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Optimal fishing time window: an approach to mitigate bycatch in longline fisheries

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ABSTRACT. One of the main concerns of the ecosystem approach to fisheries is the mitigation of bycatch, especially in pelagic longline fisheries. Bycatch represent unmarketable species and protected species for some of them. Various mitigation measures already exist to reduce bycatch in longline fisheries, notably concerning the equipment used and the strategy of fishing gear deployment. However, measures that concern the hours of gear deployment remain poorly studied. Using hook-timer data collected during scientific longline fishing campaigns between 2004 and 2014 in the South West Indian Ocean, we developed a method to identify optimal fishing practice that maximizes bycatch reduction and swordfish yield (in number). Here we found that hourly capture patterns of swordfish and bycatch (sharks, turtles) are different and allow to identify an optimal fishing practice that consists in fishing between 18pm and 9am. This methodology certainly provides a relevant bycatch mitigation approach that benefits to fishermen but also allow to mitigate the impact of longline fisheries on the ecosystem.

KEYWORDS. Optimal fishing index | Byctach | Swordfish | Hook-timers | Longline | South West Indian Ocean

1. Introduction

The interaction of fishing gears and vessels with non-targeted marine species (= bycatch; Hall, 1996) that co-occur with targeted species is currently a major issue in the fisheries management and ecosystem conservation (Alverson et al., 1994; Hall et al., 2000; Jackson et al., 2001; Gilman et al., 2006). The development of fisheries worldwide and the degradation of marine habitats through overfishing or more complex processes over various ecosystem scales have given rise to growing concerns on the sustainability of current approaches to the management of marine living resources and ecosystems. Interactions of fisheries with non-targeted species can be complex, and may occur in several ways: directly as bycatch (catch of unwanted species, either lethal or not), habitat alteration, animal disturbance, and depredation (damage of the catch or fishing gears by unwanted species).

Bycatch species are very diverse and belong to many groups: teleost fish, sharks, but also birds, mammals and sea turtles (Alverson et al., 1994; Hall et al., 2000; Jackson et al., 2001; Gilman et al., 2006, 2007). The ratio of bycatch versus targeted catch varies depending on fishing gears and techniques. This ratio ranges from 0.39 to 12.13 in number of individuals caught for squid netting and shrimp trawling respectively, with levels of 0.40 to 1.58 for most pelagic longline fisheries (Alverson and al., 1994).

In Reunion Island, a semi-industrial fleet of pelagic longliners consisting of approximately 30 active vessels operates in the exclusive economic zones of Reunion Island, Madagascar and Mauritius. Drifting longlines are deployed at night with a shallow gear configuration (6-7 hooks between floats), squid bait and light-sticks attractors, to target mostly swordfish *Xiphias gladius*. Discarded bycatch in Reunion Island pelagic longline fishery are mostly blue sharks *Prionace glauca* (38%), stingrays *Pteroplatytrygon violacea* (24%) and a generic group of very long fish called "snooks" (20%; mainly longnose lancetfish *Alepisaurus ferox* and snake mackerel *Gempylus serpens*) by the fishermen (Sabarros et al., 2013).

Several mitigation methods for bycatch reduction in longline fisheries, such as tori lines and/or night setting, offal management, etc., have been established and adopted by Regional Fisheries Management Organisations (RFMOs), including the Indian Ocean Tuna Commission (IOTC) (IOTC, 2014). These mitigation measures are enforced in certain situations. Other measures that are recommended but not mandatory, for example the use of circle hooks instead of J-hooks, reduces deep hooking and therefore post-release mortality for sea turtles (Gilman et al., 2006). Also, the reduction of the fishing effort in the upper surface layer (no branchlines above 100 m depth) does reduce the rate of shark and sea turtle bycatch (Beverly et al., 2004, 2009).

So far, few studies have investigated the timing of gear setting and hauling as a potential bycatch mitigation measure (Carruthers et al., 2011; Bach et al., 2014). In this study, we analyzed the hourly distribution of swordfish captures versus non-target species, and tested a range of fishing time windows in order to identify an optimal fishing time window that reduces bycatch while maintaining a rather good swordfish yield.

2. Material and Methods

2.1. Data

Data were collected during 82 night fishing operations from several scientific longline fishing cruises lead by IRD and CAP RUN (CAPPES, SWIOFP, PROSPER) between 2004 and 2014 in the South West Indian Ocean (Figure 1; Cauquil et al., 2015). Branchlines were equipped with hook-timers (HT) that are triggered when the bait is attacked by a predator and that record the time since the attack. The time of capture or hooking contact (triggered HT without capture) is calculated using retrieval time (time on board) and the HT data at retrieval:

$$Tc = Tb - Tht$$

Tc: Capture time; *Tb*: Time on board; *Tht*: Hook timer data

Among the 2257 available HT data we removed occurrences associated to hooking contacts and hooking success (i.e., capture) with HT data inferior to 5 minutes assuming that the HT was triggered during hauling. We used a total of 377 HT data for the species considered in this study.

2.2. Analyses

The methodology consists in testing a range of fishing time windows and calculating the expected loss or gain in captures, for swordfish and non-target species respectively. The purpose is then to identify an optimal fishing time window that maximizes non-target species reduction while maintaining a reasonable swordfish yield. The steps of this methodology are presented in Figure 2.

2.2.1. Capture per unit of effort (CPUE)

The fishing effort corresponds to the number of hooks soaked, and thereby available to predators, during a given time period. The fishing effort per hour was calculated using the number of hooks deployed and the estimated setting and hauling speeds (in number of hooks deployed per hour).

The hourly distribution of catch per unit effort (CPUE) was calculated by dividing the hourly distribution of capture by the hourly fishing effort for swordfish and bycatch species respectively. In this study, bycatch species include non-marketable species such as sharks, rays, and teleost fish. Non-target species that are however sold on the market such as tuna and istiophorids were excluded here from that bycatch group of species.

Hourly CPUE distributions for swordfish and bycatch species are presented cumulated over time (Fig. 3). They represent the cumulated percentage of CPUE at a given time over the total CPUE assumed to be made by the end of the time period considered. These distributions were bootstrapped 1000 times in order to obtain an estimation of the median and 95% confident interval.

2.2.2. Fishing simulations and capture reduction matrix

We simulated fishing operations where we made the setting time vary from 1pm to 12pm, and the end of hauling between 1am and 6pm. Using the cumulated CPUE, we quantified the expected capture loss in each simulation by calculating the proportion of captures made compared to the reference fishing operation that encompasses the maximum time window:

$L(ts,te) = CPUEcum(ts) + (100 - CPUEcum(te))$

$L(ts,te)$: Loss in % of total captures; *ts*: Fishing start time; *te*: Fishing end time; $CPUEcum(t)$: Cumulated CPUE at time *t*

Percentages of theoretical losses for swordfish and non-target species are presented in separate matrices (Figs. 4 and 5).

2.2.3. Fishing time optimization for bycatch mitigation

In order to identify the optimal fishing window that maximizes bycatch reduction while maintaining decent swordfish yield, we developed a "ratio index" (*RI*) that corresponds to the ratio between bycatch losses and swordfish losses previously calculated from reduction matrices, for each fishing simulation, and weighted by their relative total captures:

$$RI(ts,te) = \frac{L(ts,te)_{bycatch} \times n_{bycatch} + 1}{L(ts,te)_{swordfish} \times n_{swordfish} + 1}$$

$RI(ts,te)$: Optimal fishing index; $L(ts,te)$: Loss in percent of total captures; *ts*: Fishing start time; *te*: Fishing end time; *n*: total number of captures. +1 is used to avoid division by 0 in case swordfish loss percent is equal to 0.

RI increases with greater bycatch reduction (high value of $L_{bycatch}$) and reduced swordfish loss (low value of $L_{swordfish}$). *RI* calculated for each fishing simulation is presented in a matrix that can be used to identify the best fishing practice (Fig. 6).

3. Results

3.1. Swordfish hourly CPUE versus bycatch

The curve of the cumulated CPUE for swordfish shows different phases (Fig. 3). Swordfish captures mostly occur at night, starting from dusk (around 6pm) till dawn (around 4am). The capture rate is about 10% per hour at night. When the sun rises (between 4am and 7am), the hourly capture rate slows down to 3%. After 7am there is almost no swordfish captures, and 100% of swordfish captures are made by 8am.

Among bycatch for which we had HT data, sharks were the most abundant, dominated by a blue shark, *Prionace glauca* (N = 43, 37%), silky shark *Carcharhinus falciformis* (N = 12, 10%) and oceanic whitetip shark *Carcharhinus longimanus* (N = 10, 9%). Other significant bycatch species were the longnose lancetfish *Alepisaurus ferox* (N = 21, 18%) and the pelagic stingray *Pteroplatytrygon violacea* (N = 6, 5%). The hourly cumulated CPUE of these bycatch species shows a higher rate of catch in the afternoon with 10% of total bycatch capture per hour (Fig. 3). From 6pm, throughout the night till the next day at 2pm, the catch rate for bycatch is relatively constant, around 3% per hour. At 8am, 54% of bycatch total catch are made.

3.2. Capture reduction matrices

Bycatch reduction increases as setting starts late (after 8pm) and the gear is hauled early (before 7am), with a reduction rate ranging between 64 and 95% (Fig. 4).

Reduction in swordfish captures is relatively high with about 13.5% per hour for fishing simulations that start after 8pm (Fig. 5). Early gear retrieval, i.e., end of hauling before 2-3am, also greatly reduce swordfish catch. Fishing operations starting before 7pm and ending after 8am do not increase swordfish catch.

3.3. Fishing time optimization

The *RI* matrix highlights optimized fishing operations with a *RI* varying between 58 and 65 when setting starts between 5pm and 7pm and hauling of the gear ends between 8am and 10am. Based on this results: the best practice consists in setting at 6pm and fishing hauling before 11am. The least optimized fishing operations start after 1pm and end before 4am or after 3pm with *RI* ranging between 0 and 10. Fishing operations starting after 7pm are also among the less optimal fishing operations.

4. Discussion

Bycatch mitigation is an important concern in ecosystem-based management to fisheries. Reducing fishing pressure on non-target species, and thereby mortality, by optimizing species' targeting, improves the conservation of non-target sometimes vulnerable species.

For that purpose, the methodology presented in this study is useful to adjust the fishing timing in order to minimize capture of non-target species without affecting target species catch. The "*Ratio Index*" approach constitutes a potential bycatch mitigation opportunity as it is demonstrated in this study on swordfish-targeting pelagic longline fishery in the South West Indian Ocean. Reduction and *RI* matrices are operational tools that provide relevant guidance to fishermen to identify best practice. For example, a fisherman that targets swordfish by setting his gear at 4pm and finishing hauling of the gear around 2pm the next day has an *RI* of 21 (Fig. 6). This corresponds to 18% of bycatch reduction (Fig. 4) and 0% of swordfish's loss (Fig. 5) compared to a reference fishing operation starting at 1pm and finishing at 7pm the next day. If that fisherman chooses to optimize his fishing practice by, instead, setting just after 6pm and finishing hauling the gear before 9am, the predicted *RI* of his fishing operation would equal 65 (Fig. 6) with a reference bycatch reduction of 56% (Fig. 4), and no swordfish loss (Fig. 5). This corresponds to a improvement of 39% in bycatch reduction compared to his previous practice, and still without impacting swordfish catch.

The general pattern shown in this study is driven by the ecology of the species to some extent. Swordfish come to the upper layers above 100 m at night to feed and this is where they are targeted by longliners (Bach et al., 2014). When the sun rises, swordfish go back down to the depths between 300 and 700 m (Carey and Robinson, 1981; Abascal et al., 2009; Abecassis et al., 2012). Swordfish capture only occurs during the night and setting between just after 6pm and finishing hauling before 9am (optimum fishing time) allows to fully exploit swordfish at night in the upper layers while it considerably reduces bycatch (56%) since the capture of rates of non-target species such as blue shark, longnose lancetfish, silky shark, oceanic whitetip shark and pelagic stingray, is higher during daytime. Fishing after 9am will not increase target catch but only generate more bycatch. The optimization of fishing timing is essential to assure efficient bycatch mitigation; the actual fishing time used by many fleets is generally too long (Carruthers et al., 2011; Bach et al., 2014).

If such approach would have to be considered, it would be more relevant to smaller longliners (<1000 hooks deployed) that can more easily adjust the timing of fishing (because setting and hauling take less time) than larger vessels (>1000 hooks deployed). Further analyses would include testing the ability of vessels from different segments of the fleet to adjust the timing of gear deployment in order to reduce bycatch.

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6. Figures

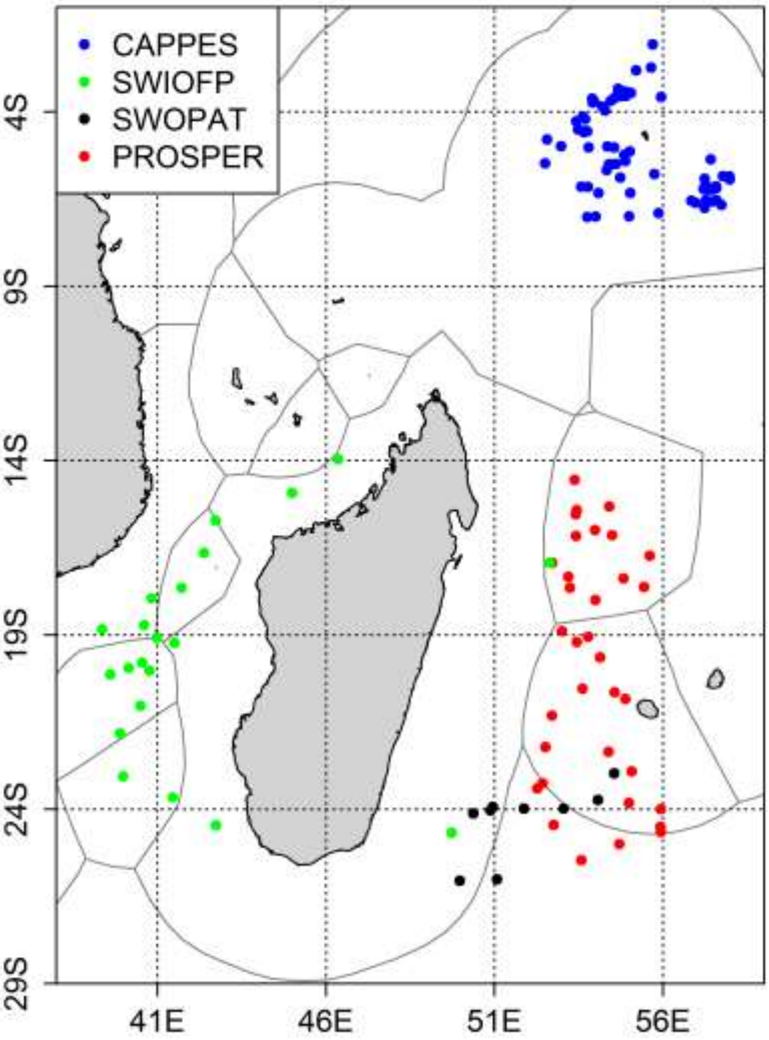

Figure 1. Location of scientific surveys carried out in the South West Indian Ocean.

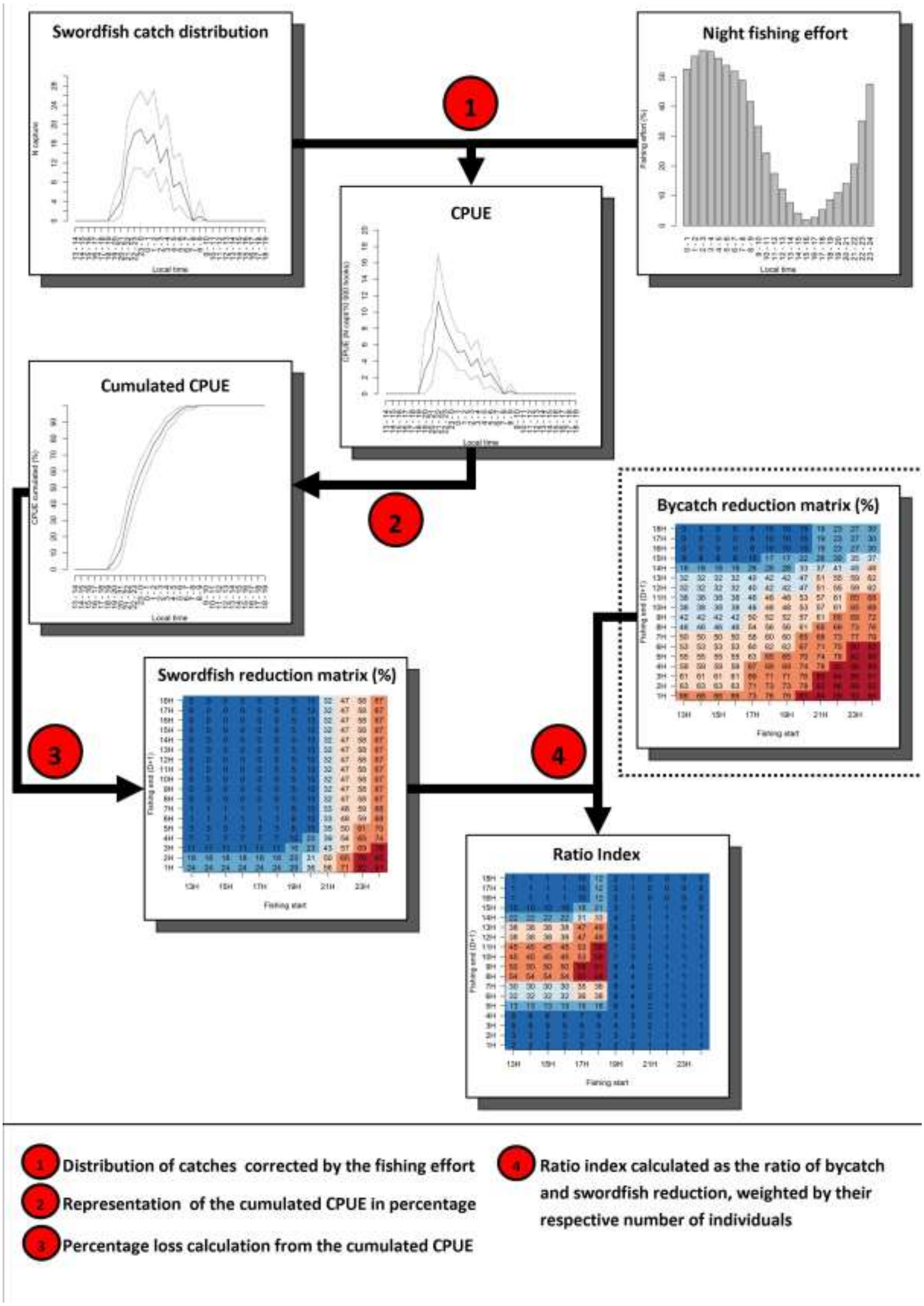

Figure 2. Summary diagram of the methodology used to determine optimal fishing practice.

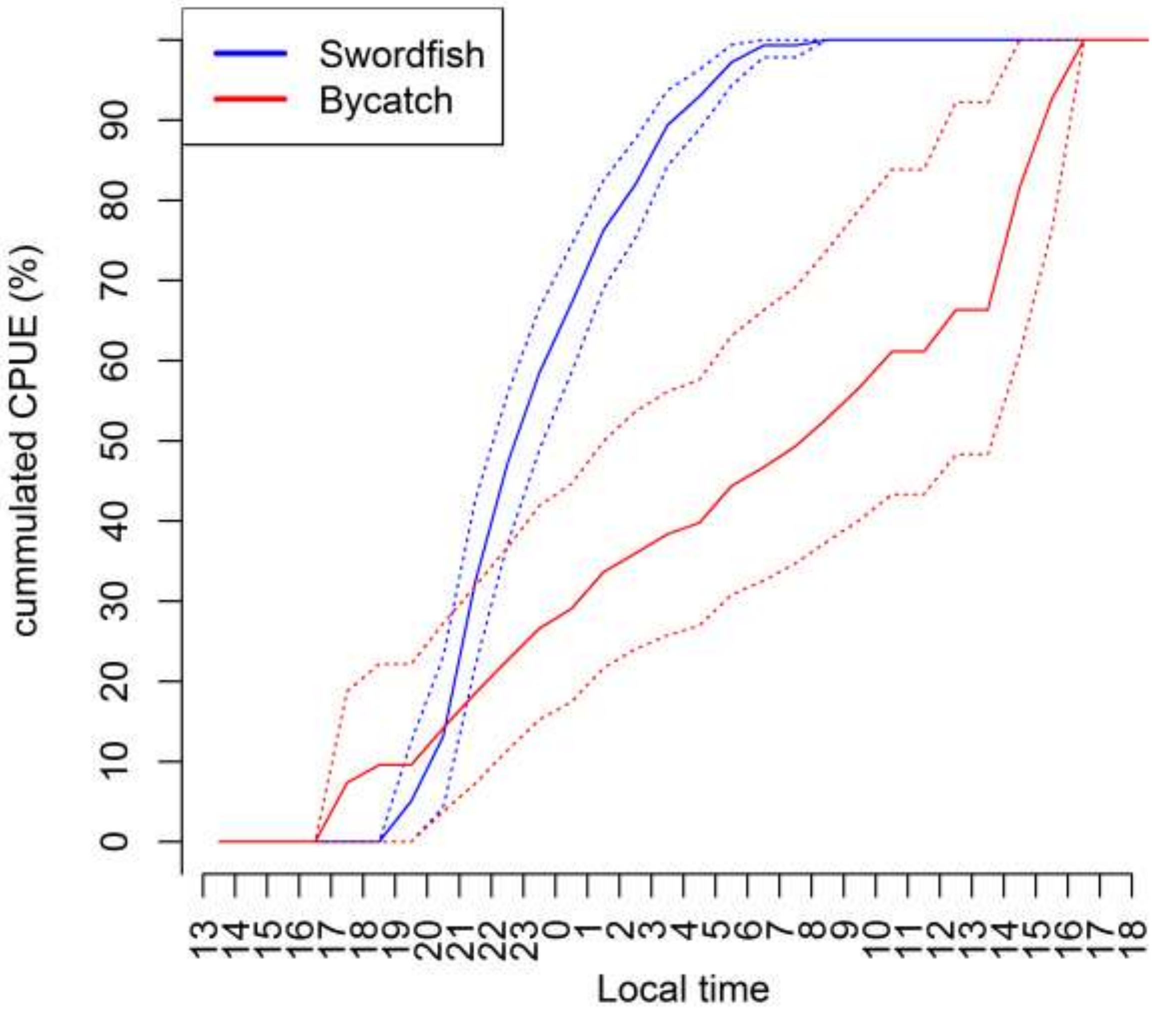

Figure 3. Cumulated CPUE (in percentage of total captures) for swordfish and non-target species during the instrumented fishing experiments.

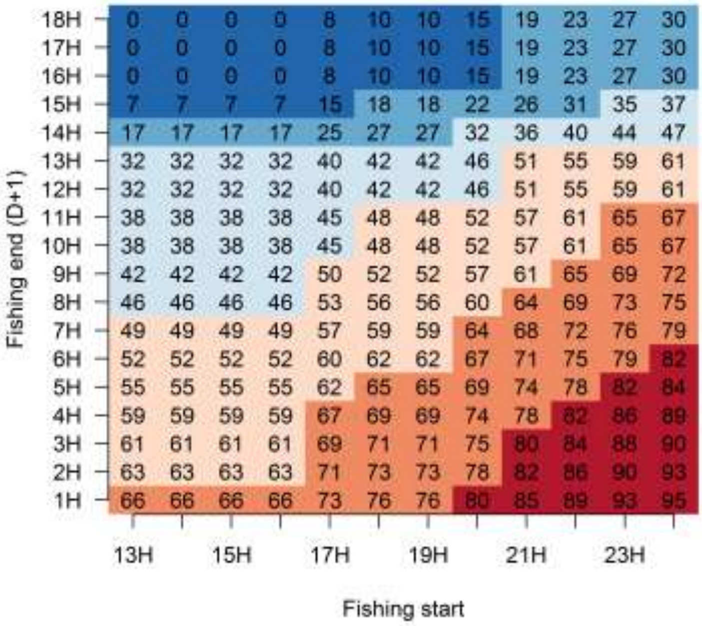

Figure 4. Non-target species reduction matrix.

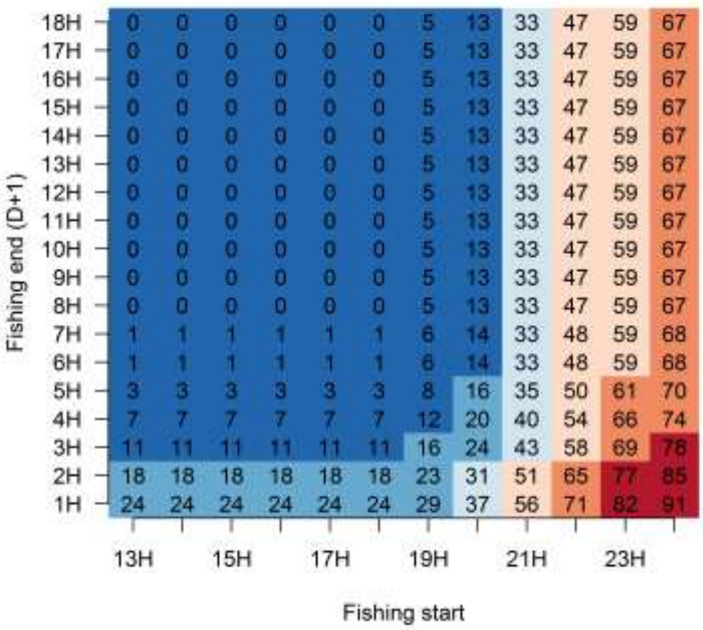

Figure 5. Swordfish reduction matrix.

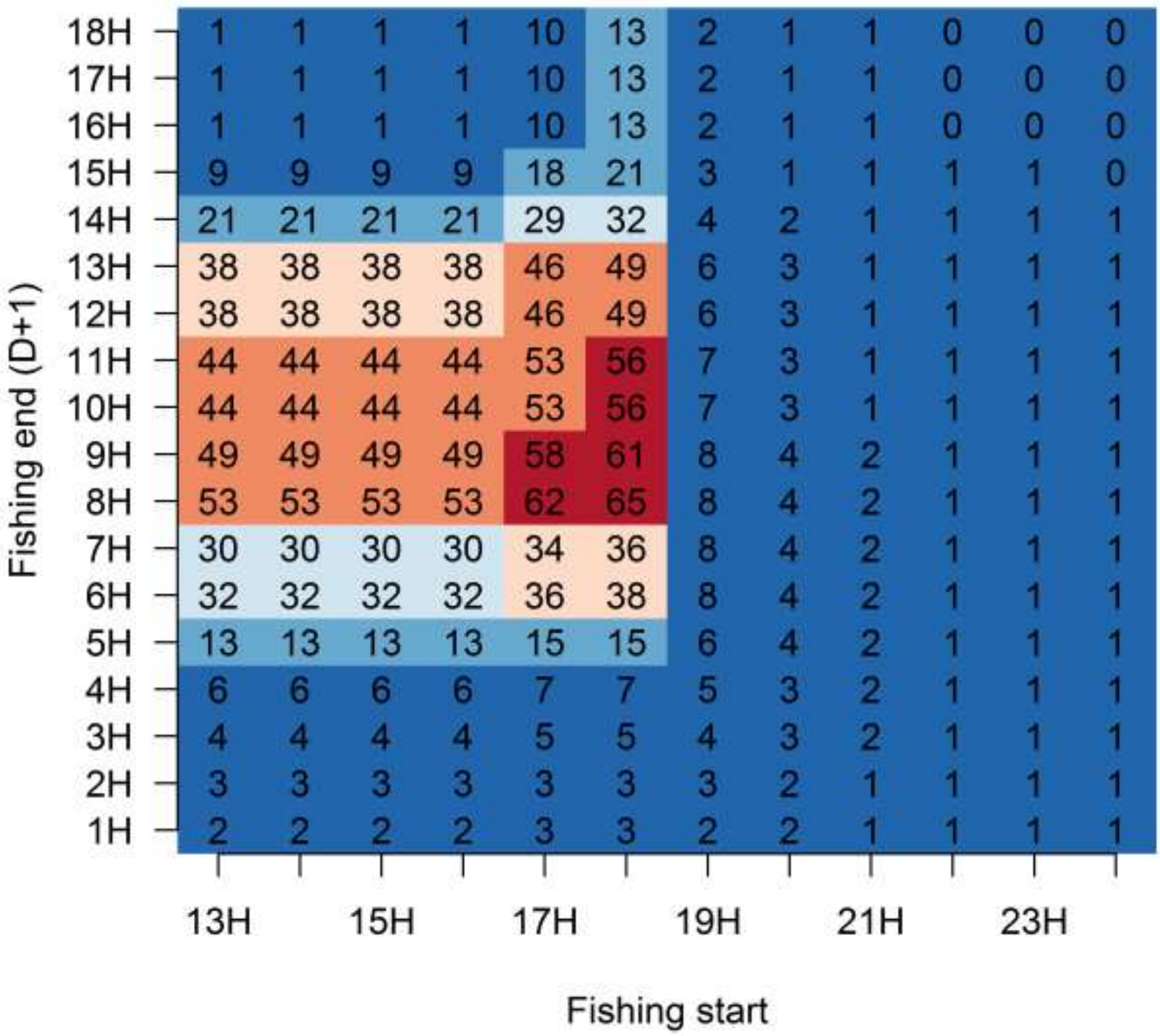

Figure 6. Ratio Index (RI) matrix for fishing simulations targeting swordfish