Title
Controlling Marine Invasive Species: The case of the Indo-Pacific Lionfish Invasion in the Southeast U.S. and Caribbean

Authors
Kling, David M
James, Sanchirico N

Publication Date
2014-05-16

California Sea Grant College Program
Progress Report

Project Information

Year
Number E/MRE-6
Grant No.: NA11OAR4170179
Start Date: 6/1/2011 **Completion Date:** 5/31/2013
Title Controlling Marine Invasive Species: The case of the Indo-Pacific Lionfish Invasion in the Southeast U.S. and Caribbean

Project Leader

Last Kling First David **Init** M
Institution University of California, Davis
Department Agricultural and Resource Economics
Address 2210 I Street, Apt 11C
City Sacramento State CA Zip 95816
Phone 530-902-7154 Fax 530-752-5614
Email kling@primal.ucdavis.edu
Position Title Ph.D. Candidate

Project Leader

Sanchirico James N
Professor
University of California, Davis
Environmental Science and Policy
University of California, Davis
Davis CA 95616
530-754-9883
jsanchirico@ucdavis.edu

Project Hypothesis

Our hypothesis is that modeling features common to marine biological invasions, like the ability of the invader to disperse over long distances, will call for invasive Indo-Pacific lionfish (Pterois volitans and P. miles) control policies that diverge from those that are efficient based on models geared towards terrestrial and freshwater species, and that these differences will be economically significant.

Project Goals and Objectives

Invasive Indo-Pacific lionfish have spread rapidly along the southeast coast of the United States and into parts of the Caribbean and Latin America, and are currently expanding into the Gulf of Mexico (Schofield 2010). Lionfish prey intensively on native marine life and pose a significant threat to coral reef systems, including those within the Florida Keys National Marine Sanctuary, as well as commercially important species assemblages like the snapper-grouper complex (Morris and Whitfield 2009). Despite the threat posed to marine resources and biodiversity by lionfish and other established marine invasive species (Carlton 2001), there has been little work done on the economics of their control. In order to fill this gap, we will construct a fully-calibrated bioeconomic model of optimal lionfish management. Using the calibrated model, we will synthesize optimal management strategies for the species. We will then extend the analysis to consider second-best policies that are currently being implemented in marine invasive species management and use the resulting framework to recommend control options for lionfish in the southeast United States and the Caribbean. In addition to providing guidance for managers confronting the lionfish invasion, the formal modeling and empirical analysis we will complete as part of this project will serve as a test of our project hypothesis.

Briefly describe project methodology

Following the order of our project objectives, our work will proceed in two phases. The initial phase will focus on designing a deterministic spatial-dynamic bioeconomic model of local invasion control in which the invader disperses over long distances. This latter assumption is appropriate for the lionfish, which spreads widely via ocean currents in its larval state and exhibits high site fidelity after recruitment (Jud and Layman 2012; Ahrenholz and Morris 2010). By focusing on local management, we will be able to investigate the optimal spatial pattern of control over time when lionfish density causes relatively more damage in certain locations (e.g., within a marine protected area) and lionfish larvae flow into the system from other locations not subject to control. This local focus is especially relevant given recent findings that significant region-wide lionfish control is unlikely to be technically feasible (Barbour et al. 2011; Morris et al. 2011).

Our point of departure will be existing mathematical representations of invasion spread (Epanchin-Niell and Hastings 2010). We will also draw on the growing applied economic literature that addresses the spatial dimension of biophysical processes (Smith et al. 2009). Spatial-dynamic models have been developed to address a number of marine resource policy questions, including marine reserve design (Sanchirico and Wilen 2001). Contingent on model tractability considerations, we will investigate incorporating additional biological structure representing other features of lionfish life-history that may provide additional insights into cost-effective control beyond those that we uncover using a standard biomass model benchmark (e.g. Morris et al. 2011). For example, Tahvonen (2008) shows in a theoretical analysis that harvesting rules based on a biomass model may lead to unexpected outcomes due to neglected age structure in the exploited population.

We will parameterize the model using data on lionfish biology, spatial distribution, and information on the ecology and oceanography of the southeast U.S. shelf and the Caribbean. Data on the lionfish will be acquired from published sources and from NOAA agencies including the NCCOS Center for Fisheries and Habitat Research, the lead group within NOAA working on the lionfish invasion. We will then map data to model parameters through either direct calibration (DeJong and Dave 2007) or bioeconometric methods (Smith 2008). Once we have exhausted avenues for exploring the dynamics of the optimal control strategy analytically, we will turn to numerical dynamic optimization methods to gain additional insights (Judd 1998).

Describe progress and accomplishments toward meeting goals and objectives.

We completed work on the first phase of the project: the design of a deterministic spatial-dynamic bioeconomic model of local invasion control. Preliminary results from this modeling work were presented at last year's NMFS/Sea Grant fellows meeting. Results from the first phase model were also used to structure our discussions with lionfish experts. In May 2012, David Kling traveled to Miami where he worked with his NMFS adviser at the SEFSC (Dr. Juan Agar) and also held meetings with lionfish researchers, resource managers, and NGO personnel active in lionfish control programs and public outreach.

Building on information obtained from our consultation with lionfish experts, we completed work on the second phase of the project. In a current working paper, we consider the problem of a resource manager who seeks to minimize the present value of both invasion damage and management costs using two controls: lionfish removal effort and monitoring. We account for the manager's imperfect knowledge of local lionfish abundance by posing the control problem as a continuous-state partially observable Markov decision process (POMDP). Using a newly available approximate numerical solution method, we characterize efficient lionfish management under a range of economic and biological conditions. We find that early monitoring helps the manager limit the impact of the invasion. The importance of monitoring increases with greater process volatility. We provide results for a spatial system that illustrate the roles of population connectivity and spatial heterogeneity in determining the efficient targeting of lionfish removal effort across space. Our study also considers the problem of native species bycatch (unintentional capture of non-target species) arising from lionfish removal. We identify scenarios where tolerating some native species bycatch is worthwhile in order to suppress lionfish numbers.

David Kling presented the second phase work in several academic venues, including Oregon State University (Department of Agricultural & Resource Economics), University of Delaware (Marine Policy Program), the University of Maryland (Department of Agricultural & Resource Economics), and the University of Connecticut (Department of Economics). A version of the working paper was presented at the 2013 North American Association of Fisheries Economists (NAAFE) Forum. At the NAAFE Forum, David Kling was recognized with the Association's Best Student Paper Award (for the second phase research).

The second phase research will be the leading essay of David Kling's dissertation, due to be completed this August. We anticipate submitting the second phase research to an academic journal within the next 3-6 months.

PROJECT MODIFICATIONS: Explain briefly any substantial modifications in research plans, including new directions pursued and ancillary research topics developed. Describe major problems encountered and how they were resolved.

We made no modifications to this project.

PROJECT OUTCOMES: Briefly describe data, databases, physical collections, intellectual property, models, instruments, equipment,

techniques, etc., developed as a result of this project and how they are being shared.

IMPACTS OF PROJECT: Briefly describe how this project has contributed to a discipline; to developing human resources; to developing physical, institutional or information resources; technology transfer; and society beyond science and technology. Please notify CASG of impacts that occur after your project ends; CASG may contact you after your project ends to learn about additional impacts that occur over time.

BENEFITS, COMMERCIALIZATION, AND APPLICATION OF PROJECT RESULTS: Please list any companies, agencies, organizations or individuals who have used your project results, scientific/technical advice, etc., and provide names, emails and phone numbers. Briefly describe how results were used and quantify results and socioeconomic benefits, if possible.

ECONOMIC BENEFITS generated by discovery, exploration and development of new, sustainable coastal, ocean and aquatic resources (i.e., aquaculture, marine natural products, foods, pharmaceuticals).

Issue-based **forecast capabilities** to predict the impacts of a single ecosystem stressor, developed and used for management (i.e., climate change, extreme natural events, pollution, invasive species, and land resource use).

Tools, technologies and **information services** developed (i.e., land cover data, benthic habitat maps, environmental sensitivity index maps, remove sensing, biosensors, AUVs, genetic markers, technical assistance, educational materials, curricula, training).

Publications (list in appropriate category below) Each listing should be a stand-alone bibliographic reference, including all authors' names. For each Publication type, specify title, authors, date and journal details, where appropriate (repeat headers as necessary).

Technical Reports

Title	Authors	Date

Conference Papers, Proceedings, Symposia

Peer-reviewed journal articles or book chapters

Non-peer Reviewed Reprints

Publications, Brochures, Fact Sheets

Books & Monographs

Handbooks, Manuals, Guides

Electronic publications: (non-print formats).

Maps, Charts, Atlases

Theses, dissertations

Newsletters, periodicals

Program reports (annual/biennial, strategic plans, implementation plans)

Educational Documents

Topical Websites and Blogs

Miscellaneous documents (not listed above).

MEDIA COVERAGE: Select 'Yes' or 'No'. If yes, describe any radio, TV, web site, newspaper, magazine coverage your project has received. Send original clippings or photocopies to the Sea Grant Communications Office.

MEDIA NOTES: Brief description of the type media coverage your project has received.

DISSEMINATION OF RESULTS: List any other ways in which results of your project have been disseminated. Indicate targeted audiences, location, date and method.

WORKSHOPS AND PRESENTATIONS: A brief description of location, date, time, topic, number of attendees and name of presenter.

Location: Oregon State University, Corvallis, Oregon; Date: November 26, 2012; Time: 12:00 - 1:30 PM; Title: Taming the lionfish; Topic: A spatial-dynamic bioeconomic model of local lionfish control under imperfect information; Presenter: David Kling; /// Location: ASSA annual meeting, San Diego, California; Date: January 4, 2013; Time: 8:00 AM - 8:30 AM; Title: Taming the lionfish; Topic: A spatial-dynamic bioeconomic model of local lionfish control under imperfect information; Presenter: David Kling; /// Location: University of Connecticut, Storrs, Connecticut; Date: January 14, 2013; Time: 3:30 PM - 5:00 PM; Title: Taming the lionfish; Topic: A spatial-dynamic bioeconomic model of local lionfish control under imperfect information; Presenter: David Kling; /// Location: University of Delaware, Newark, Delaware; Date: January 24, 2013; Time: 3:00 PM - 4:30 PM; Title: Taming the lionfish; Topic: A spatial-dynamic bioeconomic model of local lionfish control under imperfect information; Presenter: David Kling; /// Location: University of Maryland, College Park, Maryland; Date: January 28, 2013; Time: 3:30 PM - 5:00 PM; Title: Taming the lionfish; Topic: A spatial-dynamic bioeconomic model of local lionfish control under imperfect information; Presenter: David Kling /// Location: 2013 NAAFE Forum. St. Petersburg, Florida; Date: May 22, 2013; Time: 2:10 PM - 2:30 PM; Title: Taming the lionfish; Topic: A spatial-dynamic bioeconomic model of local lionfish control under imperfect information; Presenter: David Kling

COOPERATING ORGANIZATIONS: List those (e.g., county or state agencies, etc.) who provided financial, technical or other assistance to your project since its inception. Describe the nature of their cooperation.

Federal Organizations

Regional Organizations

State Organizations

Nongovernment Organizations

International Organizations

Industry Organizations

Academic Organizations

Sea Grant Organizations

Other Organizations

INTERNATIONAL IMPLICATIONS: Does your project involve any colleagues overseas or have international implications?

The lionfish invasion is a growing threat to native marine life throughout the Caribbean, Western North Atlantic, and Gulf of Mexico. This research has implications for the design and implementation of local-scale lionfish suppression programs in other affected countries. Our results should be of interest to resource managers in both the United States and abroad.

AWARDS: List any special awards or honors that you, or any co-project leaders, have received during the duration of this project.

2013 NAAFE Forum Best Student Paper Award (David Kling)

KEYWORDS: List keywords that will be useful in indexing your project.

invasive species; bioeconomic; lionfish; partially observable Markov decision process; approximation methods

PATENTS: Please list any patents or patent licenses that have resulted from this project, and complete the patent statement form available on the web site.

NOTES: Please list any additional information in the notes area

FOR ALL STUDENTS SUPPORTED BY THIS GRANT, PLEASE LIST:

Volunteer Count

Graduate Student Info