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Review

Looking beyond the mortality of bycatch: sublethal effects of incidental capture on marine animals

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ABSTRACT

There is a widely recognized need to understand and reduce the incidental effects of marine fishing on non-target animals. Previous research on marine bycatch has largely focused on simply quantifying mortality. However, much less is known about the organism-level sublethal effects, including the potential for behavioural alterations, physiological and energetic costs, and associated reductions in feeding, growth, or reproduction (i.e., fitness) which can occur undetected following escape or release from fishing gear. We reviewed the literature and found 133 marine bycatch papers that included sublethal endpoints such as physiological disturbance, behavioural impairment, injury, reflex impairment, and effects on reproduction, feeding, and growth for animals that survived a fisheries interaction. Of the 133 identified articles, 22 documented sublethal effects of capture using metrics directly related to fitness, life history, or population-level processes. Sublethal effects were classified as either short-term (e.g., acute stress response), which could lead to long-term or delayed sublethal outcomes (e.g., growth, reproduction), which are directly fitness-relevant and could have had population-level effects. We recommend further investigation into the effects of injury on fitness, and the effects of capture stress on reproduction. It is completely unknown whether sublethal effects can have significant consequences at the population- or ecosystem-level. To date, the potential for discards to suffer from sublethal fitness effects has been almost entirely ignored, and added knowledge on the topic could benefit both conservation and management.

Contents

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1. Introduction

The catch of non-target animals (bycatch) in small-scale and industrial commercial fisheries has been widely recognized as a leading threat to the conservation of Earth's biodiversity (Gray, 1997; Kappel, 2005; Davies et al., 2009). Particularly over the last two decades, this issue has come to the forefront both in fisheries management (Crowder and Murawski, 1998; Gilman, 2011) and in conservation science (Lewison et al., 2004a; Soykan et al., 2008). From a conservation perspective, a number of globally important issues have been identified whereby populations of key species (often charismatic megafauna) have been affected by fishing activity targeting other species (e.g., Hall, 1998; Tuck et al., 2001; Lewison et al., 2004b). In many marine commercial fisheries, the landed non-target catch is returned to the sea (referred to as discards) because of economic (e.g., lack of market, inefficient economic return), regulatory (e.g., harvest regulations, endangered species legislation), or other (e.g., social pressure, conservation ethic) reasons, often with the hope that some or all of the released animals will recover from the capture stress and survive. Global estimates of marine bycatch and discards have varied considerably (Alverson et al., 1994; Kelleher, 2005), but could be as high as 40% of total catch (38.5 million tonnes of biomass annually; Davies et al., 2009). Global discard rates may be declining, likely owing to technological innovation (e.g., Broadhurst, 2000), and a shift to using previously-discarded species (Kelleher, 2005). However, if a real downward trend in discarding rates does exist, it may be largely attributable to declining overall catches (Zeller and Pauly, 2005). Fisheries bycatch can thus be considered a significant component of the overall issue of overexploitation, which is the primary driver of declining abundance and diversity of life in the oceans (Gray, 1997; Gilman, 2011).

Given the global scope of the problem, considerable resources have been devoted to examining various aspects of bycatch, resulting in over 1000 research papers published in peer-reviewed journals over the last few decades (Soykan et al., 2008; Raby et al., 2011). The majority of research in the realm of bycatch and discards has been conducted from a high level of biological organization, focusing on the quantity of bycatch and discards and then attempting to consider those values relative to overall population size as well as natural mortality. For example, there have been a number of important reports on bycatch rates, both on a broad scale (Alverson et al., 1994; Kelleher, 2005; Harrington et al., 2005; Davies et al., 2009) and in specific contexts (Romanov, 2002; Rogan and Mackey, 2007). Resulting species declines have been documented, highlighting the need for management intervention (Hall, 1998; Tuck et al., 2001; Lewison et al., 2004b; Wallace et al., 2008).

Important as that research is, additional studies aimed at lower levels of biological organization (e.g., organismal) have the potential to add to bycatch management (e.g., Farrell et al., 2001a; Davis, 2010). The organism-level endpoint that is easiest to incorporate into management is whether an animal is dead or alive following a fisheries interaction. Conveniently, mortality (especially immediate mortality at time of landing or haul back) is also relatively easy to observe – at least to the extent that it has regularly been measured in a variety of contexts (e.g., using biotelemetry or net pen holding – see Donaldson et al., 2008; Yergey et al., 2012). While much of the bycatch literature has focused on bycatch rates or immediate mortality, numerous studies have also evaluated the survival of animals (primarily fish) being released from fishing vessels (i.e., post-release or delayed mortality; Kaimmer and Trumble, 1998; Davis, 2002; Parker et al., 2003; Broadhurst et al., 2006; Carruthers et al., 2009; Campana et al., 2009; Benoît et al., 2012). It is now well known that bycatch is often dead when it is discarded or that discards can die after release (Hill and Wassenberg, 2000; Davis, 2002). In cases where it is not possible to avoid bycatch there has been a growing effort to understand the fate of organisms that escape fishing gears or are landed and released alive (Davis, 2002; Ryer et al., 2004; Moyes et al., 2006; Stoner, 2012a, 2012b). In some instances, that research has generated solutions to mortality (e.g., Farrell et al., 2001a, 2001b; Broadhurst et al., 2008, 2009).

Although mortality is the most significant possible impact on fitness, sublethal effects such as stress and injury experienced by captured (or escaped) animals could alter their behaviour, growth, or reproduction, reducing their performance relative to conspecifics. Despite the now-extensive literature on the fate of discards, exceptionally few studies have used sublethal endpoints. Added information on the potential sublethal consequences of capture and release could provide a more holistic understanding of fisheries bycatch as a conservation problem. Fisheries managers are normally concerned with biological parameters beyond mortality. Indeed, changes in growth and reproduction have obvious and direct effects on population dynamics and life-tables. Yet, our understanding of sublethal effects in discards is sparse and in most cases, non-existent. Nevertheless, there has been considerable work describing injury (Kaimmer and Trumble, 1998), vitality and reflex impairment (Davis, 2010; Benoît et al., 2013), and physiological disturbances (Chopin et al., 1996; Farrell et al., 2001a; Marçalo et al., 2006; Renshaw et al., 2012) following capture. Though these "at-release" sublethal metrics have frequently been described, they have seldom been linked to fitness outcomes other than survival.

The primary objective of this review is to synthesize research that looks beyond bycatch mortality and provides information about sublethal outcomes. Special attention was given to sublethal fitness outcomes, here defined as a measure of lifetime reproductive success, as it is through changes in fitness that sublethal effects can have a population-level influence. The second and final objective was to identify gaps and recommend future directions of research. The general layout of the paper is as follows: (i) a summary of results of a literature survey, (ii) a concise review of existing knowledge and case studies, (iii) commentary on research opportunities and approaches, and (iv) summary and conclusions.

2. Literature survey

For the purpose of this review, sublethal effects were defined as any non-lethal physical, physiological, or behavioural consequence that resulted from capture and release or escape from fishing gear. We classified sublethal effects as either short-term (e.g., injury or acute stress response) or delayed (e.g., growth, reproduction; Fig. 1). For simplicity, the focus of this study was marine commercial fisheries. We certainly recognize that bycatch occurs in freshwater fisheries (see Raby et al., 2011), but there are very few papers that examine sublethal outcomes (e.g., Colotelo et al., 2012). In recreational fisheries, the failure to demonstrably link capture stress with sublethal fitness measures has been a persistent challenge to translating research into management action (Cooke et al., 2013). Although we explicitly exclude freshwater and recreational fishing from this review, the principles and research trends described below are generally transferrable to those sectors, as has been advocated by Cooke and Cowx (2006).

To gather all research papers relevant to the sublethal effects of capture, we conducted a literature search ending 30/04/13 using a two-step process. The first step used a variety of search term combinations (fish*, discard*, capture*, stress, capture stress, injury, impair*, escap*, gear, encounter, bycatch, bird, mammal, turtle, invertebrate, response, physiology, sublethal) in ISI Web of Science and Google Scholar to generate a comprehensive list of >600 studies