The Bioeconomic Paradox of the Commercial Lionfish Fishery

La Paradoja Bioeconómica de la Pesquería Comercial de Pez León

Le Paradoxe Bioéconomique de la Pêche Commerciale du Poisson-lion

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EXTENDED ABSTRACT

INTRODUCTION

Market-based harvest of invasive species offers a compelling approach to control their abundances and mitigate impacts without using public resources. Historic examples of highly abundant species driven to collapse or extinction—e.g., North Atlantic cod or passenger pigeon—suggest that extirpating valuable species should be attainable. Under this theme, fisheries for invasive lionfish (*Pterois volitans/miles complex*) have been promoted as a market-based solution to reduce lionfish densities and mitigate their ecological impacts (Morris et al., 2012). Ex-vessel price of lionfish in the USA is approximately \$10–\$14 per kg (\$4.50–\$6.50 per pound) and similar to high-value reef fishes such as snappers and groupers. Bioeconomic theory shows that, in the absence of collectively-agreed-upon or mandated harvest control rules, unregulated harvest will escalate until profits are zero at the open access equilibrium (OAE). This higher level of effort can reduce the stock biomass of the population below that which supports production of maximum sustainable yield (MSY). In contrast to traditional fisheries management, the societal objective for commercialized invasive species harvest like lionfish will be to control the population for ecological benefits. If demand can be generated and sustained, then an unmanaged fishery would be expected to operate at the OAE solution without any public interference. However, it is not guaranteed that such a fishery will develop, be economically sustainable, nor achieve its desired ecological benefits.

The recently developed commercial fishery for invasive lionfish in the northern Gulf of Mexico (nGOM) provides a bioeconomic case study to examine market-based invasive species control. We examined whether open access equilibrium (OAE) commercial harvest will be high enough to control an invasive species, and, if not, what types and how much additional support may be necessary. To do so, we quantified biological and economic characteristics of the nGOM lionfish spearfishing fishery with a variety of approaches and data sources. We then used these parameters to estimate equilibrium reference point solutions for OAE and MSY and conduct time-dynamic simulations of the fishery.

METHODS

Bioeconomic models were developed for the purposes of finding equilibrium solutions and producing time-dynamic simulations. Equilibrium solutions at OAE were computed for stock size, effort, and yield. MSY solutions were also computed for reference. Time-dynamic simulations were developed to consider whether the fishery would converge towards an equilibrium, which were developed with recursive differential equations to model iterative changes in the stock and effort where effort responds to annual profit (Conrad, 1999). Both of these approaches use two, coupled production models: first, biomass (X) production as a function of the population's intrinsic population growth rate (r) and environmental carrying capacity (K) and, second, harvest production (or yield, Y) as a function of fishing effort. Two alternative methodologies were used to estimate the key growth parameter of r for biological production. First, population net growth models were fit to a timeseries of lionfish density estimates collected from remote operated vehicle surveys (Harris et al., 2019) with two different endpoints. Second, demographic models were used to estimate r with age-structured vectors of lionfish survival and fecundity (McAllister et al., 2001). Parameters for the harvest production model were estimated by fitting to commercial spearfishing landings data of annual yield and effort. Collectively, we modeled a range of alternative scenarios with four different estimates for r and two levels of stiffness of harvester response to profits (for the time-dynamic models). We also modeled alternative economic scenarios for different values for the price of lionfish and values of cost per unit effort.

Generalized results, discussion, and recommendations

Our bioeconomic models indicated nGOM lionfish populations are robust to fishing pressure under a variety of scenarios. A profitable and economically sustainable fishery was predicted; however, more removal effort than what would be predicted under the current free-market conditions may be necessary to impart significant declines in the regional biomass.

To reach Y_{OAE}, current yield would need to increase approximately 4× and effort by approximately 8× than the peak levels observed in 2017. Given status quo conditions, the equilibrium model estimated that Y_{OAE} would be close to but still less than Y_{MSY}. This yield was predicted reduce the stock size by approximately half of K. These estimates appear consistent with other lionfish population models (Bogdanoff et al., 2020; Chagaris et al., 2017).

Not all of our time-dynamic simulations reached equilibrium. Scenarios where price was increase and stiffness was also high often projected cyclical boom-bust fisheries whereby high levels of yield would crash stock biomass; subsequently effort would decline and biomass would recover to repeat the cycle. In the scenarios where yield was high enough to nearly collapsed the stock biomass, stock biomass levels were always predicted to recover with dynamics similar to the initial invasion absent any changes to the ecosystem that might increase biological resistance. Such a rebound seems reasonable given that immigration and larval replenishment from metapopulations should prevent extinction and allow for repopulation.

Alternative scenario modeling indicated that more favorable economic conditions (i.e., lower fishing costs and/or higher ex-vessel prices) would incentivize harvest efforts and could reduce X_{OAE} to below X_{MSY}. To do so required increasing effort that resulted in diminishing returns—and ultimately declines—in lionfish yield. Although this would be economically inefficient for traditional fisheries, it represents a viable management objective (or rather, a lack of management via harvest controls) to reduce invasive species biomass and encourage harvester engagement (e.g., potentially more fishers harvesting lionfish).

Inferences from these models should remember that our assumptions and data limitations likely impact the reliability of our predictions and preclude the ability to set tactical targets. The retrospective accuracy our forecasts may largely depend on what levels the lionfish stock stabilizes—or whether it stabilizes at all—following their 2018 density declines (Harris et al., 2020). Some recovery in nGOM lionfish recruitment levels observed in late 2018 suggests lionfish populations have begun to rebound, but it is unknown whether densities will return to previous levels and also whether such natural population cycles may be isolated or recurrent events.

Invasive species managers are unavoidably forced to make rapid decisions with imperfect information that balance the potential for long-lasting damages of an invasive species versus the costs and possible unforeseen impacts of control efforts (Strayer et al., 2006). Our models have forecasting limitations for tactical management, particularly for the time-dynamic models, but may offer valuable strategic advice to how much investment is warranted to support control efforts. Efforts to explicitly parameterize and examine the bioeconomics of commercialized invasive species management can help set objective targets, test assumptions (or at least make them explicit), consider ecological-economic feedbacks, assess costs and benefits for policies (e.g., publicly-funded programs), and provide quantifiable metrics for adaptive management.

KEYWORDS: Lionfish, Bioecomics, Population modelling, Invasive species, Fisheries management

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