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Assessing the drivers of the collapse of Winter Flounder: Implications for management and recovery☆

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A R T I C L E I N F O

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A B S T R A C T

Winter Flounder populations have declined throughout the southern New England/Mid-Atlantic (SNE/MA) region since the 1980s, and evidence suggests near extirpation of some local populations. Previous research has focused on the correlation between temperature and declining stock-productivity, supporting the hypothesis that a warming climate is a primary driver of the species decline. Our objective was to critically investigate several potential drivers of Winter Flounder's regional decline and collapse in the SNE/MA region by evaluating them in relation to management actions, spawning stock biomass (SSB), recruitment, productivity (PROD) and fishing mortality (F). Results indicate that the SNE/MA stock has remained below the 40% unfished biomass threshold ($B_{40\%}$) since 1984, and that F was above the maximum sustainable fishing rate (F_{MSY}) for most of the period between 1995 and 2010. We found a negative relationship between F and SSB between 1981 and 2000. Correlative analysis between young-of-the-year PROD and a number of biological and physical parameters resulted in 8 (out of 21) significant relationships. However, after correcting for multiple comparisons only two, the abundance of Striped Bass and Summer Flounder, remained significant. The PROD and recruitment analyses did not indicate strong environmental drivers and suggested recruitment compensation during the early 2000s in some surveys. In summary, we did not find evidence of a global environmental driver, such as temperature, explaining the decline of Winter Flounder. Rather, our analysis indicates that long-term overexploitation and failure of management to control harvest rates preceded and was likely a primary driver in the species decline and lack of recovery. Finally, following decades of overfishing, attempts to rebuild the Winter Flounder fishery likely will require a longer-term commitment than management has shown to date.

1. Introduction

Collapse of fish stocks can have severe economic and ecological consequences, leaving managers and stakeholders alike seeking to understand what went wrong (Worm et al., 2006; Coll et al., 2008). The eastern seaboard of the United States is one of many regions that has suffered from stock collapses of major fisheries that have impacted fishing communities and altered regional marine and estuarine ecosystems (Fogarty and Murawski, 1998; Hennessey, 2000; Shackell et al., 2012). When a collapse occurs, attempts are made to determine the drivers that preceded the crash and/or are limiting recovery of the stock from a depleted state. These can range from climate change (Brander, 2013; Pershing et al., 2015), predation (Bundy et al., 2009; Hammill et al., 2014), poor management (Hennessey, 2000; Costello et al., 2008), overfishing (Hutchings, 2000; Worm et al., 2006; many others), habitat degradation (Seitz, 2014), regime shifts (Anderson and

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Abbreviations: AICc, Aikaike's Information Criterion corrected for small sample sizes; ASMFC, Atlantic States Marine Fisheries Commission; BIC, Bayesian Information Criterion; B40%, 40% of unfished biomass threshold; CTDEEP, Connecticut Department of Energy and Environmental Protection; EEZ, Exclusive Economic Zone; ESRL, Earth System Research Laboratory; F, fishing mortality; FMP, Fishery Management Plan; FMSY, the maximum sustainable fishing rate; NEFMC, New England Fisheries Management Council; NEFSC, Northeast Fisheries Science Center; NOAA, National Oceanic and Atmospheric Administration; NYSDEC, New York State Department of Environmental Conservation; OAR, Office of Oceanic and Atmospheric Research; OISST, Optimum Interpolation Sea Surface Temperature; PROD, productivity; R, The R Project for Statistical Computing; R/S, recruits per spawner; SF, Summer Flounder; SNE/MA, Southern New England/Mid-Atlantic; SSB, spawning stock biomass; SST, sea surface temperature; YOY, young-of-the-year

☆ For abbreviations of survey data sources, see Table 1. For abbreviations of environmental variables examined in our analysis, refer to Table 2.

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Piatt, 1999; Steneck et al., 2004; Frank et al., 2005), and lack of a forage base (Smith et al., 2011; Essington et al., 2015). Even when a cause of decline can be pinpointed, management responses such as moratoria and rebuilding imperatives are costly, politically challenging to enact, and difficult to continue when stocks fail to recover in a timely fashion (Layzer, 2006; Khan and Neis, 2010; Boettiger et al., 2016).

A combination of several stressors, acting in concert or on separate life history stages, often contributes to scientific uncertainty surrounding persistent population declines, further complicating management responses (Charles, 2002; Kutil, 2011). A problematic scenario occurs when a stock experiences poor environmental/biological conditions following overfishing, resulting in a situation where even strict management actions do not produce the expected recovery (Rouyer et al., 2011). Continuation of seemingly ineffective management actions is unpopular because measures to recover a species may require sacrifice and compromise on the part of stakeholders (Charles, 2002). When global-scale issues such as climate change are implicated in a stock's collapse, it can be especially challenging to find the political will to create stakeholder buy-in for necessary actions to meet recovery targets.

Environmental and biological drivers are not often evaluated in the stock assessment process. Inclusion of environmental and biological indicators, where appropriate, represents progress in understanding population dynamics, and provides a platform to evaluate drivers of a species' decline in abundance (Hare and Able, 2007; Pershing et al., 2015; Dolan et al., 2016; Miller et al., 2016). However, isolating factors through correlative analysis, without robust estimation of the relative impact of competing factors on stock productivity, can misidentify causes of a stock's collapse, often without contributing much predictive power (Scheuerell and Williams, 2005). For many years, evidence has accumulated that past overfishing can have impacts on fish populations that persist long after recovery measures are enacted through altering age structure and life-history traits (Rouyer et al., 2011; Hutchings and Kuparinen, 2014; Gårdmark et al., 2015). Often, these effects manifest at the same decadal-scale timeline as symptoms of population response to climate change and variability, thus making it extremely difficult to disentangle the relative impact of climate versus overfishing on stock recovery (Rouyer et al., 2011; Hidalgo et al., 2012). In the case of Winter Flounder, (*Pseudopleuronectes americanus*, Walbaum), it is becoming common to hear that some stakeholders have lost faith in attempts to recover the depleted stocks, seeing the fishery instead as an inevitable victim of climate change. This viewpoint discounts the impact of the long history of fishery overexploitation upon this species.

Winter Flounder inhabit coastal waters of eastern North America from Labrador to Georgia (Bigelow and Schroeder, 1953). The population in the United States is managed as three stocks: Gulf of Maine, Georges Bank, and Southern New England/Mid-Atlantic (SNE/MA) (see Table 1 for definitions and abbreviations). Since the late 1980's, SNE/MA Winter Flounder have undergone a severe reduction in biomass, declining to < 9% of target biomass levels in 2009 (NEFSC, 2011), before increasing to 23% in 2014 (NEFSC, 2015). Despite this slight recent improvement, Winter Flounder is no longer a viable fishery in New York, where commercial catch is currently < 3% of peak levels observed in the 1980's and recreational catch is < 0.3% of peak levels (NOAA Office of Science and Technology, noaa.gov). Recruitment indices for the SNE/MA stock in 2013 fell to a low point of 4% of estimated levels observed in the 1980's (ASMFC 2016). Recent genetic and telemetry data suggest Winter Flounder display meta-population structure with local stocks nearing extirpation in parts of its range (Sagarese and Frisk, 2011; O'Leary et al., 2013; Frisk et al., 2014). Following the guidance outlined by Petitgas et al. (2010), the severely depleted status of meta-populations off Long Island, NY, the overall status of the SNE/MA stock, decline in adult age structure, decline of recruitment and loss of the regional fishery supports the conclusion that the Winter Flounder population(s) have collapsed in the region.

Table 1
Description of survey data including source, area, gear, analyses conducted and name used in the manuscript.

Source	Area	Gear	Analysis	Name
NYSDEC	Manhasset, Little Neck and Jamaica Bays	Seine	Productivity, recruitment	“Long Island estuaries”
NYSDEC	Manhasset and Little Neck	Seine	correlational	“North Shore estuaries”
NYSDEC	Jamaica Bay	Seine	correlational	“Jamaica Bay”
CTDEEP	Long Island Sound	Trawl	Productivity, recruitment	“Long Island Sound”
CTDEEP	Coastal Connecticut	Seine	Productivity, recruitment	“Connecticut estuaries”
NEFSC	Southern New England/Mid-Atlantic	Trawl	Productivity, recruitment	“SNE/MA”

The general poor state of Winter Flounder has led to multiple studies evaluating drivers of this species' decline. The primary focus of recent research has been on climate-related declines in recruitment productivity. Bell et al. (2014) estimated a decline in productivity in Winter Flounder's stock-recruitment relationship and argued the lack of recovery of Winter Flounder was due to warming estuarine conditions. Manderson (2008) found that recruitment synchrony is now dominated by large-scale climatic factors, reducing variation between bays, suggested this reduces the capacity for bet-hedging strategies at the meta-population level.

Interactions between climate change and predation have been highlighted by research suggesting climate related range shifts for several species in the northeast shelf finfish species complex (Nye et al., 2009; Pinsky and Fogarty, 2012; Bell et al., 2015). Winter Flounder may have decreased potential for range shifts due to spawning site fidelity (Wuenschel et al., 2009; Sagarese and Frisk, 2011; Bell et al., 2015), but one of their primary predators (Sagarese and Frisk, 2011), the Summer Flounder (SF) (*Paralichthys dentatus*) underwent an apparent range expansion (Nye et al., 2009; Bell et al., 2015) coinciding with the decline of Winter Flounder. Warmer winter temperatures and earlier spring warming may allow predators such as SF to enter estuaries earlier, shortening the window of time that developing larvae and young-of-the-year (YOY) can grow in low predation-risk conditions (Taylor, 2005).

To determine the drivers of the decline of Winter Flounder, a review of the species' biomass, fishing and management history is necessary to place potential changes in stock productivity in context. Repeated failure to meet management targets on schedule cannot be overlooked as a potential cause of limited productivity. The central objective of this paper is to critically evaluate several potential drivers of Winter Flounder's regional decline and collapse in the Southern New England region, including analysis of historical overfishing, management and recruitment productivity. First, we provide a timeline of regional management, SSB and F for the SNE/MA (See Fig. 1 for description of study areas). Second, we provide for New York's Long Island coastal stocks analyses of abundance and productivity trends, evaluating abundance in relation to predator abundance and in relation to temperature trends. Finally, we estimate stock-recruitment relationships and relate them to biological and environmental drivers. For comparison, recruitment relationships are also derived for the Long Island Sound and the SNE/MA stock of Winter Flounder.

2. Methods

2.1. History of management, spawning stock biomass (SSB) and fishing pressure (F)

Management of Winter Flounder in state waters has been governed by Interstate Agreement under the Atlantic States Marine Fisheries