Effective Science-based Fishery Management is Good for Gulf of Mexico's "Bottom Line" – but Evolving Challenges Remain

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The northern Gulf of Mexico (GoM) is an ecologically and economically productive system that supports some of the largest volume and most valuable fisheries in the United States. The benefit of these fisheries to society and to the surrounding Gulf communities has varied historically, commensurate with the fish population sizes and the economic activities they are able to sustain. Following reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) as amended by the Sustainable Fisheries Act in 1996, strict requirements were put into place for rebuilding overfished stocks, including several in the GoM. Now 2 decades later, we can assess the impacts of fisheries management, as guided by the MSA and implemented by the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service, the Gulf of Mexico Fishery Management Council, the Gulf States Marine Fisheries Commission and other state and international agencies. The northern GoM has experienced increases in biomass levels for many stocks, concurrent with increased commercial landings and revenues, increased recreational fishing effort, and a steadily growing regional ocean economy over the past decade (Karnauskas et al. 2017). However, it is critical to interpret these trends in the context of other major drivers in the Gulf ecosystem, and to ensure that all resource users can reap the benefits of a well- managed fisheries system for years to come.

The Gulf of Mexico Ecosystem Status Report (Karnauskas et al. 2017) is one framework for thinking about the Gulf of Mexico ecosystem holistically, and provides a comprehensive backdrop against which the broader effects of management can be understood. The report provides a broad perspective for understanding the larger system context by synthesizing ecosystem-scale indicators intended to track the status and trends of the GoM large marine ecosystem. The most recent 2017 report demonstrates the generally positive trends in fish populations that have been observed despite a developing coastal landscape, extensive wetland loss, and increasing human population with the potential to exert additional stress on the coastal ecosystem. However, multiple indicators point toward a physical and socioeconomic environment with increasingly extreme events, and heterogeneity in the spatial patterns of some trends. Thus, while celebrating the clear successes of fisheries management in the region that have led to a near end to overfishing and restoration of most populations to optimal levels, we must understand the physical, biological, and socioeconomic context in which these changes have occurred, and also prepare for new challenges that lie ahead.

There are more than 70 stocks falling under various Fishery Management Plans of the management bodies with authority in the GoM (Gulf of Mexico Fishery Management Council, International Commission for the Conservation of Atlantic Tunas). In the late 1990s, over one-third of assessed stocks in the Gulf of Mexico underwent overfishing, but by 2015, this number had dropped to less than 3% (Figure 1). These changes are documented with periodic assessments of the status of major fished stocks; these assessments not only track the status of the stocks, but also provide scientific advice for sustainable levels of catch. Effective management to limit harvest has led to more sustainable rates of fishing and the rebuilding of previously overfished stocks. For example, Vermilion Snapper *Rhomboplites aurorubens*, Red Grouper *Epinephelus morio,* and King Mackerel *Scomberomorus cavalla* were rebuilt to sustainable levels between 2006 and 2008, respectively. Red Snapper *Lutjanus campechanus*, an iconic species in the GoM that has historically experienced intense exploitation, was no longer subject to overfishing in 2012 and is currently approaching its rebuilding target. In 2014, NOAA declared that the Gag Grouper *Mycteroperca microlepis* population was rebuilt, and in 2015, Greater Amberjack *Seriola dumerili* and Gray Triggerfish *Balistes capriscus* were removed from overfishing lists (NMFS 2016). As of 2013, nearly all economically important fish species were at biomass levels at or above the mean biomass over the last 3 decades (Karnauskas et al. 2017).

Fishing effort, landings, and revenues were initially reduced in response to management restrictions; however, both recreational and commercial sectors have rebounded in recent years. The timing of these rebounds suggests the positive influence of management; for example, population rebounds were observed in nearly all stocks following the 1996 reauthorization of the MSA, which required managers to end overfishing and rebuild overfished stocks. Other external forces can also drive or enhance population increases; for example, emergency fishery closures put in place after the *Deepwater Horizon* oil spill may have led to increased abundance of shrimp species (van der Ham and de Mutsert 2014). Total commercial landings in the northern GoM have generally remained stable over the past 2 decades, and commercial revenues have increased since 2010 (Figure 2). In 2015 recreational fishing effort was, for the first time in 3 decades, above average in terms of both the number of angler trips and angler days (Figure 3). Presumably, increases in both the commercial and recreational sectors are driven partly by a growing human population, although other factors (e.g., implementation of catch shares, gas prices) also play a major role. Additionally, the total ocean-related gross domestic product from the Gulf of Mexico region has been increasing over the past decade (Figure 4).

The broad suite of indicators developed in the Ecosystem Status Report suggests that fisheries management has produced generally beneficial changes, which have resulted in increased stock sizes, more fishing opportunities, and enhanced economic growth. However, trends in some of the largest fishery sectors in the GoM have been driven heavily by external factors, which certainly play a significant role in observed trends. Penaeid shrimp are the highest value fishery and Gulf Menhaden *Brevoortia patronus* the largest biomass fishery in the Gulf, and therefore these industries heavily impact trends in commercial landings and revenues. Both the shrimp and menhaden industry have undergone recent changes that have been attributed largely to external economic forces rather than fundamental changes in the state of the Gulf ecosystem (Keithly and Poudel 2008; Smith and Vaughan 2011). For example, shrimping effort has decreased by nearly 75% since the 1990s (Isely 2016), most likely in response to the explosion of low-cost shrimp imports. Declines in the industry have also occurred as a result of rising fuel prices, the introduction of a federal limited permit program, and loss of vessels and infrastructure during major events such as Hurricane Katrina.

While overfishing has been steadily reduced over time and stock biomasses have been generally increasing, not all stocks have recovered to optimal population levels, and in a few cases, stock sizes have decreased even though fishing pressure has been reduced. This suggests that other ecosystem factors may be inhibiting full recovery and effective management may need to take these factors into account. Trends in some economically important stocks have been attributed to changes in the physical environment (e.g., SEDAR 2014), as variability in temperature, salinity, ocean currents, and other abiotic factors can influence the abundance and availability of harvested species and the prey base on which they depend. The suite of abiotic indicators investigated in the status report conveys some of the anomalous physical conditions observed in recent years. For example, marked increases in both sea surface temperature and hypoxia—exceeding levels not previously observed—were reported off the coast of Texas in 2015 (Figure 5), and in 2017 the largest measured hypoxic zone on record was reported (LUMCON 2018). In some cases, the population-level effects of extreme episodic environmental events are well documented; for example, it is estimated that nearly one-third of Red Grouper biomass was lost in 2005 due to mortality from severe red tide (SEDAR 2015). Events of this nature, when they occur with increasing frequency and severity, will challenge management to maintain optimal economic use of the resources while preventing stocks from becoming overfished (Harford et al. 2018). Hence, while recent fisheries management has generally been effective in rebuilding or maintaining most stocks at sustainable and optimal levels, future management may need to adapt to a changing ecosystem, including a changing climate, increasingly frequent extreme events, and a growing human population.

In addition to underlying changes in the abiotic environment, the Gulf of Mexico has been exposed to a number of anthropogenic stressors. Clearly, episodic events such as the *Deepwater Horizon* oil spill can lead to damaging effects on the growth and well-being of coastal populations, employment, social connectedness, and fishing opportunities (Sandifer et al. 2017). Notwithstanding this extreme but anomalous event, population density and the rate of urbanization of coastal regions have continued to increase, exerting increased pressure on coastal resources. At the same time, sea level has continued to rise, in some places at an accelerated rate, which is gradually reshaping coastlines and exacerbating challenges related to the development and maintenance of coastal infrastructure and access to coastal and inland resources.

While the health of fish stocks and the overall Gulf–ocean economy appear to be improving, there are concurrently increasing numbers of people utilizing, and in some cases dependent on, a limited base of natural resources. Recovering stocks and a growing economy (both in the Gulf region and beyond) have spurred more recreational fishing.

Artificial reef programs are increasingly popular for their ability to enhance recreational fishery opportunities, and have led to the deployment of at least 15,000 structures in Gulf waters in the last 3 decades (Karnauskas et al. 2017). All of these factors—increasing stock sizes, increasing numbers of anglers, and increasing access to fisheries—will have the effect of driving catch rates and fishing mortality higher, either directly or in-directly. When these increases occur simultaneously, as in the case of Red Snapper, management has restricted fishing seasons to frustratingly short lengths (e.g., days) in order to maintain catches below sustainable quotas (Goethel et al. 2018). In essence, due to complex socio-ecological feedbacks within the system, sometimes the very successes we celebrate (e.g., a Red Snapper population that has doubled or tripled over the life-time of some anglers) can create new management challenges.

Single species fisheries management approaches, as implemented over the past several decades in the United States, have been largely responsible for rebuilding stocks and subsequently increasing economic benefits to communities dependent on the marine environment. However, the observed recoveries of fish populations do not necessarily benefit all stakeholders equally, as fishing opportunities are unevenly distributed across space (e.g., a fisherman may not hold quota for a species that becomes more locally abundant). As a growing human population puts increased pressures on resource extraction from a finite ecosystem, the optimization of resource use across all user groups becomes increasingly important. Management actions on one species clearly can have effects on other species via shifting fishing effort, altered predator and prey populations, and changes in bycatch or discards, and better accounting of these factors may allow for more efficient use of resources. Additionally as extreme conditions become more prevalent, we must remain aware that we are only looking at a piece of the puzzle—over half of GoM waters are encompassed by Mexico, and we generally lack the data with which to meaningfully account for connectivity of populations with the southern GoM. Thus, while the economic losses related to overfishing may be largely behind us, a number of challenges lie ahead to ensure optimal resource use in an increasingly competitive and dynamic environment.

Addressing these challenges requires not only a better understanding of the intricate system connections and feedbacks, but also a broad foundation of monitoring and assessment that allow the full range of ecosystem components to be measured. These measures provide the ability to track ecosystem change and evaluate the consequences of human actions, natural events, and the efficacy of management systems. Traditionally, ecosystem components have been monitored using sampling programs such as fisheries surveys, and these long-term time series remain critically important. Additionally, efficiencies have been gained through satellite- based monitoring systems, sophisticated physical instrumentation, and advanced unmanned technologies. Finally, with the increasing recognition that humans are an integral component of coastal and marine ecosystems, greater attention is being devoted to measuring key components of human activity and well-being. Understanding the broader condition of the GoM ecosystem, identifying linkages and tradeoffs among different components, and optimizing resource use in a manner that benefits a diverse set of users, will require continued efforts to employ a holistic ecosystem approach and can be achieved through transdisciplinary and integrative science.

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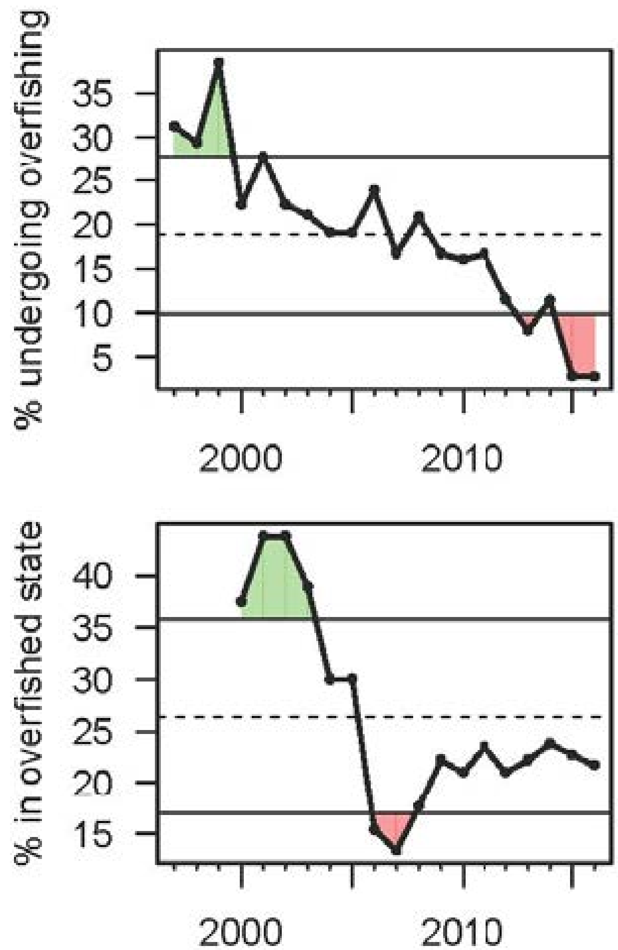

Figure 1. Proportion of assessed, U.S. federally-managed Gulf of Mexico stocks determined to be undergoing overfishing (i.e., fishing rate higher than optimal; top) and determined to be in an overfished state (i.e., population biomass less than optimal; bottom). Dashed line represents the mean indicator value over the time series; solid lines denote plus or minus one standard deviation from the mean. Further details on calculation of indicator values are found in Karnauskas et al. 2017.

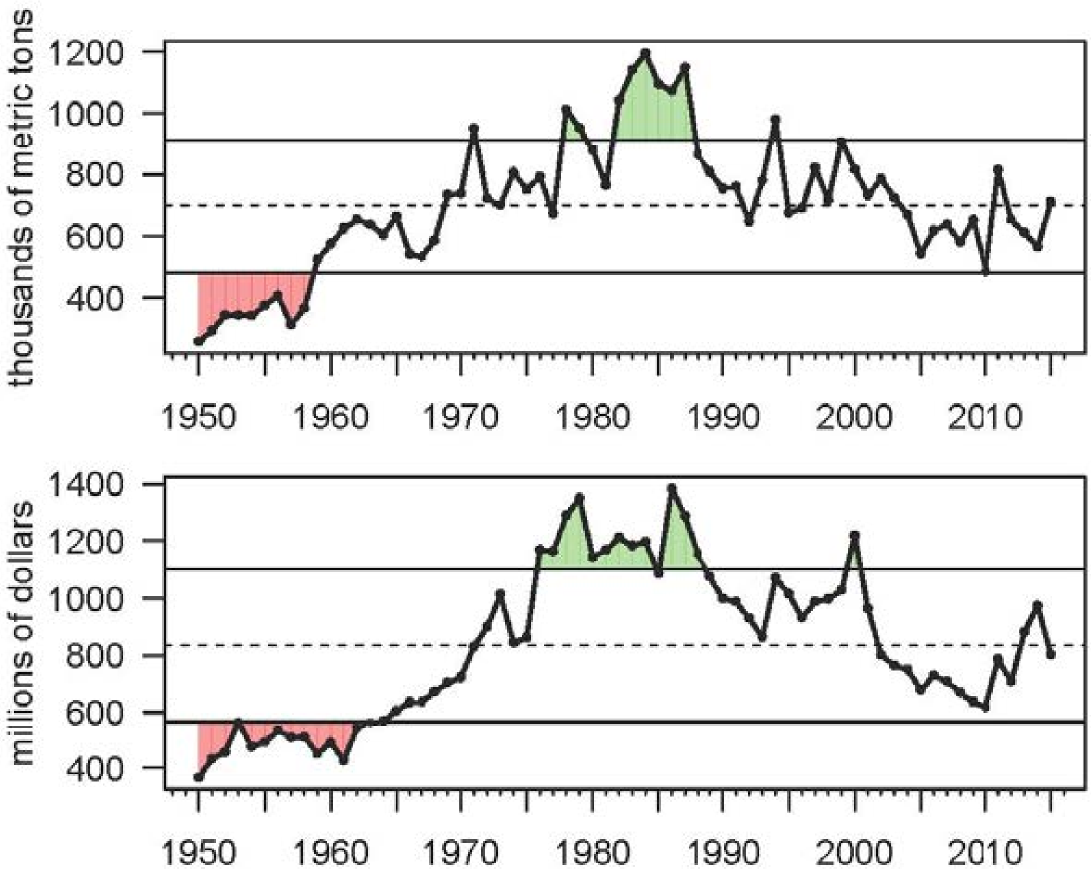

Figure 2. Total commercial landings for the U.S. Gulf of Mexico (top) and the associated inflation-adjusted commercial revenues (bottom).

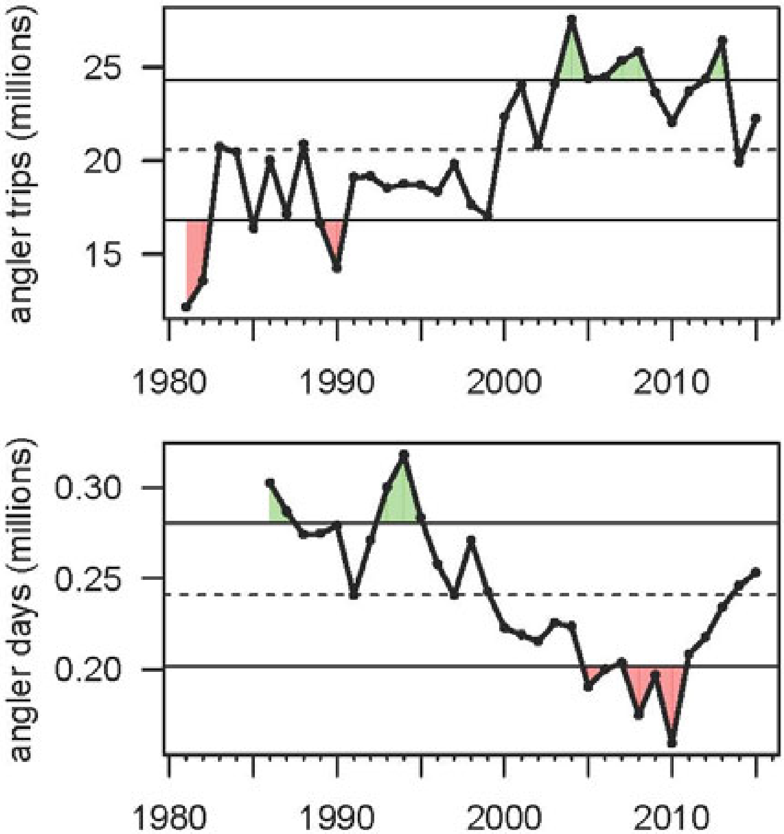

Figure 3. Gulf-wide U.S. recreational fishing effort expressed in terms of angler trips (top) and angler days (bottom).

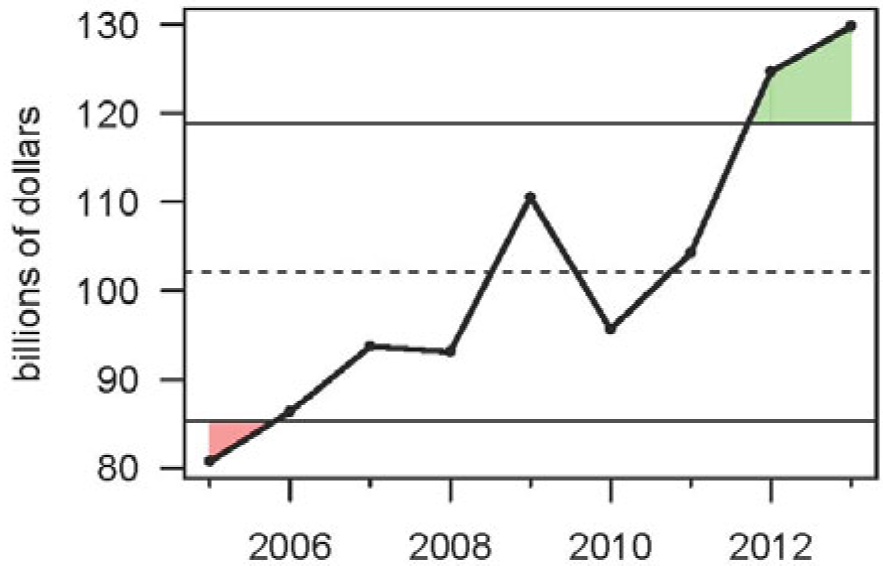

Figure 4. Total ocean-related gross domestic product (inflation-adjusted) across the U.S. Gulf of Mexico region.

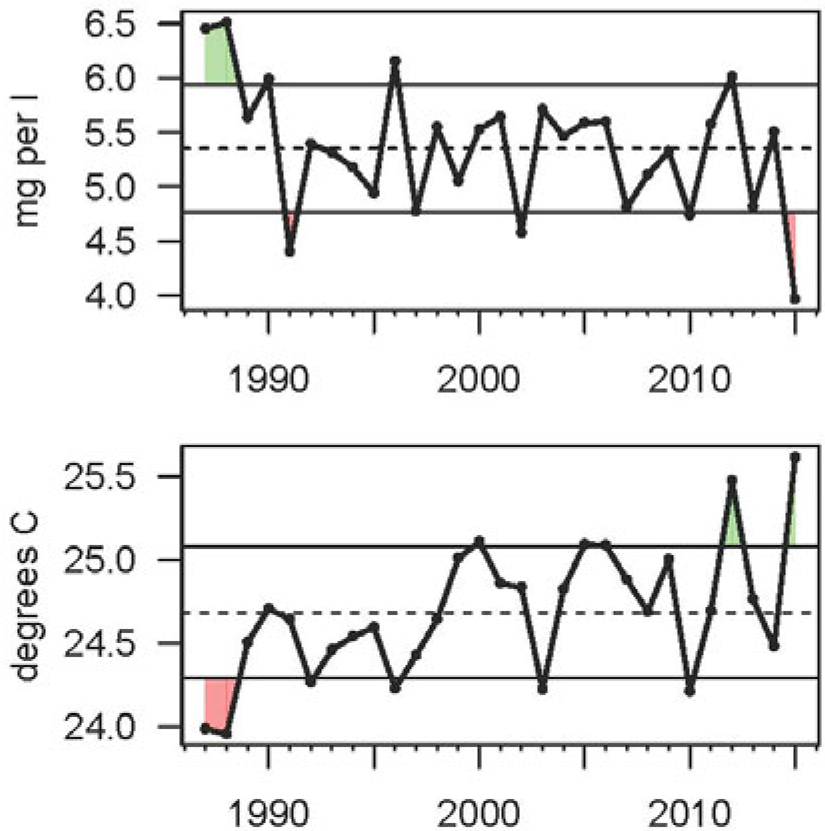

Figure 5. Average summertime (June–July) bottom dissolved oxygen concentrations (top) and average annual sea surface temperature (bottom) for the Texas continental shelf.