics related to depredation. It has been noted that killer whales take advantage of seasonally abundant prey within their home range and they appear more frequently when Swordfish are caught in great numbers (Secchi and Vaske Jr. 1998) but they are also sighted more frequently in autumn and winter (Passadore *et al.* 2012). Consequently, using season specific estimates of depredation by species (like those provided by Passadore *et al.* 2015b) appears justified in order to more appropriately quantify the annual depredation amounts.

Spatial variability was a consideration in the analysis and resulted in depredation estimates by area, however these could be fine-tuned if the catch and effort data was available at a higher resolution. Currently, the catch and effort for each 5x5 grid square encompasses 100 killer whale habitat suitability values that are reduced by a single value. Orca distribution in relation to longline fishing is more nuanced than that and areas where they co-occur, like the highly productive Brazil-Malvinas Confluence Zone (Passadore *et al.* 2012), are smaller than a single 5x5 grid square. Thus, an examination of the sensitivity of the depredation estimates to the resolution of the data is warranted.

On the scale of the respective species TACs, the estimated catch of Swordfish and Albacore lost to depredation was small and was even considered to have minor economic impacts in the case of the Uruguayan longline fishing industry (Passadore *et al.* 2015b). Even across the entire ICCAT convention area, loss to killer whale depredation is small, however other species also contribute to unreported removals and collectively may represent an important source of fishing related mortality (Forselledo *et al.* 2014, Passadore *et al.* 2015b). Tracking trends in this mortality over time is not only important from a stock assessment perspective but also from a socio-economic and a trophic standpoint given the extent of the loss of catch (up to 100%) and the measures that fishermen employ to prevent it. An additional unquantified impact deserving some consideration is the potential of killer whales to affect catch rates by scaring catch away from the gear or by consuming bait. Unpublished data from the Uruguayan fleet observer program support a decrease in the catch of tuna due to the presence of killer whales in the vicinity of the fishing vessel.

Depredation of Swordfish by killer whales can only occur where both co-occur. Quantifying the degree of depredation depends on counting remnants of fish and associating them with the correct predator. Empty hooks tell no story and underscore the potential to underestimate the depredation amounts. Fortunately, in the case of Swordfish, it is felt that it is easier to quantify the depredation because killer whales leave the sword and head behind but in the case of Albacore it is more likely that they will eat the whole fish (Secchi and Vaske Jr. 1998). An additional concern affecting the interpretability of the indicators is the nature of the relationship between the amount depredated and the amount caught. Here we assume they vary together and there is some justification in the observation that depredation rates did not decrease when fish catches were high (Dalla Rosa and Secchi 2007).

Indicators of depredation and DPUE, while subject to the uncertainties described above, have value in tracking the potential impacts of killer whales on ICCAT longline fisheries and could provide support to the stock assessment processes of the depredated species. Furthermore, the method of constructing indicators demonstrated here provides an interim approach for characterizing the impacts that ICCAT fisheries have on species for which data may be limiting.

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Table 1. Mapping parameters used to create the environmental envelope for mapping *Orcinus orca* (killer whale) habitat suitability (N=1518) (https://www.aquamaps.org/ShowMapParam.php?SpecID=ITS-Mam-180469&user_session=7)

	Min	***Preferred Min (10th)***	***Preferred Max (90th)***	***Max***
Depth (m)	0	100	2400	6000
Water temp. (°C) (surface)	-1.95	-1.45	27.8	32
Salinity (psu) (surface)	5.4	31.97	35.86	39.5
Primary Production (mgC·m-²·day -1)	0	211	1523	3894
Sea Ice Concentration (% cover)		0	0.49	1.5
Distance to Land (km)	0	9	344	2286

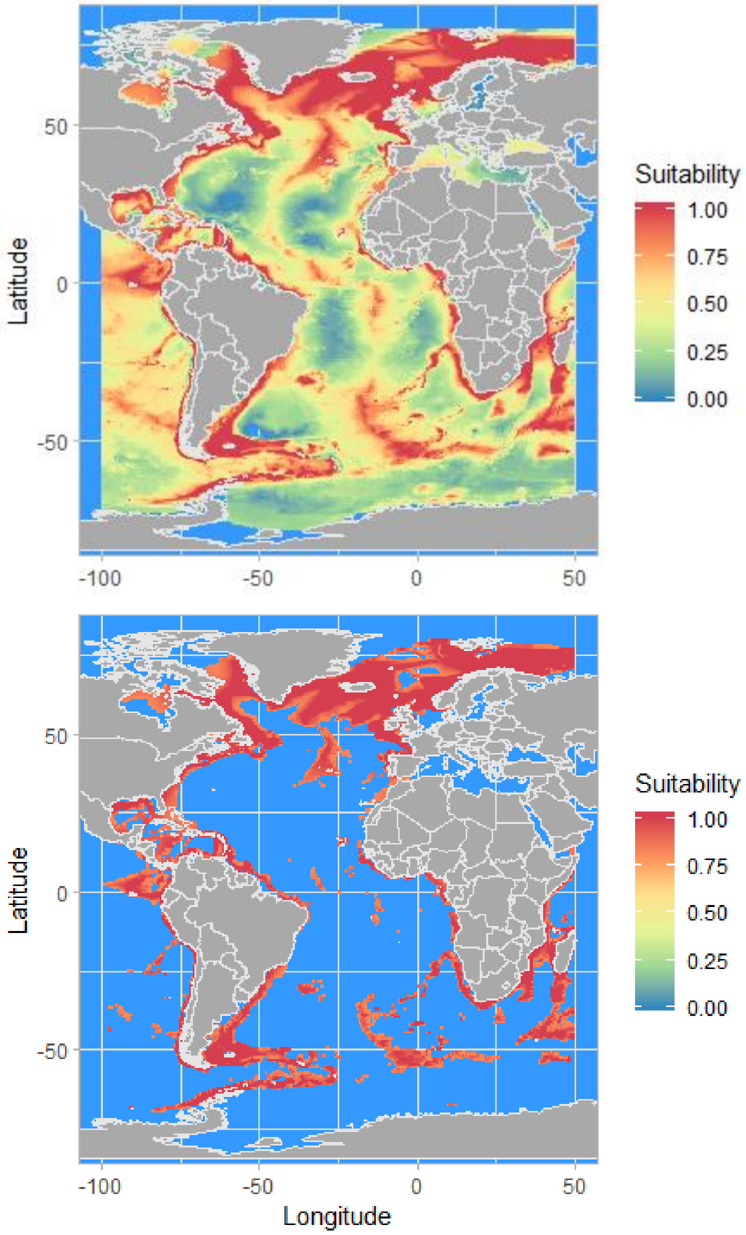


Figure 1. Estimated native distribution maps for *Orcinus orca* (killer whale). Distribution range colors indicate the degree of suitability of habitat which can be interpreted as the relative probability of occurrence. The bottom plot reflects the distribution for probabilities greater than 0.8 (www.aquamaps.org, version of Aug. 2016. Web Accessed 20 Feb. 2019).

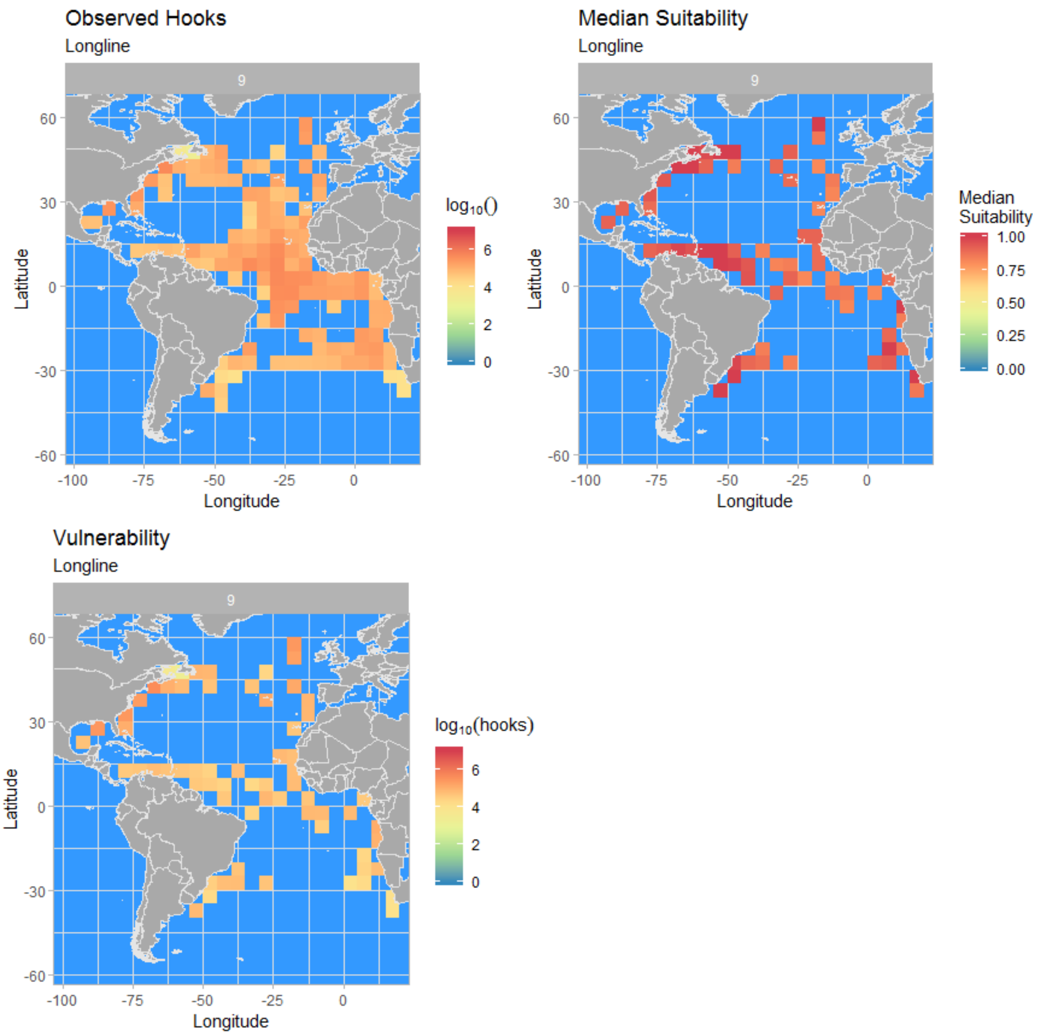


Figure 2. Effort distribution of pelagic longline gear (observed hooks) for September 2010 (top left) by 5-degree grid squares. *Orcinus orca* (killer whale) habitat suitability mapped to 5-degree grid squares (top right). Vulnerability of *Orcinus orca* to longline gear (bottom left) expressed as the product of effort (observed hooks) and the probability of occurrence.

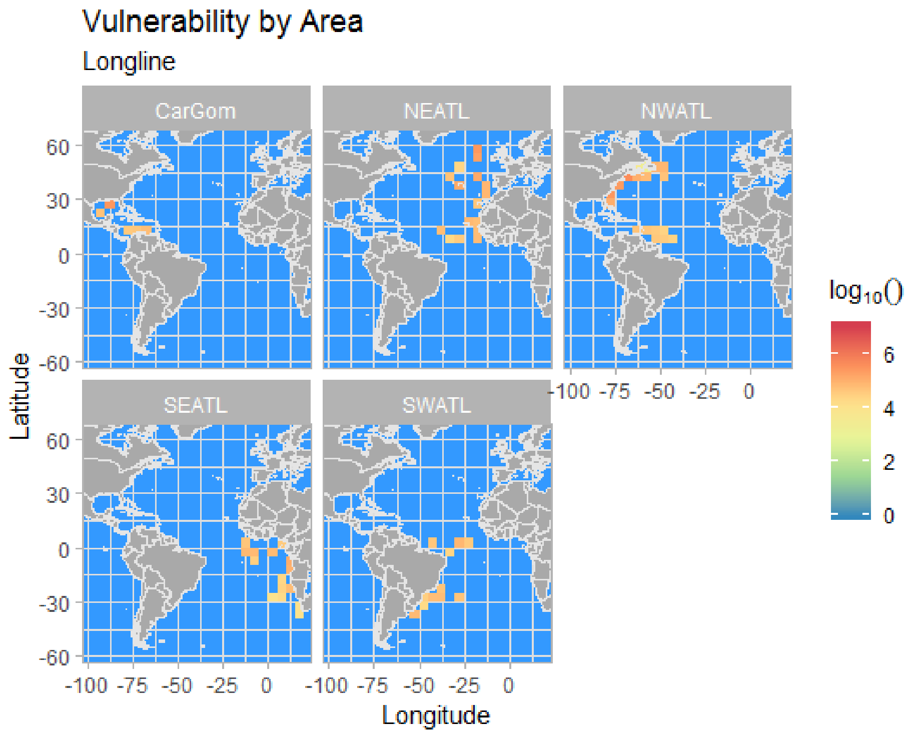


Figure 3. Vulnerability of *Orcinus orca* to longline gear by area in September of 2010. Vulnerability is the product of effort (observed hooks) and the probability of occurrence.

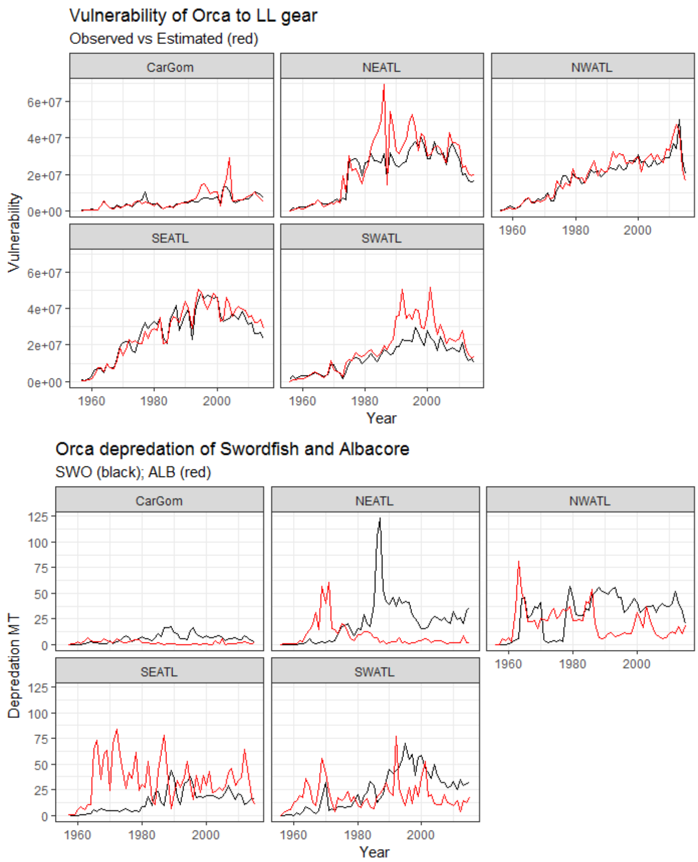


Figure 4. Total estimated vulnerability to longline gear by area across all flags, months and grid cells (top plot). Total estimated depredation losses to *Orcinus orca* of Albacore and Swordfish catch (bottom plot).

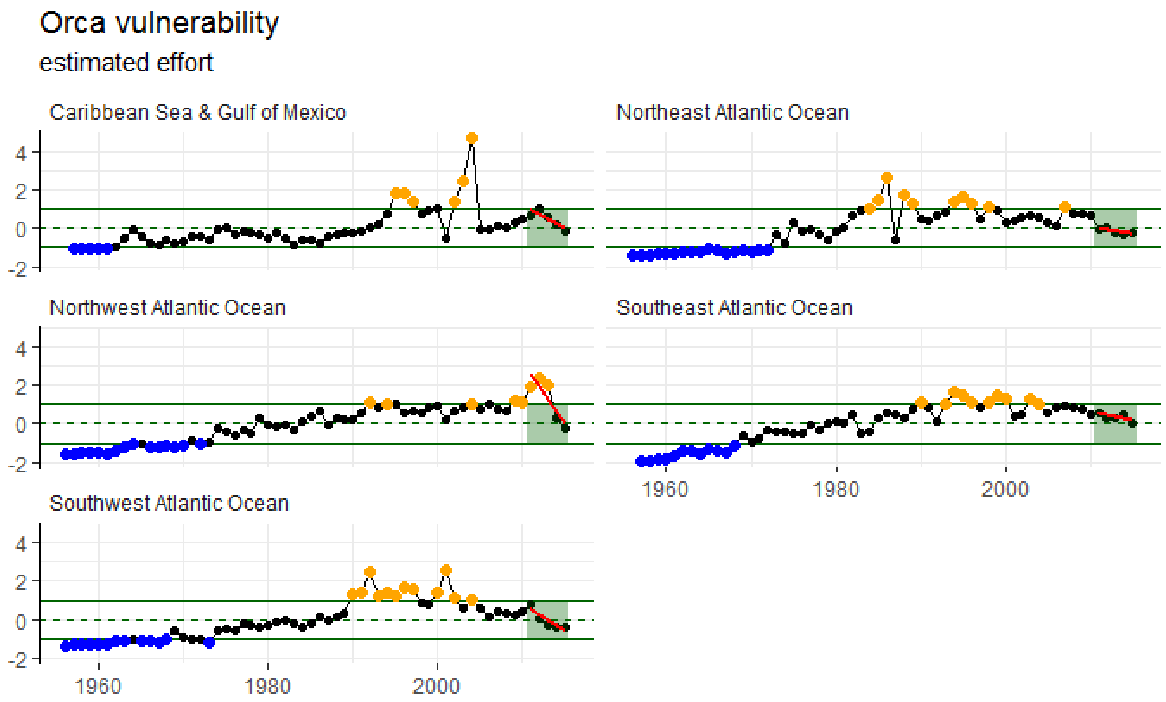
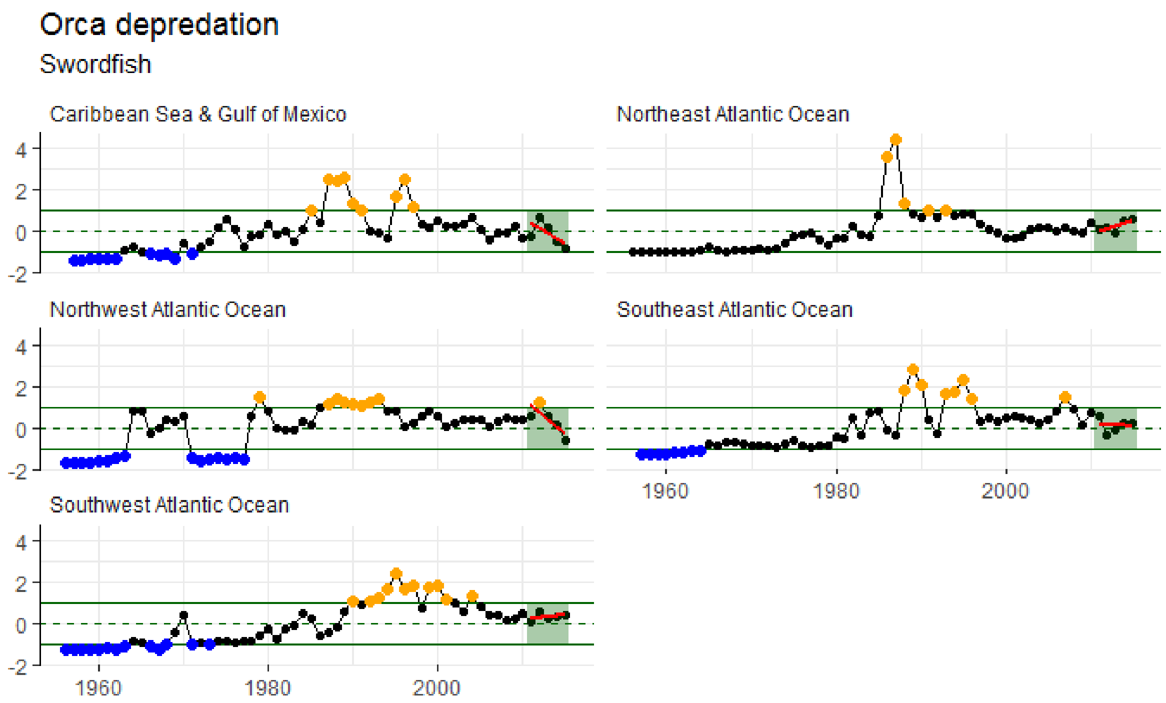


Figure 5. Indicators of *Orcinus orca* vulnerability to longline gear by geographic area. The vulnerability scores were scaled and centered on the respective series mean. Values >= 1 std are orange. Values <= -1 std are blue. Red trend lines are for the last 5 years and were fit with a linear model.



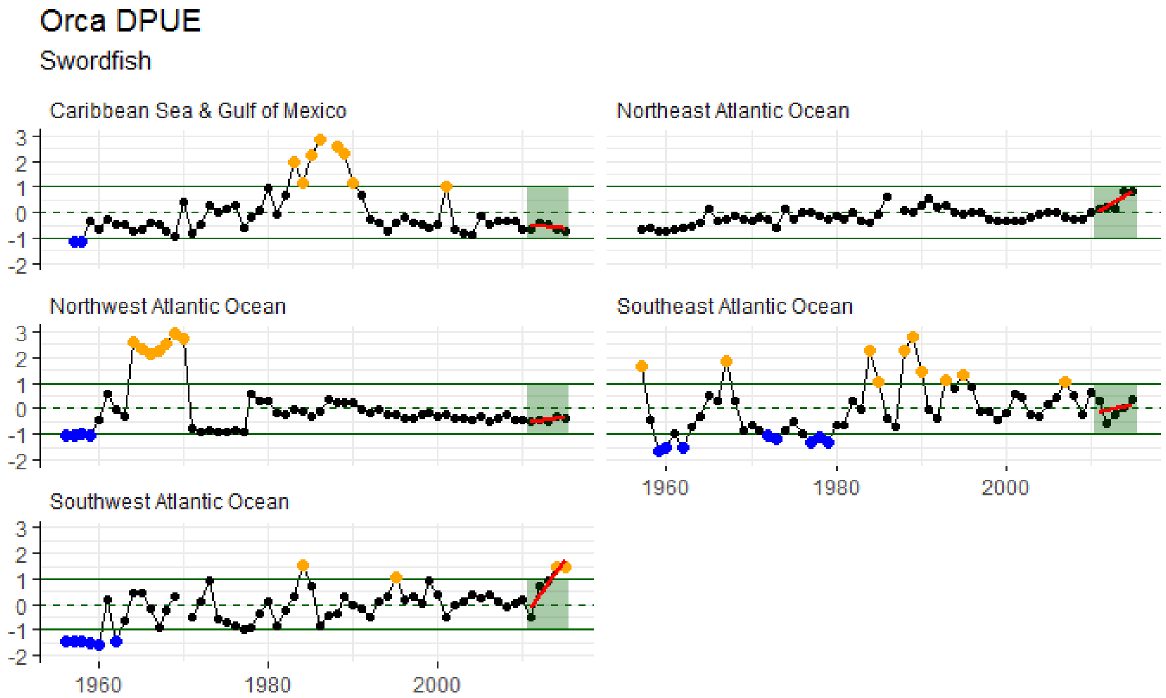
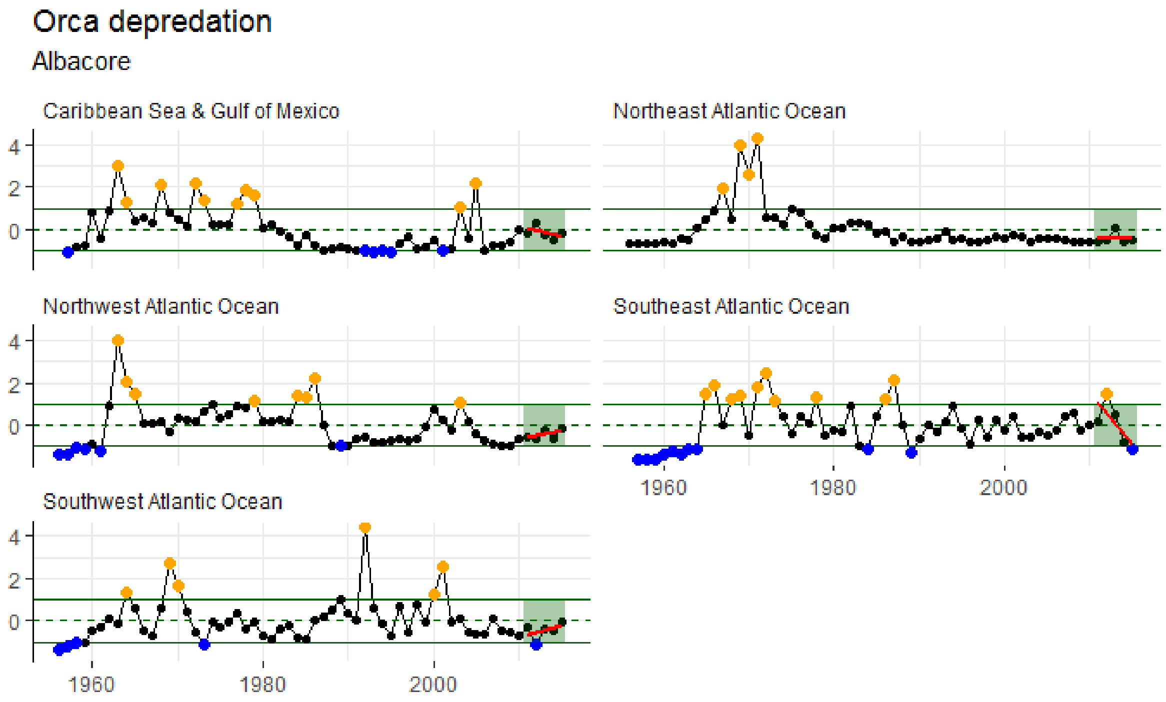


Figure 6. Indicators of *Orcinus orca* depredation of longline Swordfish catch (top) and the depredation per unit effort (bottom) by geographic area. The scores were scaled and centered on the respective series mean. Values >= 1 std are orange. Values <= -1 std are blue. Red trend lines are for the last 5 years and were fit with a linear model.



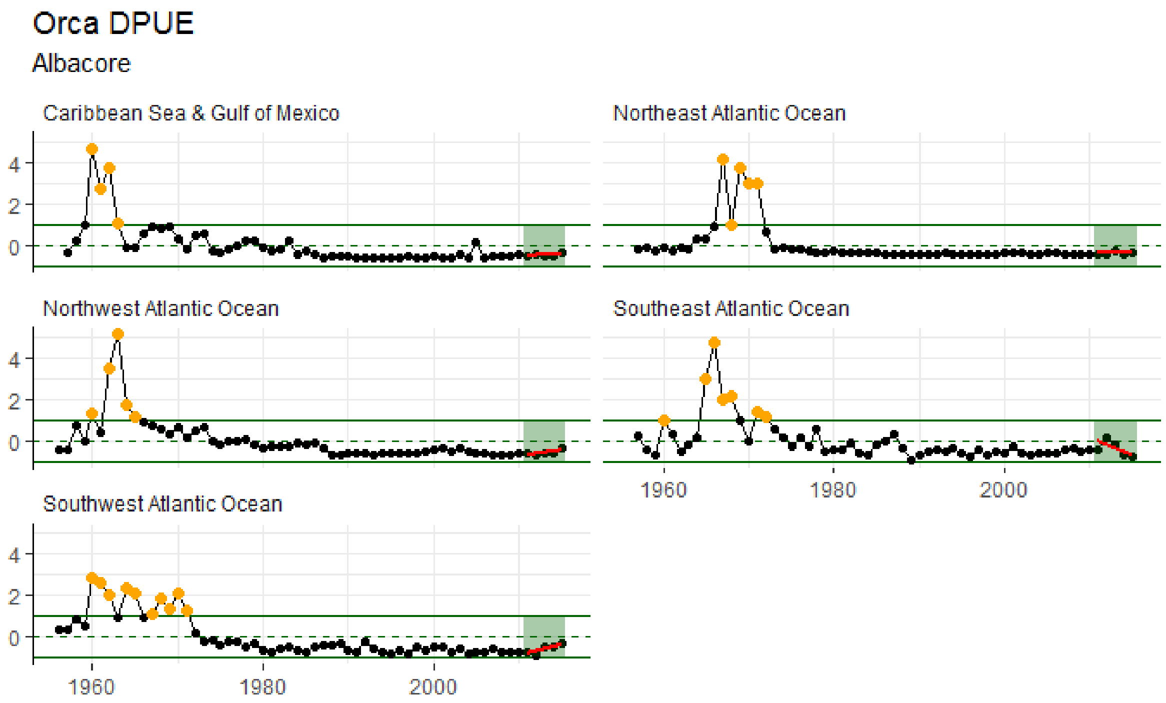


Figure 7. Indicators of *Orcinus orca* depredation of longline Albacore catch (top) and the depredation per unit effort (bottom) by geographic area. The scores were scaled and centered on the respective series mean. Values >= 1 std are orange. Values <= -1 std are blue. Red trend lines are for the last 5 years and were fit with a linear model.