Fisheries Research 206 (2018) 96–108

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Experimental capture and handling of chum salmon reveal thresholds in injury, impairment, and physiology: Best practices to improve bycatch survival in a purse seine fishery

Katrina V. Cook[a,*], Scott G. Hinch[a], Maryann S. Watson[b], David A. Patterson[c], Andrea J. Reid[d], Steve J. Cooke[d]

[a] Department of Forest Sciences and Conservation, University of British Columbia, Vancouver, BC V6T 1Z4, Canada
[b] Marine Affairs Program, Dalhousie University, 1355 Oxford Street, PO Box 15000, Halifax, NS B3H 4R2, Canada
[c] Fisheries and Oceans Canada, Cooperative Resource Management Institute, School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC V5A 1S6, Canada
[d] Department of Biology and Institute of Environmental Science, Carleton University, Ottawa, ON K1S 5B6, Canada

ARTICLE INFO

Handled by Bent Herrmann

Keywords:
Release mortality
Commercial fisheries
Pacific salmon
Fish stress physiology
Discard
Fish management

ABSTRACT

Recommendations and regulations regarding handling of non-target fish (i.e. bycatch) are often vague and subjective in commercial fisheries. Identifying how different components of capture influence the condition of discarded fish can help develop specific guidelines and best handling practices. Using an experimental approach, we modified the severity of capture stressors in commercial purse seine fisheries for Pacific salmon and monitored indices of injury and reflex impairment in chum salmon (*Oncorhynchus keta*), a species commonly discarded from these fisheries. Study fish were held for 5 or 10 days. Modeling of changes in injury and impairment sought to disentangle the latent effects of capture stressors and the role of sex and maturity. Thresholds in physiological responses to times (i) pursed in the net and (ii) air exposed on deck were also evaluated. Injury progressed throughout holding, was more extensive in females, and accelerated faster in less mature fish. Both crowding severity and set size (i.e. estimated number of fish caught) increased injury and impairment, effects that were exacerbated with time pursed. Physiological indicators of exhaustion also increased with time pursed and 15 min was identified as an important transition point, potentially representing the temporal limit to anaerobic exercise. The time between 1 and 3 min of air exposure was identified as being important to survival, and after 6 min of air exposure, endogenous energy stores may have become exhausted. Resulting recommendations include keeping nets loose during sorting, releasing fish prior to 15 min of being pursed, and keeping air exposure within the range of 1–2 min, or less. Additionally, females and less mature fish appear to be more susceptible to the injurious effects of capture.

1. Introduction

For non-target fish discarded from fisheries, evaluations of how condition changes under different scenarios can help determine appropriate measures to maximize probability of survival (Benoît et al., 2012). Fish captured in fisheries incur physical injury (from minor mucus and scale loss to large wounds), exhaust themselves fighting against entrapment, and can be subject to rapid environmental changes and oxygen deprivation through exposure to hypoxic conditions or direct exposure to air (Davis, 2002). Air exposure is arguably one of the most severe forms of acute stress that a fish can experience (Cook et al., 2015) and unsurprisingly, several studies have found that reducing the time that non-target fish spend exposed to air has the greatest impact on their survival (e.g. Humborstad et al., 2009; Benoît et al., 2010). The degree of injury sustained during capture is likewise important to survival outcomes (Baker et al., 2013; Meeremans et al., 2017) and, when combined with the stress of capture, can lead to performance-altering behavioural changes (e.g. weakened swimming or predator evasion abilities; Davis, 2002). By quantifying the magnitude of injury sustained in addition to abilities to respond to stimuli (i.e. impairment, typically measured through reflex action testing; Davis, 2007), we can evaluate key aspects of the fishing process that limit the survival of non-

Abbreviations: AIC, Akaike information criterion; DFO, Fisheries and Oceans Canada; POLR, proportional odds linear regression; RM-LME, repeated measures linear mixed effects

* Corresponding author.
E-mail address: katrina.vcook@alumni.ubc.ca (K.V. Cook).

https://doi.org/10.1016/j.fishres.2018.04.021
Received 25 October 2017; Received in revised form 23 April 2018; Accepted 24 April 2018
Available online 23 May 2018
0165-7836/

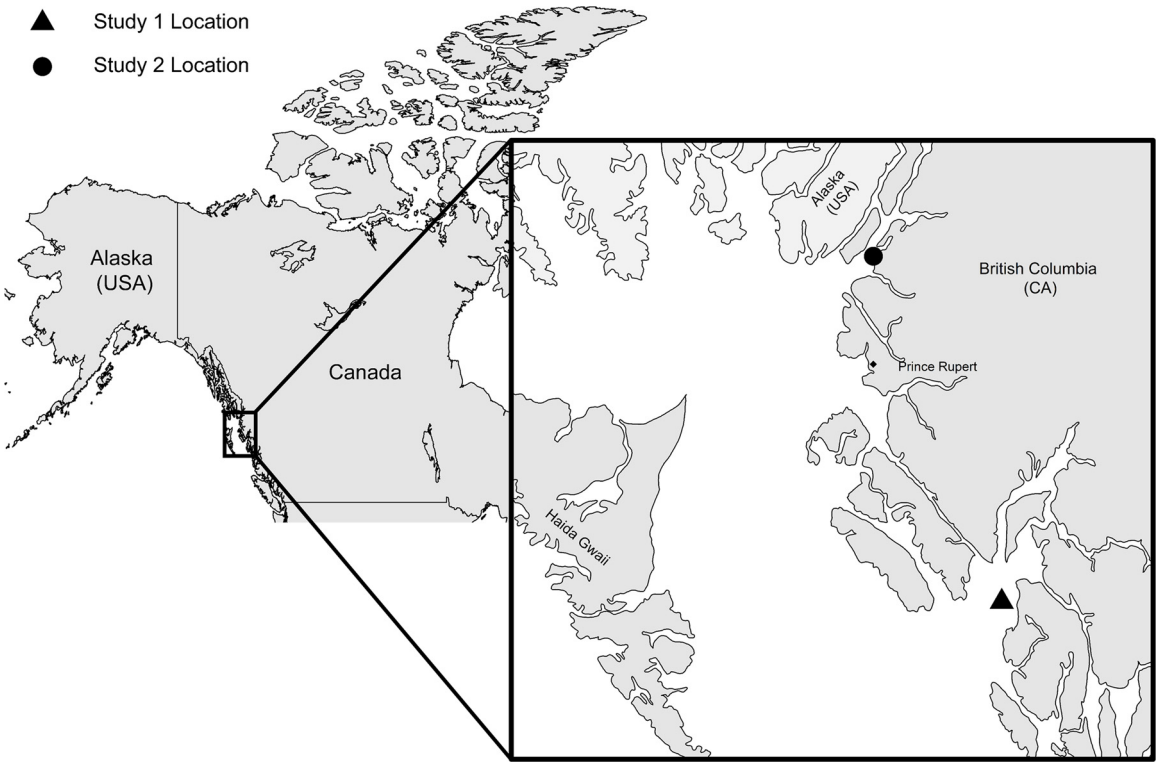

Fig. 1. Map of study locations across two years of research with the purse seine fleet on the northern coast of British Columbia, Canada. The first year of research (Study 1) was conducted on the southern end of the North Coast of BC, and the second year of research (Study 2) near the coastal border with Alaska (USA).

target fish.

Many interacting factors contribute to the magnitude of injury and impairment sustained by non-target fish during capture, especially in commercial operations where capture durations may be protracted. Although many of these factors cannot be changed or controlled, such as the gear encounter itself, others can be avoided or minimized through gear and vessel modifications, or improved fish handling. Specific recommendations regarding aspects of handling are lacking from most commercial fisheries that practice discarding (for exception see Poisson et al., 2014). Subjective recommendations are often given to simply prioritize the return of non-target species to the water by a means that minimizes harm. Although much weight can be placed on human behaviour and willingness to comply, sociological research has revealed greater compliance with suggested best handling practices given clear evidence of their effectiveness (Watson et al., in press; Campbell and Cornwell, 2008).

In British Columbia (BC), Canada, coastal commercial fisheries targeting Pacific salmon (*Oncorhynchus* spp.) capture a mixture of co-migrating species and populations, some that are able to support exploitation and others that are of conservation concern (Shaklee et al., 1999). Those of conservation concern are protected in part by a program of mandatory release. Currently, the conditions of license for fisheries targeting Pacific salmon in Canada indicate that non-target fish are released with 'the least possible harm' [Fisheries and Oceans Canada (DFO), 2017]. However, there remain concerns regarding handling practices in many commercial operations and vague directives leave release practices open to multiple interpretations (Watson et al., in press). There is thus a need for science-based assessments of the specific aspects of the capture process that are most harmful for discarded fish. Moreover, as Pacific salmon fisheries target adults on their homeward migration, captured fish are undergoing dramatic physiological and physical changes in preparation for spawning. The speculation that maturation may confer a certain resiliency to capture stressors also warrants investigation (Raby et al., 2013).

Research was conducted with the purse seine fleet of BC's North Coast. Chum salmon (*O. keta*), commonly discarded from these fisheries, were the focal species. North Coast seine fisheries targeting Pacific salmon are managed as mixed-stock fisheries and encounter broad geographic aggregates of all species. The status of North Coast chum stocks has been a concern in recent years, and therefore commercial fisheries targeting other salmon species typically operate under non-retention provisions for chum (Spilsted and Pestal, 2009). Seine catches are increasingly dominating the proportion of total salmon landings in BC (Haas et al., 2016). Therefore, with large catch volumes relative to other gear types, the number of discards and hence the magnitude of impact to non-target populations, can be high. With few large chum populations in central and northern BC, maintaining abundance and diversity of small populations is critical to maintaining their resiliency (Spilsted and Pestal, 2009).

In an experimental purse seine fishery, we sought to understand the relative effect of various capture stressors on chum salmon bycatch by modifying the severity of standard capture and handling stressors. Through holding studies, we were able to observe latent effects of treatments. Chum salmon have relatively short freshwater migrations. Therefore, the maturity of those encountered in coastal fisheries progresses through the season thereby providing an opportunity to test the effect of maturation status on condition following a fishery interaction. Evaluating injury, reflex impairment, and physiological stress indicators immediately upon capture and observing the progression of injuries in the days following capture, our ultimate objective was to inform best handling practices for salmon incidentally captured in purse seine fisheries.

2. Materials and methods

Data from two years (i.e. 2015 and 2016 fishing seasons) of research with the commercial purse seine fleet of BC are presented. Research was conducted within the northern coastal regions of BC, but locations differed by year. Study 1 was completed in DFO Management Area 6 from Jul-19 to Aug-12, 2015, and Study 2 in DFO Management Area 3