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A historical review of selectivity approaches and retrospective patterns in the Pacific halibut stock assessment

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ABSTRACT

The Pacific halibut stock assessment has proven to be a particularly challenging application for the estimation of selectivity. Contributing factors include: extremely pronounced temporal changes in length-at-age, a steep vulnerability curve for commonly used hook sizes, a minimum length limit, relatively late (~age 6–10) appearance of fish in survey and fishery data, and geographic heterogeneity in demographic parameters coupled with pronounced spatial trends in population abundance over time and significant ontogenetic migration over the stock range. Historical stock assessments have variously modeled selectivity as a function of length or age, employing nonparametric forms in attempting to account for these various factors. Despite these efforts, a strong retrospective bias in model results occurred during three separate time periods; each of which ultimately required modification of the selectivity parameterization to ameliorate that bias. This paper provides a summary of historical approaches, and the methods employed to address the most recent retrospective pattern.

1. Introduction

Integrated statistical fisheries stock assessments are now standard approaches in many parts of the world (Hilborn and Walters, 1992; Quinn and Deriso, 1999; Maunder and Punt, 2013; Fournier and Archibald, 1982; Megrey, 1989). These models fit to available fisheries-dependent and/or fisheries independent data and provide estimates of management-related quantities including reference points, stock size, and harvest rates. Time-series of catch and relative abundance estimates, together with biological information (lengths, ages, or both) from these time-series provide information on the population trend and the demographic components contributing to that trend.

A crucial aspect of these analyses lies in defining the observed number of fish at a particular length or age, relative to the number of fish estimated to exist at that length or age in the population dynamics model. This relationship is variously referred to as efficiency, effectiveness, or the combination of selectivity, and catchability. Because various definitions are used interchangeably in the fisheries literature, in this paper we identify and use four distinct terms:

(1) *Availability*: the relative probability a fish will be in the same area at the same time that the gear is being deployed.
(2) *Vulnerability*: the relative probability a fish that is present when and where survey (or fishing) gear is deployed will be captured (also commonly denoted as "gear selectivity" or "contact selectivity).
(3) *Selectivity*: the length- or age-based probabilities used to relate fish predicted to exist in a population to those that are observed in the data; this represents the combination of both vulnerability and availability.
(4) *Catchability*: the scaling coefficient between an index of abundance (or catch-per-effort) and the abundance at length or age that is most selected.

There are a number of biological and technical factors that can contribute to differences in vulnerability, availability, or both as a function of fish length, age, or both (Olsen and Laevastu, 1983, provide a detailed conceptual map of many factors influencing longline catch rates in general). Biological factors can include ontogenetic shifts among habitats, behavioral differences due to changes in diet, differences in growth rates among different habitats, morphology (jaw dimension, body length or shape, etc.), and many others. Technical factors may include physical aspects of sampling/fishing (mesh or hook size, set duration, towing speed, etc.), gear performance in different habitats, regulatory length-limits, and many others. These factors may be temporally variable or static; however in both cases interactions among them may result in highly variable selectivity or catchability over time.

The Pacific halibut stock assessment and management system has a long history of data collection and scientific analysis, serving

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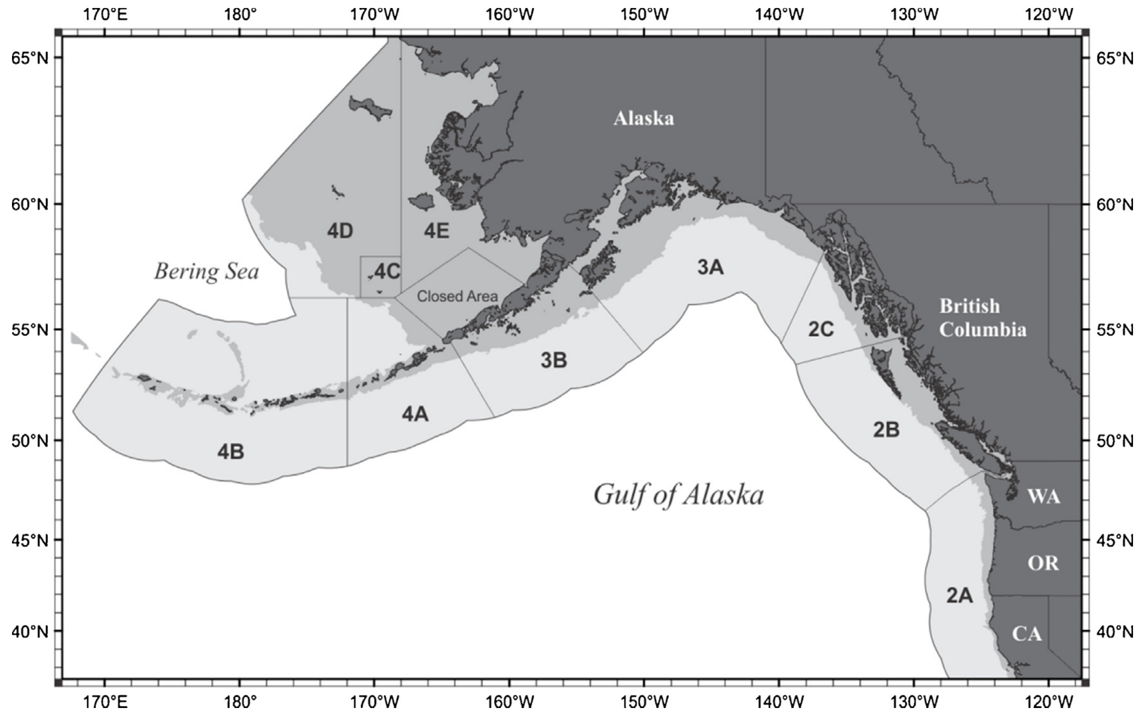

Fig. 1. International Pacific Halibut Commission regulatory areas.

as a testing ground for many of the fisheries modeling approaches that have been developed over the last several decades (Clark, 2003). Despite this history (or perhaps causing this history), Pacific halibut present a suite of difficult challenges to the modeling of selectivity. Such challenges are frequently present in other fisheries, but are infrequently observed *en masse* in a single stock assessment application. As such, Pacific halibut represent a unique and potentially illustrative case-study.

In this manuscript, we review the approaches taken over several decades of the Pacific halibut stock assessment, with a particular emphasis on the treatment of selectivity. We identify a recurrent theme of simplifying selectivity assumptions that, over three distinct time-periods, each became increasingly mismatched with the underlying population dynamics. We summarize the retrospective patterns in biomass estimates (and therefore management-related quantities) that appear to be a result of these mismatches. We then present the results of the most recent stock assessment as a more flexible long-term solution to these historical issues.

2. A brief overview

The Pacific halibut stock assessment (Stewart et al., 2013a), conducted annually by the International Pacific Halibut Commission (IPHC), estimates the status of the resource in the northeastern Pacific, including the territorial waters of the United States and Canada (Fig. 1). The directed halibut fishery, closely monitored and managed for nearly 100 years, is prosecuted primarily with longline gear throughout its geographic range (Gilroy et al., 2013). Other sources of removals include sport (Williams, 2013a) and subsistence fisheries (Williams, 2013c), bycatch in other (non-halibut) fisheries (Williams, 2013b), as well as discard mortality of released halibut in the directed fishery (Gilroy and Stewart, 2013). Much is documented in IPHC publications about the history of fishery removals, population trends, and biological characteristics. Total halibut removals (including all sources of mortality: target fishery landings and discards, bycatch in non-target fisheries, research, sport, and personal use) have ranged from 34 to 100 million pounds (15,000–45,000 mt). Since all halibut are landed in a dressed form, and most are immediately processed by removing the head, all weights used in catch reporting, sampling, and stock assessment are in units of net pounds (head and organs removed; approximately 75% of round weight). The average annual removal over the last 100 years (1913–2012) has been 64 million pounds (29,000 mt) and removals were consistently above that value from 1985 through 2010. After a peak in 2004, annual removals have decreased each year in response to management measures intended to stabilize a declining trend in survey indices, fishery catch rates, and stock assessment estimates. The 2013 removals are projected to be 49 million pounds (22,000 mt).

Both fisheries-dependent and fisheries independent data are collected and compiled by regulatory area and then aggregated to the coastwide level, such that inputs to the assessment represent total coastwide estimates. Indices of abundance are geographically weighted and biological summaries (length-, weight-, and age-composition data) represent the sum of the number of fish estimated across all areas. The annual IPHC setline survey (Henry et al., 2013; Soderlund et al., 2012) uses standardized fishing gear at fixed-locations to generate annual estimates of catch Weight-Per-Unit-Effort (WPUE), length-at-age, and proportions-at-age by sex. The commercial longline fishery generates logbook-based WPUE, as well as length-at-age, and catch-at-age sampled by IPHC port samplers. The 2012 setline survey WPUE was 12% higher than in 2011; the first increase since the current geographically comprehensive survey began in 1997 (Fig. 2). However, the coastwide trend in WPUE has differed substantially among regulatory areas. Individual length-at-age (and therefore weight-at-age) has varied markedly over the historical record. Ten-year old halibut sampled from the core of the stock distribution (area 3A) have ranged from over 40 pounds (18 kg) in the middle portion of the 20th century to just over 10 pounds (4.5 kg) in the early and late parts of the century. The cause for these trends is currently unknown, but they are believed to result from both internal and external influences on the halibut stock. Maturity data indicates little change in maturity-at-age (corresponding to large changes in maturity-at-length) over the history of data collection (Clark and Hare, 2006a). Other important sources of uncertainty include the spatial and migratory aspects of