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Informing fishery assessment and management with field observations of selectivity and efficiency

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ABSTRACT

Stock assessments and resulting fishery management decisions may be highly sensitive to the assumed selectivity pattern and implied estimates of fishing efficiency of fisheries and resource surveys. Catchability and selectivity are typically estimated parameters in stock assessment. However, stock assessment models can mis-specify the form of selectivity or produce unrealistic estimates of catchability. Misspecification of the form of size-selectivity may produce biased estimates of abundance and fishing mortality. Inaccuracies in estimates of catchability (the product of efficiency and availability) are inversely proportional to the resulting bias in stock size estimates. Field experiments can be used to examine the form of selectivity and to estimate efficiency, and the results can be used to directly inform those important parameters and to help avoid unrealistic estimates. We provide several examples to demonstrate the implications of selectivity and catchability on stock assessment and fishery management as well as how field observations can improve both assessment and management.

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1. Introduction

Understanding the effect of fishing on fish populations is essential for evaluating status of the fishery resource (Punt et al., 2014) and managing sustainable fisheries (Butterworth et al., 2014). Regulating fishing technology and the spatiotemporal patterns of fishing behavior are common ‘input control’ tactics (Cochrane et al., 2009) to achieve strategic objectives such as Maximum Sustainable Yield (MSY; Mesnil, 2012), ecosystem goals (Jennings and Revill, 2007), or optimum yield of multispecies fisheries (Suuronen and Sarda, 2007). Managing fishing gear and behavior can effectively modify size-selectivity and efficiency of capture and has been widely proposed for discard mitigation (Catchpole and Gray 2010). Limiting the selectivity of small fish of the target species can allow them to realize a greater portion of their growth potential (Beverton and Holt, 1957), and reducing the selectivity of immature fish allows more of them to survive to the age of reproduction (Gabriel et al., 1989). Limiting retention or capture of the largest fish of the target species can also protect the most productive spawners (Hixon et al., 2014) and conserve large fish for recreational opportunities. Managing the efficiency of fishing effort can effectively decrease the probability of capture, thereby reducing fishing mortality, particularly for rebuilding target and non-target species (Kennelly, 2007).

Despite the effectiveness of regulating fishing gear and behavior, selective fishing can also lead to the loss of productivity (Svedang and Hornborg, 2014). An alternative approach to managing selectivity and efficiency of fishing is ‘balanced fishing’ in which fishery resources are harvested in proportion to their availability and productivity (Garcia et al., 2012; Jacobsen et al., 2013). However, even a balanced fishing approach is expected to remain somewhat selective (Garcia et al., 2012).

In the context of this special issue of Fisheries Research on “Balanced Fishing and Selective Fishing” (He et al., 2016), our role is to review selectivity and efficiency of fisheries and fishery resource surveys as well as their influence on stock assessment and fishery management. We synthesize information from the 2014 special issue of Fisheries Research on “Selectivity: Theory, estimation, and application in fishery stock assessment models” (Maunder et al., 2014), which is focused on stock assessment modeling, with previous reviews of field experimentation (e.g., Gunderson, 1993; Engas, 1994; Godø, 1994; Walsh, 1996) and demonstrations of field experiments and observations that effectively inform assessment and management. Understanding how field research on selectivity and efficiency can contribute to the stock assessment process requires clarification of the concepts and how they are typically applied

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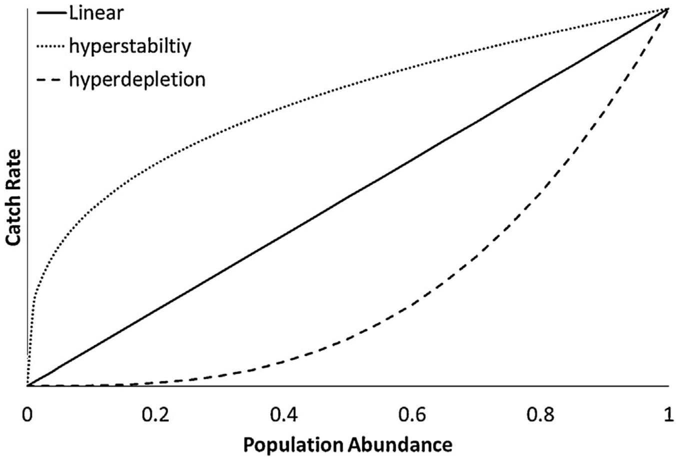

Fig. 1. The relationship between fishery catch rates and population abundance, with the typically assumed linear relationship (solid line) as well as the alternatives for hyperstability (dotted line, $\beta = 0.33$) and hyperdepletion (dashed line, $\beta = 3$).

in stock assessment models so that conservation engineers, fish behaviorists and population modelers can collaborate across disciplines more effectively.

1.1. Terminology

The terms selectivity and catchability are often confused, because they both involve probability of capture and the amount of the population available to the fishery or survey. In general, selectivity is the relative vulnerability of a demographic group of the fished population to capture by a fishery or survey, with at least one demographic group being fully selected. By contrast, catchability quantifies how many fish in the population are caught by a unit of fishing effort (e.g., an hour of fishing) or a unit of survey effort (e.g., standard tow). These terms can be defined most precisely in the context of the current convention for demographic stock assessment models and management reference points.

1.1.1. Catchability, efficiency and availability

Catchability (q) is the effect of a unit of fishing effort (E) directed on the entire population, with the effect measured as the exponential rate of fishing mortality (F) imposed on the population over a time interval t:

$$F_{\mathrm{t}} = qE_{\mathrm{t}} \tag{1}$$

Given that the catch over a time interval (C_{t}) can be derived as the product of F_{t} and the average population abundance during the interval ($\bar{N}_{\mathrm{t}}$), Eq. (1) can be expanded to relate the catch per unit effort to population abundance:

$$\frac{C_{\mathrm{t}}}{E_{\mathrm{t}}} = q\bar{N}_{\mathrm{t}} \tag{2}$$

If q remains approximately constant over time, Eq. (2) implies a simple linear relationship between fishery catch rate and population abundance (Fig. 1). The assumption of constant catchability is a major challenge for stock assessment. Changes in fishing gear or fishing behavior, either in response to changing environments, markets, or regulations, can have great influence on catchability. Fishing effort and catch per unit effort can be standardized to account for the effects of changes in fishing gear and behavior (Maunder and Punt 2004), but the effect of many variables cannot be standardized in practice.

Although Eq. (1) pertains to the fishing effort of a fishery, Eq. (2) can also be applied to fishery resource surveys, in which the relative index of abundance (e.g., catch per standard survey sample) can be scaled to the total population abundance by estimating catchability. In contrast to fisheries, resource surveys are designed to use standard fishing gear, apply standard protocols, and representatively sample density of fishery resources. Therefore, catchability of resource surveys is considered to be more consistent than catchability of fisheries.

An alternative relationship:

$$\frac{C_{\mathrm{t}}}{E_{\mathrm{t}}} = q\bar{N}_{\mathrm{t}}^{\beta} \tag{3}$$

allows for 'hyperstability' in which catch rates are relatively stable when the population is decreasing from high levels ($\beta < 1$), and 'hyperdepletion' in which catch rates decrease at a greater rate when the population decreases from high levels ($\beta > 1$).

Catchability can be decomposed into the efficiency of fishing gear (k) and availability of the population to the fishery, expressed as the proportion of the total resource area (A) that is vulnerable to the fishery (a'):

$$q = k\frac{a'}{A} \tag{4}$$

1.1.2. Selectivity

Efficiency is the probability of capturing fish that are contacted by mobile fishing gear or that actively contact fixed fishing gear. One of the primary goals of a stock assessment is to scale relative indices of abundance (either catch rates from fisheries or resource surveys) to total population abundance, by estimating q. However, q is typically an unknown parameter, and it is estimated to explain the observed time series of fishery catch while fitting the observed relative indices of abundance (surveys or fishery catch per unit effort) in the context of information on vital rates of the species (e.g., growth rates, age at maturity, natural mortality).

Selectivity (s) is the portion of a demographic group that is vulnerable to capture by fishing:

$$F_{\mathrm{t,a}} = F_{\mathrm{t}}s_{\mathrm{a}} \tag{5}$$

where $F_{\mathrm{t,a}}$ is the fishing mortality rate at time t and age a, F_{t} is the fishing mortality at time t for fully-vulnerable ages, and s_{a} is the selectivity of the age group. This definition is based on age structure of a population, but the same equation can relate to any other demographic groups (e.g., size intervals, life history stages). Although many selective processes are size-based (e.g., retention or escapement from fishing gear) or stage-based (e.g., less fishing on immature fish in the nursery grounds), most stock assessment models are age-based. Eq. (5) quantifies either constant or average selectivity during the time interval, but selectivity varies seasonally, with fish growth, condition and movement patterns (e.g., Ferro et al., 2008).

In this definition, selectivity involves the relative probability of capture for a demographic group (i.e., 'contact selectivity', Maunder et al., 2014) and the proportion of that group that is available to the fishery in time and space (i.e., 'population selectivity', Maunder et al., 2014; or 'vulnerability', Gunderson, 1993). The function expressed in Eq. (5) is often termed 'separability', because $F_{\mathrm{t,a}}$ can be separated into the components of F_{t} (which is managed through limiting total fishing effort in a year) and s_{a} (which is managed by regulating fishing technology and behavior). Selectivity is also commonly referred to as 'partial recruitment', because it quantifies the portion of a group that is recruited to the fishery.

Considering that both catchability (q) and selectivity (s) have a relationship with fishing mortality (F), Eqs. (1) and (5) can be combined (e.g., Arreguín-Sánchez, 1996; Walsh, 1996):

$$F_{\mathrm{t,a}} = s_{\mathrm{a}}qE_{\mathrm{t}}, \quad q_{\mathrm{a}} = s_{\mathrm{a}}q \tag{6}$$

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