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Evaluating the conservation risks of aggregate harvest management in a spatially-structured herring fishery

Ashleen J. Benson[a,1], Sean P. Cox[a,*], Jaclyn S. Cleary[b,1]

[a] School of Resource and Environmental Management Simon Fraser University, 8888 University Drive, Burnaby, BC, Canada V5A 1S6
[b] Fisheries and Oceans Canada, 3190 Hammond Bay Road, Nanaimo, BC, Canada V9T 6N7

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ABSTRACT

Despite broad recognition of the potential for significant spatial complexity in morphological, behavioral, and life-history traits within many fish populations, fisheries are commonly managed across large spatial scales that aggregate interacting sub-populations into single management units. Such mis-match between the ecological and management scales may lead to a loss of spatial diversity and a restricted ability of populations to adapt and persist in the presence of changing environmental conditions. Developing harvest strategies for spatially complex fish populations therefore remains a major challenge. In this study, we evaluate whether managing spatially complex fish stocks as large-scale aggregates leads to greater conservation risks. We develop a closed-loop simulation model that represents a range of dispersal scenarios and includes imperfect management knowledge about the abundances and dynamics of interacting Pacific herring (*Clupea pallasi*) sub-populations, as well as weak management control of how exploitation is allocated among sub-populations. The latter is driven by the spatial dynamics of the fishing fleet as it seeks to optimize profitability. Simulated management outcomes did not always lead to increased risks under all scenarios of dispersal, fishery spatial dynamics, and management errors. Instead, these processes interacted to either mediate or intensify the impact of inappropriate management assumptions and stock assessment errors. Management strategies aimed directly at limiting exploitation risk consistently protected spatially complex populations in the presence of incorrect management assumptions about stock structure, high fishing power, and persistent stock assessment errors. Given the pervasiveness of these errors in fisheries, we recommend further evaluation of spatio-temporal refugia for tactical management of spatially complex fish populations.

1. Introduction

Many exploited fishes exhibit a high degree of spatial variation in genetic, morphological, behavioral, and life-history traits within individual species and populations (Hilborn et al., 2003; Kerr et al., 2010; Schindler et al., 2010). Ignoring this spatial complexity when assessing and managing fisheries could erode spatial diversity, restrict species adaptation and persistence in the presence of environmental change, and reduce the success of harvest strategies (Cope and Punt, 2011; Hilborn et al., 2003). Simulations also indicate that unclear stock delineation may have a greater impact on harvest strategy performance than uncertain abundance measurements and variation in mortality and recruitment (Punt and Donovan, 2007). One precautionary approach to dealing with such uncertainty may be to create small management areas that are unlikely to contain more than one population (Taylor et al., 2000). However, the opposite approach, most commonly used in fisheries, is to aggregate interacting sub-populations into single management units that are managed and exploited across large spatial scales (Cope and Punt, 2011).

Uncertainty about the ecological processes governing spatial structure within, and connectivity among, spatially complex populations has been part of the rationale for aggregate assessment and management of spatially diverse fisheries (Sinclair, 1988; McQuinn, 1997; Corten, 2002). However, a modern precautionary approach requires taking these uncertainties into account when developing fishery harvest strategies (Stephenson, 1999). Our current understanding about the risks posed by managing

* Corresponding author. Tel.: +1 604 461 4554.
E-mail addresses: abenson@landmarkfisheries.com (A.J. Benson), spcox@sfu.ca (S.P. Cox), Jaclyn.Cleary@dfo-mpo.gc.ca (J.S. Cleary).
[1] Present address: Landmark Fisheries Research, 430 Ioco Road, Port Moody, BC, Canada V3H 2W2.

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spatially complex populations as single, aggregate stocks depends on two common assumptions embedded within fishery models: (1) populations are discrete with no exchange of adult individuals between sub-populations (Frank and Brickman, 2000) and/or (2) fishing mortality is homogeneous across populations within a spatial complex (Wilson et al., 1999; Cope and Punt, 2011). Less research has been done on the risks of managing spatially complex populations that are connected by dispersal, which is an important mechanism affecting long-term persistence and productivity of spatially structured fish populations (Stephenson, 1999; Kerr et al., 2010; Schindler et al., 2010). Population connectivity, maintained by dispersal of individuals within metapopulations, is believed to create rescue effects that increase resilience to exploitation or other extinction risks (Dulvy et al., 2003). Rescue effects caused by dispersal are further believed to reduce risks of managing spatially complex fish populations as large-scale aggregates (Cope and Punt, 2011). Although exploitation typically occurs over broad spatial scales, fishing mortality is spread unevenly across spatially structured populations, typically concentrating on populations that present more profitable fishing opportunities (Rassweiler et al., 2012). Profitability can be related to distance from ports, time periods in which prices are high relative to fishing costs, or times of year, such as spawning seasons, when fish are easier to catch. Such spatial and temporal heterogeneity in profitability exposes some harvested populations to greater exploitation rates than others (Sanchirico and Wilen, 1999).

In this paper, we examine whether aggregate fisheries assessment and management leads to high conservation risks for spatially-structured populations. Specifically, we investigate how conservation risks are affected by interactions between adult dispersal within a metapopulation and fishery characteristics that determine how exploitation is distributed among sub-populations. A key distinction between our approach and related work on this topic is that we depict weak management control of how exploitation is allocated among sub-populations in addition to simulating imperfect management knowledge about the abundances and dynamics of the fish populations (e.g. Cope and Punt, 2011; Frank and Brickman, 2000). The former is driven by the spatial dynamics of the fishing fleet as it seeks to optimize profitability. We represent these assumptions in a closed-loop simulation model in which the management system propagates realistic errors in monitoring data, stock assessment models, and rules for determining annual total allowable catches (de la Mare, 1998; Punt, 2006; Cox and Kronlund, 2008). We simulate a management system that mimics the general characteristics of the Pacific herring (*Clupea pallasi*) fishery in the Strait of Georgia (SOG), British Columbia (B.C.), Canada (Fig. 1a).

1.1. The B.C. Pacific herring fishery system

Pacific herring are managed as five major and two minor stocks within B.C. However, genetic analyses indicate that four distinct

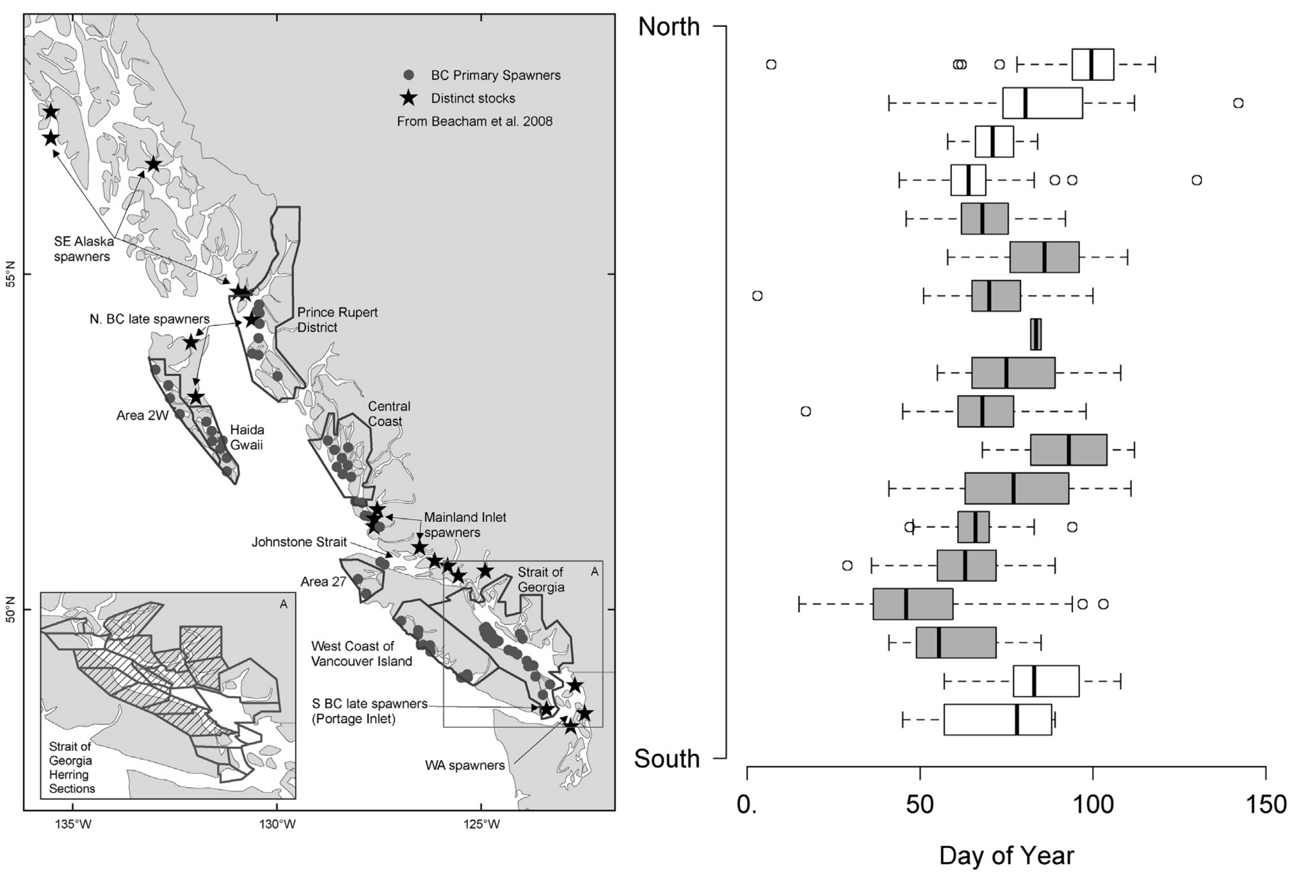

Fig. 1. (a) B.C. Pacific herring management areas, (grey boundary) and spawning locations of the B.C. primary spawners (grey filled circles) and the other genetically distinct stocks (black stars) identified by Beacham et al. (2008). Strait of Georgia (SOG) spawning sections shown on inset A; shaded (hatched) sections correspond to the 12 historically productive spawning "sections". (b) Empirical distributions for Pacific herring spawn timing for $P = 18$ SOG spawning sections. Shaded boxplots indicate the sections and data used in this paper (1928–2006), and correspond to inset A. Boxplots in (b) summarize the median, 25th, and 75th percentiles of spawning dates, the whiskers correspond to the 5th and 95th percentiles, and the open circles are outliers.