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Fishing-effort response dynamics in fisheries for short-lived invertebrates

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ABSTRACT

In complex dynamic systems like fisheries, recognizing fishing-effort responses is as critical as understanding the biology of the exploited species for making sensible management decisions. In highly seasonal fisheries, it is theoretically possible for an “interannual bionomic equilibrium” to develop under open-access, where fleet dynamics may result in balanced year-to-year harvesting due to decreasing income per time fishing as biomass declines, without endangering the sustainability of the stock. However, in some conditions, this interannual bionomic equilibrium can be pathologically low leading to overfishing and amplification of extinction risks. Here we draw three cases from short-lived and fast-growing invertebrate fisheries to illustrate two distinct effort response dynamics: (a) fishing-effort responses that lead to healthy interannual bionomic equilibrium; and (b) fishing-effort responses in which fishing remains profitable over the entire season, hence, allowing fishing fleets to maintain a high fishing-effort throughout the season. Analyzing long-term within-year catch and effort data, we found that both Gulf of Mexico shrimp and North Territory giant crab fisheries are likely currently at healthy interannual bionomic equilibria, while certain socioeconomic drivers enable the Kuwait shrimp fishery to maintain high effort through the entire shrimping season. Our findings suggest that input controls are less effective in short-lived invertebrate fisheries that exhibit fishing-effort proportional to declining stock abundance. Conversely, if not regulated, the abundance-insensitive fishing-effort response could pose biological risks and habitat destruction. Therefore, we emphasize that in common-property seasonal fisheries, fishing-effort responses be scrutinized to distinguish factors that might undermine resource sustainability.

1. Introduction

Invertebrate fisheries have been rapidly growing over the past four decades due to their increasing socioeconomic significance (Berkes et al., 2006; Sethi et al., 2010). Short-lived invertebrates such as shrimps, crabs, and squids, exhibit striking seasonal rhythm of abundance due to their high growth and natural mortality; as a result, highly seasonal fisheries arise from harvesting a single or double recruiting cohorts each year (e.g., Basson et al., 1996; Hay and Calogeras, 2000; Dichmont et al., 2003; McAllister et al., 2004; Diamond, 2005; Chen et al., 2007). However, such life-history characteristics, in addition to challenges in the aging process, have rendered most invertebrate fisheries poorly assessed and unregulated (Anderson et al., 2011; Punt et al., 2013).

Understanding the interaction between fishing-effort and species in the linked fisher/fish system has been emphasized by many studies (Wilen, 1979; Hilborn, 1985; Mackinson et al., 1997; Branch et al., 2006). Such recognition is key for an effective fisheries management: at least some fisheries regulations directly influence the dynamics of fishing-effort rather than fish stocks. Consequently, ignoring these response dynamics will lead to bad predictions as surely as misunderstandings about the biology of the species. Central to the topic of seasonal effort responses is the concept of interannual bionomic equilibrium: absent management intervention, fleet dynamics may result in balanced year-to-year harvesting due to decreasing income per time fishing as biomass declines, without endangering the sustainability of the stock. Under certain circumstances, however, this equilibrium can be at a pathologically low stock size, notably when harvest removal become either independent of the stock size, or too high at all stock sizes. Such pattern is typically observed under three circumstances. First, market demand can drive the fishery to exert high efforts even when the stock is small; in this case, the payoff rate is expected to be higher than the cost of the entire fishing operation even at very low catch rates (see Wooster (1992) for the infamous case of the red king crab). Second, in a multi-species fishery where the incidental capture of a given stock suffers from a fishing-effort level that is independent of

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the stock size (e.g., the incidental catch of billfish in the longline tuna and swordfish fisheries as reported by Graves et al., 2002). This case is exacerbated when the incidental capture occurs at a higher rate than the stock can withstand, causing severe stock size declines. The third circumstance involves the life-history characteristics of the harvested stock, particularly, the aggregation behavior either for spawning (e.g., cod) or other purposes such as defense (e.g., herring). As these fish stocks are depleted, they show a behavior known as range collapse; that is, their geographical distribution contracts (Walters and Maguire, 1996; Mackinson et al., 1997; Burgess et al., 2017). In this situation, fishers can still catch the same amount of fish even if the stock size is severely reduced, without a significant change in the amount of fishing-effort (or fishing cost).

There is limited information in the literature about the topic of fishing-effort response dynamics for short-lived invertebrate fisheries. Yet, it has been observed that the effort dynamics in, at least, some of these kinds of fisheries are consistent with, i.e., should result in, an interannual bionomic equilibrium. For instance, Walters and Martell (2004) used Australia's shrimp and rock lobster fisheries to demonstrate that those fisheries are essentially self-regulated (i.e., the harvesting activity responds smoothly to changes in stock sizes and harvest costs), so that effort ends up being far lower than the limits imposed by input regulatory measures (license limitation, seasonal closures). However, Walters and Martell (2004) emphasized that: (a) latent effort, or the difference between potential and realized effort, could undermine the resource sustainability whenever it is economically viable; and (b) input measures assist in stabilizing the interannual bionomic equilibrium. Further examples are given here by examining the Gulf of Mexico (GOM) shrimp fishery and the North Territory Gulf of Carpentaria (NT) giant mud crab fishery. Also, we investigate the Kuwait shrimp fishery to demonstrate a case where fishing-effort is persistently high over the season due to certain socioeconomic drivers that generate a lack of feedback between fishing-effort and stock abundance. First, we provide a brief description of each fishery. Then, we present the main findings and delve into the discussion of the results and implications for management.

2. Description of the fisheries

2.1. Gulf of Mexico shrimp fishery

Trawling for shrimp started in 1917 off Louisiana State, where the catches increased from 15,000 tonnes in 1918 to a maximum of 130,000 tonnes in 1986 (Diamond, 2005). In 2015, shrimp landings amounted to 89,000 tonnes with a total value of $340 million, forming one of the most valuable fisheries in the United States (NMFS, 2015). The fishery mainly exploits three shrimp species: the brown shrimp (*Farfantepenaeus aztecus*), which represents the main species; the white shrimp (*Litopenaeus setiferus*); and the pink shrimp (*Farfantepenaeus duorarum*). The GOM shrimp fishery is regulated with a suite of input controls including limited licenses and several license buybacks in the Texas fishery, gear restrictions, seasonal closures and inshore-offshore designations and mandated bycatch reductions devices and turtle excluders.

2.2. Northern Territory giant mud crab fishery

The giant mud crab (*Scylla serrata*) is the most common crab species caught in the NT waters (Hay and Calogeras, 2000). This fishery started in the early 1980s and both catch and effort built to a peak in the late 1990s, but recently showed declining trends that have raised suspicions about the status of the stock. Several fisheries are involved in exploiting the giant mud crab stock including recreational, indigenous and commercial sectors, but the commercial fishery harvests about 90–95% of the total catch using traps as the sole fishing gear (Grubert et al., 2013). Consequently, catch and effort statistics are primarily collected from the commercial fishery. The giant mud crab fishery is managed by the implementation of a suite of input measures such as restrictions from catching newly-molted mud crabs, minimum sizes, and fishing licenses. The fishing season is divided into wet season (April–October) and dry season (November–March), with the highest catches occurring between March and June (Meynecke et al., 2012).

2.3. Kuwait shrimp fishery

The exploitation of Kuwait shrimp started fifty years ago when several industrial trawlers were transferred from the U.S. Gulf of Mexico to Kuwait (Kristjonsson, 1967). Currently, the shrimp fishery is considered the most valuable fishery in Kuwait, accounting for 35% of the total landed yearly value (Al-Husaini et al., 2015). The fishery is supported by government subsidies and characterized by cheap labor wages and low fuel prices. Furthermore, an important demographic aspect of Kuwait shrimp fishery is that all shrimp fishers are foreigners, and by law, they can't own ships and must have a Kuwaiti sponsor. A direct consequence of such law is that very often ship owners demand a fixed payment from the fishers at the end of the shrimping season.

Historically, Kuwait shrimp fishery experienced rapid growth in fishing-effort attracted by high yields, reaching a peak of about 5000 tonnes in the late 1980s. Since the Gulf War to the present, the shrimp fishery is undergoing a constant fishing-effort increase while maintaining an average shrimp production of around 2000 tonnes (Al-Husaini et al., 2015). The shrimping season starts in August where fishing fleets are only allowed to fish in international waters. In September, the fishing fleets are permitted to start fishing in Kuwait's territorial waters. The most abundant and sought-after penaeid species in Kuwait is the tiger shrimp (*Penaeus semisulcatus*) with an average contribution of 60% to the overall annual catch. Therefore, the management of the shrimp fishery is based on the biology of *P. semisulcatus* (Bishop et al., 2001).

Before 1979, Kuwait's shrimp fishery lacked basic regulations such as seasonal closures. However, given the increasing commercial importance of the shrimp fishery, several input controls have since been imposed to buffer against overexploitation including fishing licenses (without entry limits), seasonal closures (5–7 months) and closed areas (3 miles away from shore). Yet, factors such as fleet overcapacity and absence of enforcement have contributed to unsustainable declines in stock biomass (Chen et al., 2007; Al-Husaini et al., 2015).

3. Material and methods

We used monthly catch and effort data to examine how within-year efforts respond to changes in stock abundance during fishing seasons (Table 1). To reconstruct the biomass trends for GOM shrimp, NT giant mud crab and Kuwait shrimp stocks, we applied a seasonal age-structured (monthly ages) model while assuming an age-vulnerability schedule and fishing mortality rate proportional to fishing-effort (using

Table 1
Data used in the analysis of fishing-effort response dynamics for Gulf of Mexico (GOM) shrimp fishery, Northern Territory (NT) giant mud crab fishery and Kuwait shrimp fishery.

Fishery	Data type (unit)	Data time-series	Data time-step	Data source
GOM shrimp fishery	Catch rate (ton/days)	1960–2006	Monthly	Louton, (thesis in prep.)
NT giant mud crab fishery	Catch rate (kg/potlifts)	1983–2010	Monthly	Grubert et al. (2013)
Kuwait shrimp fishery	Catch rate (ton/boat-days)	1991–2012	Monthly	Al-Foudari et al. (2015)