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Research Paper

The effect of hook spacing on longline catch rates: Implications for catch rate standardization

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A R T I C L E I N F O

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A B S T R A C T

Catch per unit effort (CPUE) is a widely used index of population abundance for informing stock assessments for the purpose of estimating population status and setting fishing policies. However, for CPUE to be an unbiased index, influences that are not related to population abundance (e.g., spatial variation in effort and temporal changes in gear efficiency) must be accounted for in analyses known as CPUE standardization. In longline fisheries, one important factor that can affect CPUE is the spacing between hooks ('spacing effect'), which influences effective effort and has largely been ignored in previous analyses. Here, we use the Pacific halibut (*Hippoglossus stenolepis*) long-line fishery as a case study to explore the spacing effect. Both commercial and experimental (fishery-independent) data with hook spacing, and a survey-based CPUE series, are available for this fishery. It thus provides a unique opportunity to explore the effect of hook spacing and its effect on CPUE trends. We quantify this effect using non-parametric and parametric relationships inside a spatially-explicit (geospatial) CPUE standardization model for commercial data, and non-linear mixed-effects model for experimental data. We found a clear non-linear spacing effect (i.e., hooks were less effective the closer they were), but accounting for space had a larger effect on CPUE trends than accounting for hook spacing. For this stock, it is likely the effect of hook spacing on CPUE was minimal due to little variation in average hook spacing over time. Regardless, historical and future trends in hook spacing can have important effects on longline CPUE standardization, highlighting the value of collecting this information. Accounting for hook spacing effects in other fisheries may improve estimates of trends in relative abundance and lead to better management.

1. Introduction

Catch per unit effort (CPUE) is a key source of information used to manage a wide range of commercially valuable species such as tunas, as well as vulnerable species like sharks (Maunder and Punt, 2004). CPUE is typically assumed to provide an index of population abundance (N), that is robust for detecting trends and informing stock assessments provided that catchability (q) and selectivity are constant through time and space (i.e., $CPUE = qN$). However, this assumption can be violated for a variety of reasons. One important case is when catchability varies in time and space, such as when fish densities interact with fishermen behavior, and thus spatial patterns of catch (Branch et al., 2006; Walters, 2003). Another important case is when the unit of effort varies, such as with changing technological (e.g., gear) and economic factors or targeting strategies (Bishop, 2006). Either case undermines the comparability of CPUE among years and areas, and can lead to effects like hyperdepletion or hyperstability (Harley et al., 2001), which complicates interpretation of CPUE trends as accurately reflecting true stock status trends (e.g., see Myers and Worm, 2003; Polacheck, 2006). CPUE trends are therefore typically standardized to remove effects other than changes in abundance, where possible, so they more accurately reflect changes in abundance (Bishop, 2006; Maunder and Punt, 2004).

Standardizing CPUE from baited longline gear has the additional complexity that the probability of catching a fish, and thus catchability, depends on volitional (foraging) behavior that is affected by gear configuration and environmental variables (Stoner, 2004). This has been shown for important pelagic and demersal species caught by longline (Bigelow and Maunder, 2007; Stoner and Ottmar, 2004; Stoner et al., 2006; Ward, 2008). Thus, it is important to consider variation in configuration for longline gear in CPUE standardization. Longline gear is a simple, but versatile, form of gear where baited hooks are attached to a mainline fixed at regular intervals ('fixed' gear), attached dynamically as it is deployed ('snap' gear), or attached at pre-determined points and deployed via an automated machine ('autoline' gear; see Bjordal and Løkkeborg, 1996). Longline gear can be configured to

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target demersal species such as Pacific halibut (*Hippoglossus stenolepis*) and sablefish (*Anoplopoma fimbria*), as well as pelagic species such as bigeye tuna (*Thunnus obesus*; see Løkkeborg et al., 2010). Appropriately accounting for gear configuration in CPUE standardization is thus key for a wide range of important fisheries.

Although ostensibly simple, interactions between longline gear and fish foraging behavior are complicated. A motivated fish must detect, locate, and then consume bait, but each of these factors can strongly depend on varying environmental conditions such as temperature, turbidity, and light level, among others (Stoner, 2004). In addition, intraspecies local density and size structure can affect fish behavior, such as when there is social facilitation with greater numbers of fish or a length hierarchy for feeding (Stoner and Ottmar, 2004; Stoner et al., 2006). Likewise, both intraspecies and interspecies competition for hooks can play an important role in catch rates, particularly when differences in aggression exist (Rodgveller et al., 2008; Skud, 1978). These interactions complicate the definition of a unit of effort for longline gear, which would ostensibly be a hook (i.e., catch per hook). However, the spacing between hooks influences the foraging behavior of fish by affecting the region baits are detected, called the capture field or active space. Ideally, hook spacing would be measured between hooks directly, but is typically only available as measured along the mainline. Successfully accounting for the effect of hook spacing on effort could thus improve CPUE standardization for longline gear.

Three hypotheses have been proposed for how the capture field changes with hook spacing, which we refer to as the 'spacing effect' (Fig. 1; Hamley and Skud, 1978). Consider a hypothetical set with h hooks with varying hook spacings (and thus set length) fished at reasonable densities (e.g., hook saturation is not an issue; Hamley and Skud, 1978) and uniformly distributed fish. In the *length* hypothesis, as spacing and set length decreases, overlapping capture fields compete with each other, and catch per hook will decrease (e.g., Eggers et al., 1982). In this case, the length of the set would be the unit of effective effort. Alternatively, in the *hook* hypothesis, overlapping capture fields increase fish response, canceling out the effect of hook competition, and catch per hook is constant (except where high density might lead to hook saturation). In this case, the unit of effort would be the number of hooks, and could occur when increased odor plumes from overlapping baits increased fish response from a wider area (Sigler, 2000). Lastly,

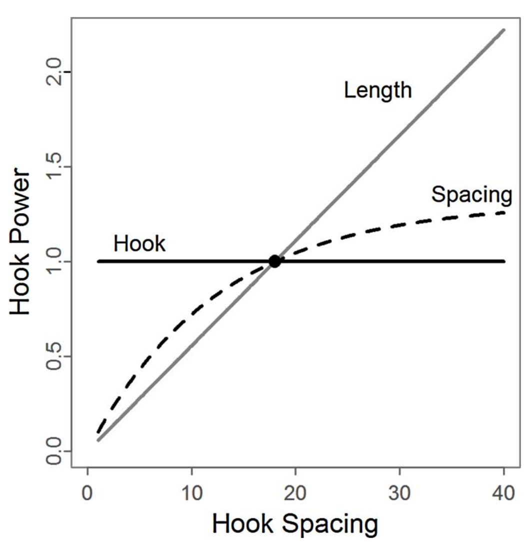

Fig. 1. Stylized representations of three hypotheses for how the power of a hook changes with hook spacing, for a set with the same number of hooks but increasing total length and thus hook spacing. In the *hook* hypothesis, the hooks do not compete and thus the effective effort is the nominal hooks. In the *length* hypothesis, hooks compete at all spacings such that the length of the set is the effective effort. Lastly, the *spacing* hypothesis is intermediate and hooks compete at lower spacings only. Figure recreated from Hamley and Skud (1978).

the *spacing* hypothesis is intermediate, such that hooks spaced widely enough are effectively independent, but hooks closer together compete, to some degree. In this case, the number of hooks are adjusted according to hook spacing, so that an "effective hook" is the unit of effort. Which of these hypotheses (hook spacing effect) is true is driven by the foraging ecology of the species of interest, not the gear itself, and is important for CPUE standardization because it defines the appropriate unit of effort for the gear.

The importance of correctly determining effective effort in a longline data set also depends on properties of the gear. Consider a case where hook spacing is consistent for all years and vessels. In this case, using the number of hooks or length of line will be equivalent up to a multiplicative factor which gets absorbed into catchability and leading to the same trend. However, ignoring effective effort when there is variation in hook spacing across either time, space, or vessel, may positively or negatively bias effort for some sets and undermine the relationship between density and CPUE. Perhaps the most important case is when an annual trend in hook spacing exists (e.g., consistent reduction in spacings over a decade), which may result in a biased effective and assumed effort (and thus CPUE), potentially creating a trend in apparent CPUE that is not related to abundance. This was the case in the Pacific halibut fishery with a notable shifts toward wider spacings from 1955 to 1970, resulting in misleading CPUE trends (Skud, 1972). Similar concerns remain because of trends over time and space in the composition of gear type, since each has a different spacing distribution (Fig. 2).

To investigate the spacing effect for Pacific halibut, Hamley and Skud (1978) initiated an experimental study (i.e., controlled fishing), but these data have insufficient samples at small spacings to adequately quantify this effect over its current applied range. In contrast, recent commercial fishery data have wide variation in hook spacings, and provide an opportunity to quantify and contrast the spacing effect to that from experimental data. In this study, we investigate the spacing effect for Pacific halibut, and its implication for standardized CPUE. First, we develop and apply a spatially-explicit (spatiotemporal) model to commercial catch data to estimate standardized CPUE trends while simultaneously estimating the hook spacing effect. Then, we reanalyze the experimental data from Hamley and Skud (1978), and compare the two relationships and test whether the same information about the spacing effect is available in commercial catch data. We conclude by discussing and demonstrating how these techniques can be used to improve CPUE standardization in longline fisheries.

2. Materials and methods

2.1. Effective hooks

We hypothesized that as the distance to its neighbors varies, so will its power and thus effective effort of a hook (Fig. 1). We thus needed a way to convert nominal hooks into effective hooks. The first step was to quantify the spacing effect with a function (f) that relates expected catch per hook with hook spacing. We explore three possible relationships below.

Next, we adopted the approach taken by Hamley and Skud (1978) and chose a reference spacing, creating what could be thought of as relative hook power. We used 18 ft (5.5 m) as a reference in this study to maintain continuity with previous studies, and due to historical relevancy in the fishery. Relative hook power is unit-less and represents the relative ratio in efficiency between hooks fished at different spacings. For instance, a hook with a relative power of 0.5 at 10 ft indicates that we expect half the catch from that hook compared to if it were fished at 18 ft, all else being equal. We then calculated the number of effective hooks in a set as:

$$h_{effective}(s) = h \cdot f(s)/f(18) \quad (1)$$

where $h_{effective}$ is the number of effective hooks, h the nominal (reported)