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Tropical cyclones, derelict traps, and the future of the Florida Keys commercial spiny lobster fishery

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ABSTRACT

Derelict commercial spiny lobster (*Panulirus argus*) traps may move hundreds of meters during high wind events, resulting in tissue abrasion, breakage, and often complete removal of critical habitat elements such as seagrass, sponge, and coral. Ghost traps continue to confine lobsters, often resulting in mortality. The legacy of trap debris in the Florida Keys (USA) combined with possible increased inputs of trap debris resulting from tropical cyclone intensification presents an immediate challenge for this fishery where social, economic, and ecological vulnerabilities to disturbance are intrinsically linked. Here, predictions of percent monthly trap loss in relation to maximum wind speed (km/h) under three scenarios of tropical cyclone intensification were evaluated across four levels of fishing effort (number of traps used). Across all tropical cyclone scenarios, *Historical* fishing effort (986,000 traps) produced the greatest number of lost traps, followed in decreasing order by *Existing* (479,000), *Target* (400,000), and *Maximum Economic Yield* (*MEY;* 180,000) efforts. Under a *Business-as-Usual* scenario of intensification, converting from *Existing* fishing effort to *MEY* reduced trap loss by over 62%. The scenarios suggest that were *Existing* fishing effort to be maintained in the coming decades, tropical cyclone-related trap loss could exceed 11 million over 60 years depending upon the rate of storm intensification. Existing programs for derelict trap removal cannot currently keep pace with accumulation; consequently, the proximal source of trap debris is increasing in the environment. The net increase in derelict traps and debris generated from their degradation will only be exacerbated under potential tropical cyclone intensification. This study underscores the need for using scenarios for future exploration of these issues, particularly incorporation of fisher responses to changes in climatic, economic, and management drivers (i.e., storms, market demand, gear reduction) that may affect trap deployment patterns.

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1. Introduction

Climate change may alter or interact with existing disturbance regimes in ways that exacerbate or mediate disturbance effects in ecosystems [1]. Coastal fisheries in particular are climate-sensitive systems where social, ecological, and economic vulnerabilities to disturbance are intrinsically linked [2,3,4]. Many coastal fisheries are susceptible to tropical cyclones (e.g., tropical storms, hurricanes), the impacts of which may be amplified under a changing climate where storm intensification is predicted [5,6,7,8]. Storms may affect resource population dynamics, resource availability, and the environment through changes in species distributions, seasonality of production, or habitat damage while simultaneously disrupting fisheries directly as a consequence of lost sea (fishing) days, shore-based infrastructure damage/loss, or elevated gear damage/loss [9,10]. Gear loss is recognized as a traditional stressor in coastal ecosystems. However, proposed adaptation options for fishery resilience to climate change often ignore potential interactions between increased storm activity, derelict fishing gear generation, and subsequent accumulation and impacts [11,12].

The commercial spiny lobster (*Panulirus argus*) trap fishery in the Florida Keys (Monroe County, Florida, USA) is a climate-sensitive fishery and is responsible for approximately 90% of the State's commercial lobster harvest. Fishing effort peaked at more than 900,000 traps in the early 1990s and was implicated in contributing to undue mortality of sublegal-sized lobsters, declining trap yields, navigation issues, conflict on the water, and pollution which led to the implementation of the of the Spiny Lobster Trap Certificate Program (LTC; Florida Statute 370.142) in 1993 [13,14]. The LTC is a market-based, transferable reduction

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program, established to create stability in the fishery by reducing the total number of traps while potentially increasing yield per trap. Although annual trap reduction rates were established under the LTC, they have been repeatedly amended over the years and a target reduction goal was not established until 2005 (400,000 traps; Florida Administrative Code R. 68B-24.009). Currently, the number of traps is reduced by approximately 0.3% each year which has delayed progress toward meeting the target reduction goal. Under the current reduction rate, the target goal would not be reached until the year 2045 [T. Matthews, Florida Fish and Wildlife Conservation Commission (FWC), personal communication].

In recent years, the number of traps permitted in the Monroe County fishery has averaged 479,000 per season. Of the total traps fished, fishermen report monthly trap losses of 2-5% over the eight-month season (August 6 to March 31) in seasons without tropical cyclones, as a result of buoy line cutoffs vandalism/theft, entanglement on the bottom, the inability to find deployed traps (i.e., GPS failure), and trap degradation [FWC Commercial Lobster Fisherman Questionnaire data, http://myfwc.com/research/saltwater/crustaceans/lobster/fishery/overview/]. Gear loss is greatly exacerbated when strong winter storms or tropical cyclones occur (19–65% seasonal loss; FWC Commercial Lobster Fisherman Questionnaire data, http://myfwc.com/research/saltwater/crustaceans/lobster/fishery/overview/). Recent estimates by Uhrin and others [15] suggest a trap debris legacy upwards of one million derelict traps residing on the seafloor of the Florida Keys, within the boundaries of the Florida Keys National Marine Sanctuary, which they conclude was likely an underestimation of the number of traps lost or intentionally disposed of during the over 50-year history of this commercial trap fishery [16,17].

When derelict traps remain intact, they have the capacity to ghost fish, i.e. they can continue to confine animals, often resulting in mortality [18,19,20]. Recent estimates by Butler and Matthews [21] suggest that ghost traps kill 637,622 lobsters in the Florida Keys each year but the contribution of these losses to changes in lobster population dynamics is unknown. In addition, derelict lobster traps cause damage to benthic habitats (e.g., seagrass beds, coral reefs) by smothering or colliding with these habitats, reducing above-ground biomass, disrupting below-ground components, abrading tissue, and breaking or denuding foundation species [22,23,24,25]. When individual traps move during high winds, the area affected is often greater than the trap's immediate footprint and can encompass several square meters [23,25]. Whether these damages translate to changes in the population- and community-level dynamics of these foundation species is unknown.

Although confidence in projections of Atlantic basin tropical cyclone frequency and intensity over the coming decades remains low [5,7] there is some model consensus that hurricane intensity will increase [5,6,7,8]. Basin-wide, the number of tropical cyclones that mature into major storms (Category 3 or greater) is influenced by the Atlantic Multidecadal Oscillation (AMO; long-duration fluctuations in North Atlantic sea surface temperature) as well as variability in the strength of Atlantic thermohaline circulation [26]. More tropical cyclones advance to major storm status during warm phases of the AMO than during cool phases [26]. Major hurricane strikes in Florida also align with the observed AMO. In a warm phase, roughly three major hurricanes make landfall in Florida per decade versus just shy of one per decade (0.8) during a cool phase [27]. According to a survey of tropical cyclone activity from 1851 to 2010, 40% of all hurricanes impacting the United States strike Florida [28] with 85% of storms occurring in the three months from August through October [6] which directly coincides with the spiny lobster fishing season. In Monroe County, 26 hurricanes have made landfall since 1926, the greatest total for any county in the United States.

Scenario planning has emerged as an effective decision-making tool when faced with unpredictable and uncontrollable futures [29,30,31]. Scenario studies describe a range of possible future states often while incorporating the uncertainty inherent in social-ecological systems [31]. Scenarios have been used to describe the implications of uncertain future tropical cyclone activity in Florida but focused on economic impacts and personal property damage/loss estimates [32,33]. Overlap between peak spiny lobster fishing effort and peak hurricane season in this region [34] creates the potential for the generation of large amounts of derelict lobster traps and associated debris [23,25]. The detrimental effects of ghost traps and the damage caused by derelict trap movement presents an immediate sustainability challenge for this fishery which could be addressed using scenarios that explore plausible trap loss in the face of uncertain tropical cyclone activity.

This study asked how tropical cyclone intensification and the number of traps regulated for use in the commercial spiny lobster fishery influenced the input of derelict traps to the benthic seascape of the Florida Keys. A set of contrasting scenarios was compared that explored a range of increases in tropical cyclone intensity and a range of both increases and decreases in fishing effort. The scenarios included combinations of four fishing efforts (current number of traps in the fishery, target effort based on biologic production models, effort based on Maximum Economic Yield models, and reversion to historical effort) and three tropical cyclone regimes (past tropical cyclone trend, past trend with two separate levels of tropical cyclone intensification), yielding 12 scenarios. For each 60-year scenario the total number of traps lost was determined.

2. Materials and methods

2.1. Data compilation

Data on monthly percent trap loss for six fishing seasons (1997–98, 1999–00, 2000–01, 2001–02, 2003–04, 2005–06) were obtained from a Florida Fish and Wildlife Conservation Commission (FWC) database of annual mail-in surveys (Commercial Lobster Fisherman Questionnaire) administered to licensed commercial lobster fishermen reporting 45 kg (100 lbs) of landings in a given season. Among questions related to overall effort and location of fishing activity, fishermen are specifically asked to report the number of lobster traps lost each month of the eight-month season (August 6 through March 31). For the six seasons of available data, the number of respondents averaged 180 (range: 65–241). A monthly weighted mean percent trap loss for each of the six seasons of available data was obtained from FWC [FWC, unpublished data].

To account for variability in storm tracks and resulting differences in wind fields across the Florida Keys during the passage of storms, historical continuous wind measurements were downloaded from the NOAA National Data Buoy Center website (http://www.ndbc.noaa.gov/) for three Coastal-Marine Automated Network (C-MAN) offshore platform stations located in the Upper (MLRF1, Molasses Reef, Key Largo), Middle (SMKF1, Sombrero Key, Marathon), and Lower (SANF1, Sand Key, Key West) Keys. Continuous wind speed (m/s) measurements at each C-MAN station include six 10-min average values of wind speed each hour. Wind speeds were converted to km/h. Wind speed data were then subset to include only the eight months of the commercial spiny lobster season (August 6 through March 31 of the following year). Because the relationship between monthly trap loss rates and wind speed was critical for this study, it was important that all high wind events, tropical cyclone or otherwise, were accurately represented in the wind speed observations. This included the