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Size-selectivity for British Columbia Sablefish (*Anoplopoma fimbria*) estimated from a long-term tagging study

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ABSTRACT

The underlying size-distribution of commercial fish stocks is usually unknown, so fishery size-selectivity must be estimated as a latent process embedded within age-structured stock assessments. However, dome-shaped fishery size-selectivity, in particular, is often inestimable because decreasing selectivity is confounded with mortality at older ages. In this paper, we test for dome-shaped selectivity in British Columbia's Sablefish fishery using a long-term tagging data set. We incorporate alternative fishery size-selectivity assumptions within a mark-recapture framework based on an asymptotic logistic model and dome-shaped models using gamma and normal probability density functions. We also fit each model using both time-invariant and time-varying parameterizations. Our results strongly suggest dome-shaped size-selectivity for tagged-Sablefish in longline trap, longline hook, and bottom trawl fisheries. Time-varying models were generally favored over time-invariant models, although alternative time-varying models often produced similar statistical fits. Dome-shaped selectivity in longline fisheries could be a function of fishery targeting, fish movement, or by lower reporting rates for large size-classes.

1. Introduction

Size-selective fishing causes most stocks to experience size-specific fishing mortality rates that make the composition of commercial landings data different than the underlying population. Fishery selectivity models, ranging between asymptotic (e.g., logistic) and dome-shaped (e.g., normal), attempt to reduce bias in the age- and size-composition of commercial fisheries data by providing a series of scaling coefficients that represent the proportion of fish within a given age or size class that are exposed to the full fishery exploitation rate. Asymptotic models assume the fishery is equally efficient at catching all fish larger than the first fully selected size-class, while dome-shaped models assume intermediate size-classes experience the highest relative fishing exploitation rate.

In fisheries with age-composition data, contemporary modeling approaches estimate selectivity parameters as a latent process within age-structured fishery stock assessments; however, dome-shaped fishery size selectivity is often difficult to detect because the descending limb of dome-shaped selectivity models is partially confounded with decreasing relative abundance of older age-classes due to mortality. Thus, the statistical power to detect the presence of dome-shaped selectivity is low in traditional age-structured assessments. In addition, correlation among several assessment parameters can cause multiple selectivity estimates to have similar statistical fits (Kimura, 1990; Myers and Cadigan, 1995; Sigler, 1999). For example, higher natural mortality at older ages and dome-shaped selectivity parameters are likely to be confounded because both predict old individuals will be captured less frequently (Taylor and Methot, 2013; Thompson, 1994). In either case, large individuals are unobserved in size-composition data. Therefore, it is common to assume that fishery selectivity is asymptotic to stabilize parameter estimation (Crone et al., 2013). When no size- or age-composition data exists, selectivity is also often assumed to be asymptotic (e.g., Hilborn, 1990).

Assuming fishery size-selectivity is asymptotic creates risk in managing fisheries because the shape of fishery selectivity can affect the outputs of fishery stock assessment, particularly estimates of the spawning biomass and maximum sustainable yield (Maunder and Piner, 2015; Scott and Sampson, 2011). For example, within a single year, incorrectly applying an asymptotic selectivity model can cause the spawning potential to be underestimated, particularly in cases where fecundity increases with age (He et al., 2011). While underestimating the spawning potential may reduce the risk of overfishing, it increases the risk of foregone catch, which is ultimately a management trade-off (Sampson, 2014), and can also makes the stock appear more productive as similar recruitment levels are produced from lower spawning biomass. Conversely, non-linear relationships among assessment

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parameters may also cause models with misspecified asymptotic selectivity to overestimate the spawning biomass, particularly when they include temporal variation (Hulson and Hanselman, 2014). Systematic bias caused by misspecifed fishery size selectivity may also be amplified by ageing error (Henríquez et al., 2016) or unaccounted temporal variation (Linton and Bence, 2011; Sampson and Scott, 2011; Stewart and Martell, 2014).

Estimating size-selectivity from tagging data provides an alternative approach to assuming fishery selectivity is asymptotic when dome-shaped models fail to fit to age-composition data. Fishery size-selectivity models fit to tagging data have fewer confounded parameters, which increases their statistical power relative to age-structured stock assessments because the size-distribution of releases can be compared directly to the size-distribution of recovered tags (Hamley and Regier, 1973). For example, selectivity models fit to longline tag-returns for both Pacific Halibut, *Hippoglossus stenolepis*, (Clark and Kaimmer, 2006) and Alaskan Sablefish, *Anoplopoma fimbria,* (Maloney and Sigler, 2008) indicate selectivity for these stocks may be dome-shaped, despite age-structured stock assessments fit to age-composition data suggesting selectivity is asymptotic. Fitting selectivity models to tagging data is also advantageous because it requires shorter time-series than age-structured stock assessment. For instance, dome-shaped fishery selectivity for Red Drum, *Sciaenops ocellatus*, has been estimated by linking multiple three-month tagging experiments together using linear models, thereby eliminating the need to estimate growth and mortality parameters (Bacheler et al., 2010). Multiple tagging studies have also been linked together to examine time-varying selectivity for cod, *Gadus morhua* (Myers and Hoenig, 1997). Although in some cases tagging experiments may fail to fully incorporate the true spatial scales at which fisheries operate (Pierce et al., 1994; Punt et al., 2014), in a few fisheries there are large-scale government-sponsored tagging programs in which returns come directly from commercial fisheries thus eliminating this concern (e.g., Pacific Halibut – see Anganuzzi et al., 1994).

In this paper, we use a long-term tagging data set to estimate dome-shaped and time-varying fishery selectivity models for British Columbia (BC) Sablefish. Similar to many fisheries, BC Sablefish do not have high-quality age-composition data. Ageing Sablefish via otoliths is notoriously difficult and usually results in significant reader-to-reader variability (Beamish and Chilton, 1982; Kimura and Lyons, 1991). Although BC Sablefish are taken by longline trap (hereafter referred to as trap), longline hook (hereafter referred to as hook), and bottom trawl fisheries, age-composition data are only available for the trap fishery (DFO, 2016). Trap age-composition data are available beginning in 1982, but low sample sizes and unrepresentative sampling in some years make it uninformative in stock assessment. For example, the data fails to show any cohort patterns comparable to known recruitment events in the Gulf of Alaska (DFO, 2014). Without informative age-composition data, selectivity parameters defining time-varying and dome-shaped selectivity models are currently confounded by estimates of the unfished biomass and the steepness of the recruitment curve within the age-structured assessment model (DFO, 2016). Fishery size-selectivity is estimated by age within the BC Sablefish stock assessment, although age is estimated using length composition data. While stationary and asymptotic selectivity models are necessary for the age-structured assessment model to converge, they unlikely reflect how the fishery operates. For example, selectivity for Sablefish across all three gear-types (trap, hook, trawl) likely changed while implementing the Integrated Groundfish Management Act, which mandated quota for all bycatch, leading to deliberate avoidance of quota-limiting rockfish, *Sebastes* spp. Additionally, uncertainty about movement within the stock (Beamish and McFarlane, 1988; Hanselman et al., 2015; Heifetz and Fujioka, 1991) and size-based depth-stratifications (Maloney and Sigler, 2008) indicate it wouldn't be unreasonable for fishery size-selectivity to be dome-shaped (O'Boyle et al., 2016).

2. Materials and methods

We compared asymptotic and dome-shaped fishery size-selectivity models fit to tagged Sablefish recovered by the trap, hook, and trawl commercial fisheries. In total, nine fishery size-selectivity models were compared for each gear. Models included three density functions (logistic, normal, gamma) that were parameterized to include one time-invariant fishery size-selectivity model, and two time-varying alternatives.

2.1. Data

Our analysis includes Sablefish tagged and released between 1995 and 2010 on the annual British Columbia Sablefish Research and Assessment Survey conducted under a joint project between Canada's Department of Fisheries and Oceans and Wild Canadian Sablefish, Ltd (Rob Kronlund, per comm.). The survey typically takes place in late September or early October, and is the primary source of fishery independent data used within the BC Sablefish stock assessment. During the survey, external floy anchor tags are inserted at the base of the dorsal fin using variants of three main sampling protocols, which we will refer to as the Traditional Survey, the Stratified Random Sampling Survey Program, and the Inlet Program (Haist et al., 2002; Kronlund et al., 2002; Wyeth et al., 2007). Data from the Traditional Survey includes years 1995 through 2007 (Table 1). Sablefish were tagged using strings of 25 traps with the goal of tagging at least 300 Sablefish annually at nine offshore indexing localities: Languara/Frerick, Hippa Island, Buck Point, Gowgaia Bay, Capt St. James, Triangle Island, Quatsino, Esperanza Inlet, and Barkley Canyon (Fig. 1). At each site, one set was deployed at between five and seven depth zones distributed between 91 m and 824 m. In addition, sets of 65 traps were used to tag 1000 Sablefish annually at offshore tagging localities including at least four of the following: Tasu Sound, Middle Ground, Pices Canyon, Rennel Sound and Estevan Point (Wyeth et al., 2007). The Stratified Random Sampling Program was added in 2003, and continued throughout the rest of our time series. The Stratified Random Sampling Program includes sampling five spatial strata across three depth zones (100–250 fathoms, 250–450 fathoms, 450–750 fathoms), using a total of 110 sets of 25 baited traps. The Inlet Program was implemented in all years of our time series (1995–2010) and includes at least the following four inlet indexing locations: Portland Inlet, Gill Island, Finlayson Channel, and Dean/Burke Channel (Fig. 1). Exact numbers of Sablefish

Table 1
Annual numbers of Sablefish tagged and released by the Department of Fisheries and Oceans Canada during the Sablefish Research and Assessment Survey. Releases are separated by survey protocol (StRs = Stratified Random Sample). In some cases the type of release is unavailable (Unknown). Sampling locations for each survey can be referenced in Fig. 1.

Year	Traditional	Inlets	StRs	Unknown	Total
1995	9278	3186	0	3339	15,803
1996	21,523	3776	0	2679	27,978
1997	15,360	3067	0	1069	19,496
1998	13,867	5958	0	1998	21,823
1999	16,034	9512	0	1703	27,249
2000	17,481	3042	0	2252	22,775
2001	13,590	4087	0	508	18,185
2002	5884	3522	0	10,370	19,776
2003	8788	4346	11,415	0	24,549
2004	8585	4834	5549	0	18,968
2005	7191	3360	5678	0	16,229
2006	8432	2474	7970	0	18,876
2007	8284	1695	6298	0	16,277
2008	0	1293	6839	2	8134
2009	0	2070	5177	0	7247
2010	0	3871	5827	0	9698
Total	293,063	154,297	60,093	54,753	23,920