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NEW ENGLAND FISHERY MANAGEMENT COUNCIL

NORTHEAST HOOK FISHERMAN'S ASSOCIATION

August 24, 2014

New England Fishery Management Council
50 WATER STREET | NEWBURYPORT, MASSACHUSETTS 01950 | PHONE 978 465 0492 | FAX 978 465 3116
Thomas A. Nies, *Executive Director*

Dear NEFMC & NMFS:

We represent a small group of Commercial Fishermen with the Limited Access Handgear HA Permits, employing the use rod and reel, handlines or tub trawls to catch Cod, Haddock and Pollock along with small quantities of other regulated and non-regulated marine fish.

We are very concerned with the latest GOM cod stock assessment. We propose the reason for the "surveyed" drop in GOM cod stocks was directly attributed to the record high climate temperatures and associated GOM record warm water temperatures for the winter 2012 & 2013 year. The normal cyclic ecology of the GOM, shown below, was disrupted.

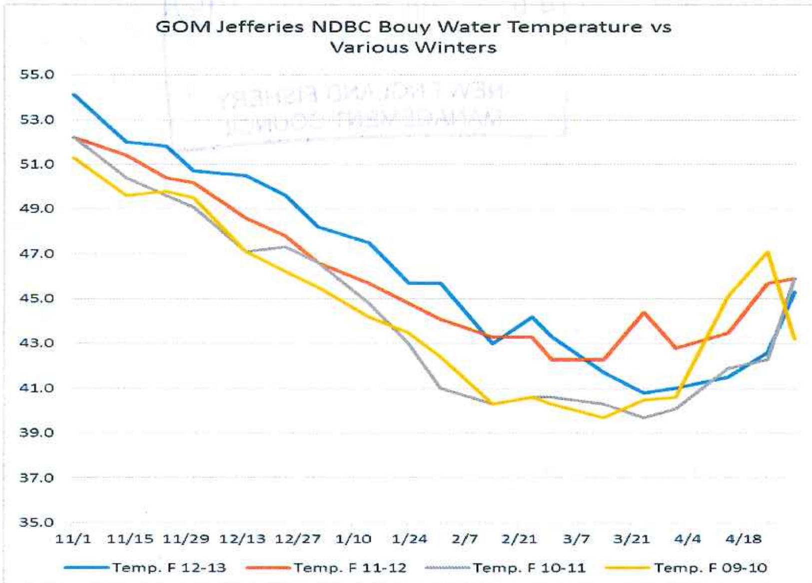
WINTER COLD WATER SNOWFALL OXYGEN NUTRIENTS	→	SPRING NUTRIENT SNOW MELT RUNOFF INTO OXYGEN RICH GOM	→	PLANKTON BLOOM PLANKTON EATING FISH COD

"*In 2012, the contiguous United States (CONUS) average annual temperature of 55.3°F was 3.2°F above the 20th century average, and was the warmest year in the 1895-2012 period of record for the nation. … Precipitation totals in 2012 ranked as the 15th driest year on record.*"
http://www.ncdc.noaa.gov/sotc/national/2012/13#cei

"*But when temperature sensitive historically native to the GOM fish disappear we don't necessarily know where they specifically went to find cooler water.*" Fisherman's Voice August 2013, Volume 18, No. 8
http://www.fishermensvoice.com/201308MarineHeatWaveResearchAtGMRI.html

"*Water temperature impacts on Atlantic cod biology and ecology are well documented (Drinkwater 2005). For example, shifts in the distribution of cod to cooler, deeper water have been identified on Georges Bank when bottom temperatures exceed 10°C (Serchuk 1994).*" "*Cod are a subarctic species, and the stocks in the Gulf of Maine and on Georges Bank are at the southern limit of their range.*" The Future of Cod in the Gulf of Maine, Gulf of Maine Research Institute, June 2013

The data shows how warm the GOM was from 2012-2013.



All indications are that the winter of 2012 and 2013 severely disrupted the ecology of the GOM. The GOM water was at a record high. There was less oxygen & nutrients present for the seasonal plankton bloom in the GOM. This caused the forage fish (herring & mackerel) to change their migration patterns. We believe the GOM cod shifted their migration or dispersed from seasonal aggregations due to the weather anomaly that occurred during winter of 2012 and 2013. **Stock assessments that include this weather anomaly is not an accurate assessment of the GOM cod since the cod were not present, in their normal abundance to count.**

Questions:

1. What was the plankton counts for the winter 2012-2013 compared to previous years?

2. What was the abundance of herring, mackerel & silver hake for the winter 2012-2013?

3. If the data from the winter 2012 & 2013 was discarded, as an ecological anomaly, what would the status of the GOM cod stock be?

4. What does the data from the 2014 fishing year for GOM cod stocks show?

   For all the forgoing scientific data and unanswered questions we are requesting that the latest stock assessment for GOM cod be held in abeyance and not used to change the ACL for the 2015 fishing year.

Respectfully,
Marc Stettner /s/

NEHFA MEMBERS: Marc Stettner, Timothy Rider, AJ Orlando, Hilary Dombrowski, Paul Hoffman, Christopher DiPilato, Ed Snell, Scott Rice, Roger Bryson, Brian McDevitt, Anthony Gross, Doug Amorello

The Future of Cod in the Gulf of Maine

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JUNE 2013

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Gulf of Maine Research Institute
Science. Education. Community.

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Abstract: Abundant cod have supported a commercial fishery in the Gulf of Maine for more than 400 years. In 2008, after decades of overfishing, the Gulf of Maine cod stock appeared poised for recovery as the industry began the transition to a catch share-based management system known as sectors. However, a subsequent assessment in 2011 found that the stock was still overfished. Beginning with the 2013 fishing year, quotas of Gulf of Maine cod will be reduced by 78%, dealing a sharp blow to an already struggling industry. Here, we review potential causes for the lack of recovery of the stock and suggest strategies to build the sustainability of the stock and the industry. We highlight the value of understanding the impact of environmental changes, including rising temperatures and changes in forage fish abundance, and the need to develop a comprehensive picture of stock structure and life history variability. Including environmental conditions and more realistic stock structure in assessment models is necessary to accurately monitor the stock and to design new management strategies. Finally, the steep cut in cod quotas creates a strong incentive for fishermen to reduce their catch of cod while targeting more abundant species such as pollock. Innovations in fishing gear and business planning could help the industry be more profitable by reducing fuel costs and maximizing the value of their catch. The steep challenges facing cod and the cod fishery are shared by many other fisheries, and strategies to understand and rebuild this stock and its fishery should be transferrable to other fisheries struggling to adapt to climate and economic changes.

Since the first Europeans came to New England to catch cod over 400 years ago, the cod fishery has been an important part of the social and economic fabric of communities around the Gulf of Maine (*Figure 1*). Now, the viability of the cod fishery in the Gulf of Maine is threatened by an unexpected decline in abundance. Several factors, including environmental changes and fishing, have likely contributed to the reduced abundance of cod, and efforts to stem this decline over recent decades have been largely unsuccessful.

Ensuring that the Gulf of Maine cod fishery is both ecologically and economically sustainable will require improved understanding of this species and new management strategies. Although our discussion will focus on cod, the issues we present are equally relevant to other fish species in the Gulf of Maine, including haddock, pollock, and flounder, many of which are caught and managed together with cod as part of the groundfish fishery. The challenges facing cod, such as those from changing economics and climate, are shared by species and fisheries around the world.

History of the Gulf of Maine Cod Fishery through 2008

At the turn of the twentieth century, fishermen in the Gulf of Maine targeted cod, haddock, and other groundfish on sail-powered vessels using hook and line gear. The fishing grounds extended between Cape Cod and the Grand Banks, and over 800 dory schooners landed around 30,000 metric tons (mt) of cod annually (Murawski et al., 1998). At this time, Gulf of Maine cod represented around 40% of these annual landings (*Figure 2*). Over the next few decades, a suite of key technological developments

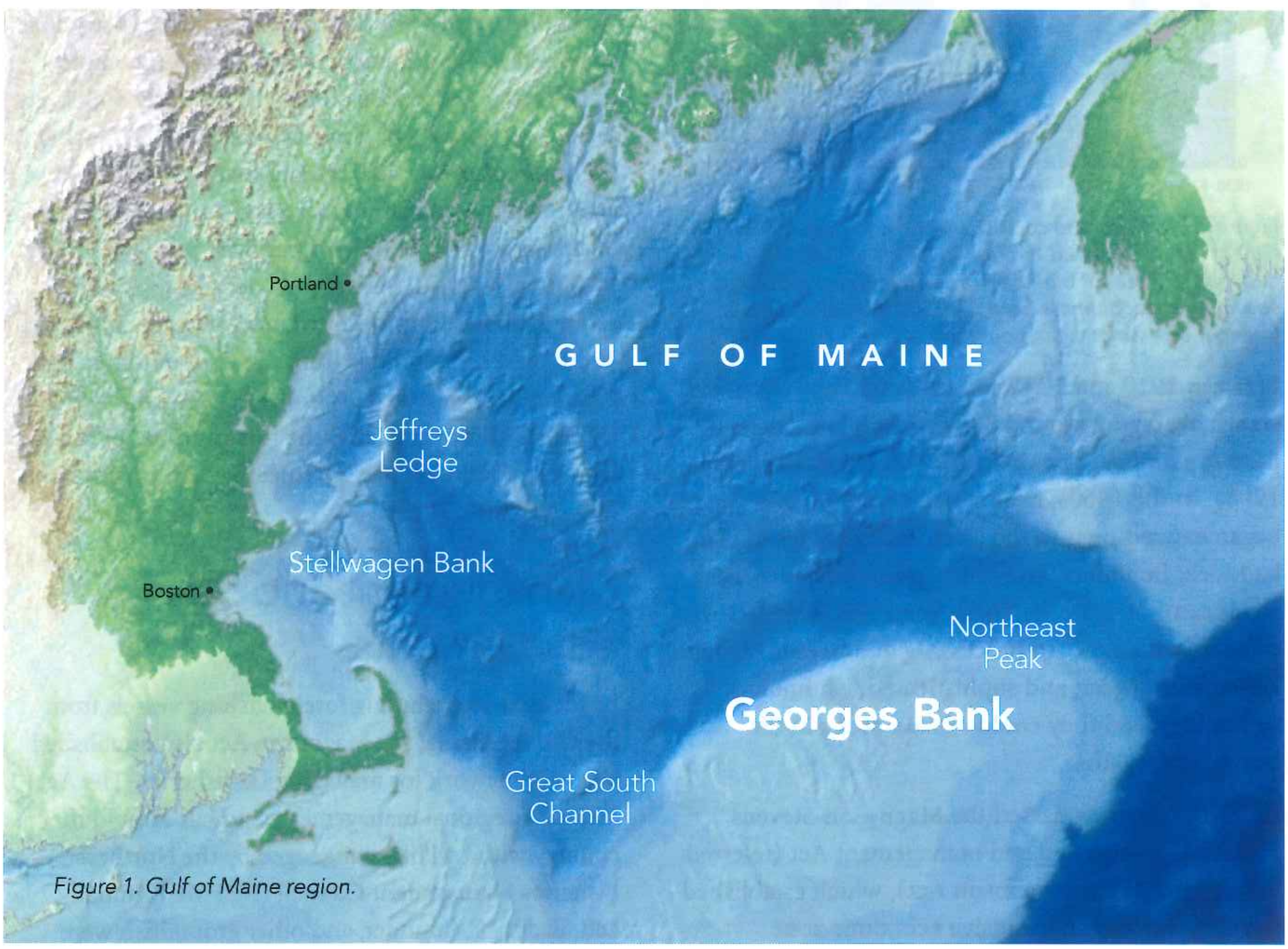

Figure 1. Gulf of Maine region.

were introduced that had a profound impact on cod stocks. By 1910 steam-powered trawlers were common (Murawski et al., 1998). These trawlers could pull larger nets through the water at higher and more consistent towing speeds and could quickly move between fishing grounds to maintain high catch rates. The modern otter trawl was introduced at this time, and this gear swept larger swathes of the seabed during a single tow. Along with improvements in ice-making and onshore transportation, these developments permitted significantly larger volumes of high quality fish to be landed, processed, and delivered quickly to distant consumers.

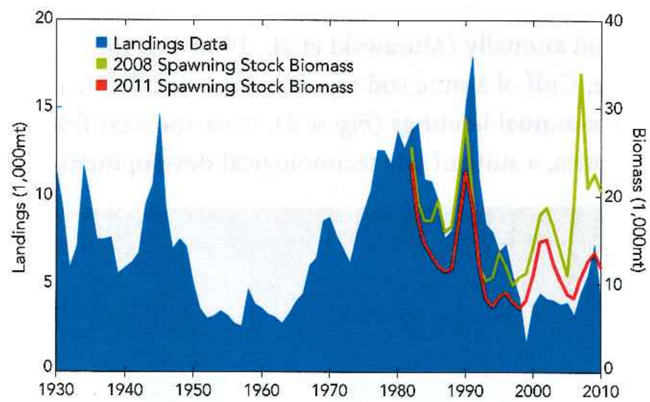

Figure 2. History of the cod fishery and cod population in the Gulf of Maine depicted through landings of Gulf of Maine cod (NAFO Area 5Y, blue bars, axis on left) and estimated spawning stock biomass from the 2008 (green) and 2011 (orange) assessments (axis on right).

Between 1910 and 1950 cod landings were relatively stable, averaging around 8,000–10,000 mt per year despite significant annual variation (Murawski et al., 1998). In the 1960s, fishing fleets from outside the US began expanding into the Gulf, and landings of cod, haddock, flounders, and other groundfish increased significantly (*Figure 2*). These fleets had large factory trawlers with onboard processing and freezer capacity, larger fishing gear, and sophisticated fish finding technology, and they could remain at sea in the heaviest of weather.

In 1976, Congress passed the Magnuson-Stevens Fishery Conservation and Management Act (referred to hereafter as the Magnuson Act), which established the US's claim to an exclusive economic zone

extending to 200 miles offshore. The exclusion of the foreign fleet prompted a resurgence of local interest in groundfish, and New England fishermen constructed or purchased large, steel trawlers that could exploit the offshore groundfish stocks. In the early 1980s, an increasing number of trawlers and gillnetters, using ever more sophisticated fishing gear and wheelhouse electronics, significantly increased annual landings of cod to around 14,000 mt per year, peaking at over 17,000 mt in 1991. As the next decade approached, groundfish landings declined, and between 1995 and 2008, total cod landings from the Gulf of Maine and Georges Bank hovered around 4,000 mt annually (NEFMC, 2013). By 2008 the total number of boats landing groundfish had declined by 50% to around 700 (NEFMC, 2013).

Management and Stock Assessments

In addition to excluding foreign fishing vessels from the Gulf of Maine, the Magnuson Act also established a new framework for managing US fisheries. The Act created 8 regional management councils around the country with cod being managed by the Northeast Fisheries Management Council (NEFMC). Initially, cod, haddock, flounder, and other groundfish were managed separately, but in 1985, all groundfish were brought under a single management plan. Although a variety of controls, including gear restrictions and area closures, have been used to limit the catch of groundfish, the most enduring strategy involved limiting the number of days a vessel could fish each year. By the mid-2000s, managing the fishery through "days-at-sea" effort controls required an increasingly complex series of area closures (to protect spawning fish and limit mortality), limits on the number of fish landed per trip, and differential days-at-sea counting (where, for example, one day at actual fishing counted as two days in certain areas).

The Magnuson Act, refined in the 1996 Sustainable Fisheries Act and then reauthorized in 2006, established the goal of managing fisheries at their optimal yield. This requires an estimate of how many fish are in a stock and how quickly new fish are being produced. Monitoring the number and weight of fish landed provides a rough indicator of the status of the stock. This knowledge can be enhanced by systematic surveys such as the bottom-trawl surveys conducted in the Gulf of Maine by National Marine Fisheries Service (NMFS), Maine, and Massachusetts. To get a more accurate estimate of the abundance and the population rates, fisheries scientists use statistical models to blend information from multiple sources, a procedure known as a stock assessment. The mathematical models at the heart of a stock assessment relate the number of fish in one year to the number in the next year using general biological information such as age, growth, size or age at maturity. Observations of the number of fish from research surveys and from the commercial and recreational catch are then used to constrain the model. The resulting model provides estimates of parameters of interest such as stock size (both numbers and weight), fishing mortality rate, and recruitment to the commercial fishery. If the data are sufficient, the models can be used to predict future stock sizes given various alternative scenarios of catch, recruitment, or growth. Most current stock assessment models do not incorporate information about how ecosystem conditions (for example, temperature or the abundance of predators and prey) influence vital rates or, ultimately, stock size.

Stock assessments estimate the current state of the population, typically described by the total biomass of fish (B), and important rates including recruitment and the rate at which fish are being caught (F). Assessments also allow scientists to estimate the biomass and fishing mortality rates that produce the maximum sustainable yield (B_{MSY} and F_{MSY}, respectively). These variables describe the status of the fishery. If the biomass is less than half of MSY ($B< 0.5B_{MSY}$), then the stock is considered to be overfished. This is distinct from overfishing, which is defined based on the rates. Technically, overfishing is occurring if $F>F_{MSY}$.

The 2008 stock assessment used a Virtual Population Analysis (VPA) model for Gulf of Maine cod and data through 2007 (NEFSC 2008). Beginning in 1982, the first year in the assessment, the stock was considered to be overfished (low biomass) with overfishing occurring (catch rates too high). The assessment found that biomass in 2007 was increasing and that the stock was no longer overfished, although overfishing was still occurring. More importantly, the assessment estimated that the population would be rebuilt by 2014. The picture from the assessment was that Gulf of Maine cod were recovering and that the fishery was one of the success stories in fisheries management. In 2008, as revolutionary changes in management were being considered for the fishery, the real picture of the stock was, in fact, much bleaker.

2008-2012: Changing Fishery, Changing Fish

With the reauthorization of the Magnuson Act in 2006, managers had a new set of federal mandates, most notably requirements to implement annual catch limits (ACLs) and accountability measures. Annual harvests could no longer exceed the limit set by the best available science, and regulations had to be in place to ensure the harvest stayed within those limits. The days-at-sea management system would require in-season adjustments to meet these standards. These adjustments had the potential to create a dangerous "race-to-fish" in which fishermen would try to catch fish early in the season, regardless of weather, before any adjustments were imposed.

As an alternative to effort controls, the NEFMC introduced sector management at the beginning of the 2010 fishing year. Sectors are cooperatives of groundfish permit holders that receive an annual allocation of groundfish stocks. Under sector management, the total allowable catch for each groundfish stock is divided among sectors according to the catch history of each sector's membership from 1996 to 2006. Thus, a sector's allocation of Gulf of Maine cod reflects the historical proportion of the commercial harvest that its members landed during that time period—if they collectively accounted for 10% of the cod landings from 1996 to 2006, then the sector is allocated 10% of the commercial catch limit. Permit holders who do not wish to join a sector can remain under days-at-sea management and fish within the common pool, which shares any allocation not represented under sectors. The switch to sectors was met with strong reservations, but many fishermen were also optimistic that the new flexibility in when, how, and where to fish would allow for improved profitability.

The optimism in the fishery was shattered by the 2011 cod stock assessment. The 2011 assessment used both a new model and new data (NEFSC, 2012). The model made improvements in three key areas: (1) it allowed for full accounting of fishery removals, including commercial and recreational discards and direct estimation of commercial discards-at-age; (2) it allowed for a better representation of Gulf of Maine cod biology, including a revised length-weight relationship; and (3) it better accounted for the uncertainty in the underlying data (e.g. recruitment indices) and allowed for more thorough exploration of alternate model formulations. Several new data sets were incorporated into the 2011 assessment. These data were collected prior to the 2008 assessment, but further analysis was needed before they could be used. The new assessment concluded that the stock was in fact overfished and likely was also much lower in 2007 than previously estimated.

So why was there such a large difference between the 2008 and 2011 assessment results? After extensive analysis, fisheries scientists concluded that the revision to the 2007 estimates was not due to the new model: using the original VPA model would have led to the same conclusions about the stock. The reevaluation of the assessment concluded that most of the new data produced only minor changes to the stock status. The exception was the more explicit treatment of discards-at-age in 2011. The 2008 assessment assumed the size composition of discards was identical to the landings when in fact many of the discards were below the minimum fish sizes allowed. The change in the data meant that biomass was, in fact, lower than estimated. Additionally, high (but variable) indices of abundance from the NEFSC spring survey led to overly optimistic estimates of the 2003 and 2005 year classes which contributed to the view of a rebuilding cod stock.

Indicators from fishery-independent data support the conclusion that the stock was not healthy. Research survey indices for 2009–2012 were at or near historical lows, and the number of tows that caught cod declined region wide (NEFSC, 2012). There was also a large decrease in the abundance of juveniles in the 2009–2011 trawl surveys, and poor recruitment was evident over the past five years. The distribution of fish is now concentrated in the western Gulf of Maine which may indicate a contraction in range or depletion of unique subpopulations in the eastern Gulf of Maine. Although the fishery was able to maintain a relatively high catch-per-unit-effort by following the fish westward, landings declined in concert with abundance. Today, the Gulf of Maine cod stock remains at very low levels, and the picture is not merely of a stock that has been overfished, but one that is performing poorly, threatening the viability of the fishery.

The Future of Cod in the Gulf of Maine

As of 2013, it is clear that the Gulf of Maine cod stock is in a state of low abundance and the cod fishery is in crisis. Some of the trends in the stock appear similar to the situation that unfolded in Newfoundland two decades ago (see sidebar). The stock is faring poorly, and fishing alone cannot account for its reduced performance. Successfully weathering the current storm and emerging with a healthy stock and sustainable fishery will require a concerted effort to understand the factors driving the poor stock performance and to evaluate options for enhancing the management and profitability of the fishery. We have organized these efforts around four assertions:

1. **Understanding Environmental Change:** Shifts in the Gulf of Maine ecosystem have impacted cod and the cod fishery. Understanding these past events is necessary to sustain this population in a changing climate.
2. **Diagnosing Stock Structure and Movement:** Cod stock structure, behavior, and diet are more complex than previously appreciated. Building knowledge about these topics will support more effective fishery management in an ecosystem context.
3. **Improving Stock Assessments and Management:** Advances in stock assessment and innovation in fishery management are necessary to sustain the Gulf of Maine cod population.
4. **Increasing Profitability:** The limited availability of cod will challenge the industry. Novel marketing strategies and innovative application of gear and information technology will support an economically and ecologically sustainable fishery.

Although our discussion is restricted to cod, the challenges and solutions we outline are relevant to most fisheries as they struggle to adapt to a world of increasing climate and economic changes.

1. Understanding Environmental Change

Cod, like other fish species, are affected by and respond to environmental conditions they experience throughout their life. Larval survival is strongly influenced by environmental conditions such as

Lessons from Newfoundland

Changing ocean conditions. Changing centers of distribution. Overfishing. Declining cod. Have we not seen these challenges before elsewhere? In the Gulf of Maine, cod have gone through a rocky couple of decades. Overfishing led to declines in Gulf of Maine groundfish abundance in the 1990s, including cod, which set off a series of management actions aimed at curbing effort and mortality. These restrictions appeared to be working up until 2008, when the cod assessment indicated that rebuilding was underway. However, due to problems with the 2008 assessment (identified in the 2011 assessment), it is now known that the Gulf of Maine cod stock was not in as good shape as was previously believed.

Newfoundland endured similar experiences with its cod fishery in the early 1990s. What can we learn from the experience in Newfoundland that will help us understand and adapt to the current Gulf of Maine cod decline? First of all, the initial overcapitalization and then high exploitation of Gulf of Maine cod, following establishment of a 200-mile EEZ, mirrors the pattern observed for the northern cod stock in Newfoundland. At the same time that the northern cod were being heavily exploited, capelin, the primary prey of the northern cod, moved southward during an unusually cold period. This prey range shift, in combination with declining abundance, led to northern cod being much more aggregated near the southern end of the stock range and more vulnerable to further overfishing by the highly efficient offshore fleet.

Has a similar "hyper-aggregation" (Rose et al. 2002) occurred in the Gulf of Maine? Comparable to the case in Newfoundland, Gulf of Maine cod appear to have shifted their distribution from throughout the Gulf of Maine to primarily the western Gulf of Maine (Figure 1). Hyper-aggregation assumes a single population (within the stock) and a range contraction due to declining abundance and other environmental shifts. On the other hand, Ames (2004) described distinct sub-populations within the Gulf of Maine which, if real, would argue against hyper-aggregation and rather support the idea of local depletion of cod within sub-regions (i.e., eastern Maine). And while the Gulf of Maine is warming, the eastern portion remains the coolest and therefore would likely serve as a thermal refuge, not an abandoned habitat, with all else being equal. As such, there is perhaps cause for even greater concern, given the possibility that the only

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winds and currents (Churchill et al. 2011), along with plankton abundance (Mountain and Kane 2010). Food availability, especially the abundance of lipid-rich forage fish, is also an important external driver of cod production (Sherwood et al. 2007). A combination of these factors, along with a recent warming trend, could explain the poor performance of the stock in recent years.

Temperature has a strong influence on fish throughout their life, affecting growth, reproduction, distribution, migration, and recruitment (Drinkwater 2005). Cod is a subpolar species and the Gulf of Maine is near the southern limit of its range in the western Atlantic. Any increase in temperature can be expected to adversely impact this stock (Drinkwater 2005, Fogarty et al. 2008), and examining how the population has responded to past changes in temperature can provide some insight into where the stock may be headed.

The Gulf of Maine is now warmer than it has ever been; however, temperatures only recently exceeded those experienced during the late 1940s and early 1950s (*Figure 3*). In 1950, the northwest Atlantic was 0.5-1°C warmer than the 1982-2011 average. However, the rest of the global ocean was, on average, 0.5-1°C cooler. The abrupt decline in landings in 1950 (*Figure 2*) coincided with this warming period, although it is unclear whether the decline was due to reduced abundance, changes in the fishery, or to under-reporting of landings.

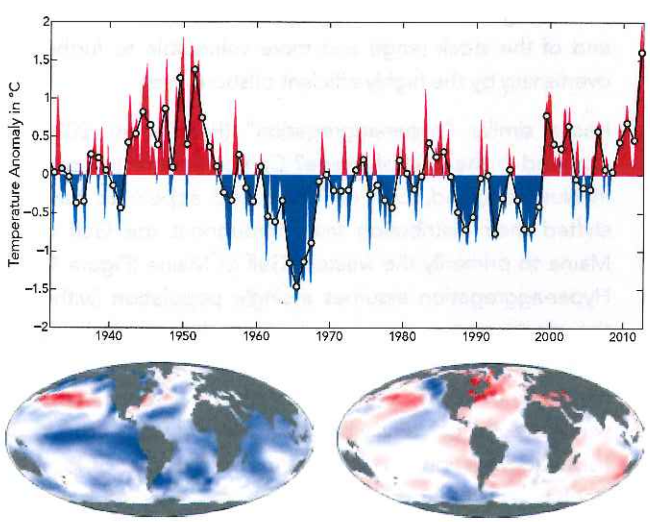

Figure 3. Monthly (shaded region) and yearly (circles) sea surface temperature anomalies for the Gulf of Maine. The anomalies were computing using ERSST data referenced to the 1982-2011 climatology. The maps are the global anomalies for the years 1950 (left) and 2012 (right), with red and blue colors indicating above and below normal temperatures, respectively.

The recent warming began in 1999 and accelerated in 2010, reaching record levels in 2012. Although annual mean temperatures have only recently exceeded the mid-century values, the recent warming has a different character than the earlier period. During the 1945-55 period, the warming was strongest during the winter, leading to increased annual minimum temperatures. With the exception of the very warm 2011/2012 winter, recent winter temperatures have been normal, and the observed warming is due to elevated summer temperatures (Friedland and Hare, 2007). This means that species in the Gulf of Maine are encountering maximum temperatures outside their historical experience.

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remaining sub-population in the Gulf of Maine coincides with the area of highest temperature.

Another valuable lesson from the Newfoundland experience is that, despite an all-out moratorium on cod fishing, it took nearly two decades for a recovery to take hold in the northern stock. Initial estimates following the establishment of the moratorium put the rebuilding time frame at just a few years. Clearly other factors were at play that held the northern cod at low abundance for many years and then allowed a sudden recovery in 2006 (DFO 2011). This recent recovery of northern cod is likely related to an increase in the abundance of capelin. Without capelin, Newfoundland cod grow poorly, lack energy reserves and spawn less frequently (Sherwood et al. 2007). What does this mean for Gulf of Maine cod? Perhaps cod in eastern Maine are also limited by a shortage of forage fish such as river herring and inshore Atlantic herring (Ames 2004). It remains to be seen whether dam removals, which are likely to lead to reestablishment of river herring runs, and restrictions on nearshore mid-water trawling for Atlantic herring will result in greater forage fish availability and a recovery of cod in eastern Maine, which has been inexplicably devoid of cod for nearly two decades.

Water temperature impacts on Atlantic cod biology and ecology are well documented (Drinkwater 2005). For example, shifts in the distribution of cod to cooler, deeper water have been identified on Georges Bank when bottom temperatures exceed 10°C (Serchuk 1994). Temperature is also an important factor determining growth rates of cod across life stages, with maximum growth rates for juvenile and adult cod occurring between 10-15°C (Drinkwater 2005). Additionally, cod age-at-maturity has been shown to decrease with increasing water temperature (Brander 1995). Fogarty et al. (2008) explored the potential impacts of increasing water temperature associated with climate change on cod in US waters. Modeling revealed that increasing temperature reduced the survival of young cod but increased their growth rates, with the combined impact of reduced cod production in the Gulf of Maine (Fogarty et al. 2008). Warming in the Gulf of Maine is also altering the composition of the entire groundfish community as southerly species move northward (Nye et al. 2009; Lucey and Nye 2010). The influence of these potential prey, competitors, and predators of cod is unknown.

Body size has important implications for marine fish populations and ecosystems, and changes in size have the potential to impact both the performance of the stock and the assessment. For example, larger fish require less food to maintain each gram of tissue (Brown et al. 2004) and larger females produce more and higher quality eggs (Berkeley et al. 2004). Thus, populations with many large individuals can withstand poor environmental conditions and recover more rapidly when conditions improve (Chesson and Warner 1981, Field and Francis 2000). Substantial declines in the mean body size of several fish species have been reported for the Newfoundland-Labrador Shelf, Scotian Shelf, and Gulf of Maine-Georges Bank region of the Northeast Shelf during the late 1980s and early 1990s (Fisher et al. 2010, Mills 2010, Shackell et al. 2010), suggesting that large-scale environmental changes are likely driving the declines in size.

Declines in cod body size in the Gulf of Maine may be related to a change in growth at the stock level. Generally, fish in colder waters, such as the eastern Gulf of Maine, grow more slowly but reach larger body sizes at older ages than fish in warmer waters, such as the western Gulf of Maine and Georges Bank (Tallack et al. 2009). As cod abundance has declined in the eastern Gulf of Maine, faster growing but smaller western Gulf of Maine fish represent a larger contingent of the population. However, changing environmental conditions may also play a role, as the timing of the declines in cod size coincides with major shifts in physical conditions and community composition in the Gulf of Maine ecosystem that may affect feeding opportunities for cod (Greene and Pershing, 2007; Lucey and Nye 2010). The shift towards smaller body sizes could have important implications for cod and for their management within an ecosystem context. The 2011 stock assessment found that the age at maturity has not changed, which suggests that cod are maturing at smaller sizes, and as such, may be producing fewer or lower quality eggs. A decline in fecundity and recruitment potential may constrain recovery of the cod population.

While temperature can influence growth and fecundity in fish, it is only one side of the equation. Robust growth and high fecundity require abundant food, and there is growing evidence that changes in food availability can constrain cod. Cod have been described as ecological generalists (Garrison 2000), but the relative importance of different prey changes as cod grow. By the time cod reach reproductive age, they likely target high-lipid forage fish such as sand lance and herring, including Atlantic herring and river herring (Ames 2004, Sherwood et al. 2007). For example, in Newfoundland, in the absence of capelin, medium-sized cod grow slowly and are less likely to spawn (Sherwood et al. 2007). Older, larger cod, which have a disproportionate impact on egg production (Martinsdottir and Steinarsson 1998), seem to thrive on being top predators and even cannibals. That is, they may have moved beyond needing forage fish.

However, without forage fish to provide the "stepping stone" to top predator status, cod can get caught in an energetic bottleneck and never reach large sizes and their full reproductive potential, or even reproduce at all (Sherwood et al. 2007).

Although Atlantic herring, the primary forage fish in the region, are currently abundant in the Gulf of Maine (TRAC 2009), forage fish limitation may still be negatively affecting Gulf of Maine cod. In the past, spawning aggregations of cod were found all along the coast of Maine in locations and seasons corresponding to runs of river herring (Ames 2004). Declines in river herring in Maine rivers due to habitat alterations (i.e., dams; Moring 2005) and possibly bycatch in the Atlantic herring fishery (Cournane et al. 2013), may be making it harder for cod to grow and reproduce, particularly in eastern Maine (Ames 2004).

Developing relationships between environmental drivers, including changes in prey abundance and distribution, and aspects of cod biology, such as recruitment and growth, will provide a mechanistic understanding of cod population dynamics. These mechanistic relationships will be critical to forecast the response of cod to environmental variability as well as climate change.

RECOMMENDATIONS

- ***1a. Develop a deeper knowledge of how temperature impacts the distribution, growth, and fecundity of cod***
- ***1b. Understand the influence of age and size structure on population resiliency***
- ***1c. Quantify the impact of herring and other forage fish on cod growth and reproduction.***

2. Understanding Stock Structure and Movement

For assessment and management, cod in US waters are divided into Gulf of Maine and a Georges Bank management units. This distinction was based on based upon traditional fishing areas and early studies of movement, growth, and spawning from the 1960s. Since then, a range of studies using tagging, genetics, and circulation modeling indicate that stock structure may be different and more complex. Modeling exercises have shown that management units that are composed of multiple biological populations can be difficult to assess with accuracy (Frank and Brickman 2000, Fu and Fanning 2004, Kerr et al. 2010). This is an area that requires further research to determine the most appropriate management units for cod.

Recent genetic analysis of Atlantic cod (Lage et al. 2004, Wirgen et al. 2007, Kovach et al 2010) revealed stock complexity at both spatial and temporal scales that raised questions about the appropriateness of the current distinction between Gulf of Maine and Georges Bank cod. Using genetic markers, Kovach et al. (2010) identified significant (statistically and biologically) genetic differentiation among three spawning complexes (*Figure 4*):

1. A northern spawning complex, which spawns in inshore Gulf of Maine waters (off western Maine to Massachusetts Bay) in the spring;
2. A southern spawning complex, which primarily spawns in inshore Gulf of Maine waters (from Ipswich Bay to southern New England, including the Great South Channel) in the winter; and
3. A population that spawns offshore on the northeast peak of Georges Bank in the early spring.

Interestingly, the strongest genetic differentiation was identified between spawning groups in the Gulf of Maine that overlap spatially but spawn in different seasons (Kovach et al. 2010). This distinction is important to understanding recruitment patterns in the Gulf of Maine stock. Both spawning groups share nursery habitat in Massachusetts Bay. However, recruitment to the northern spawning complex, centered in Ipswich Bay, depends on winds and plankton availability in May-June, whereas the southern spawning complex depends on the winds and plankton availability in December-February; hence they utilize the nursery habitat in different seasons. In addition, because low winter temperatures increase the time that winter spawning cod spend in the plankton, winter storms may potentially disperse cod eggs and larvae widely. An implication of these seasonal differences is that changes in the environment influence recruitment to these stock complexes in different ways (Runge et al. 2010; Churchill et al. 2011).

A major gap in our understanding of cod stock structure is a lack of biological data from the eastern Gulf of Maine. Historical evidence suggests that cod in this region were not only vastly more abundant but also had a more complex population structure (Ames 2004). It is currently unknown whether the scarcity of cod in the eastern Gulf of Maine is a result of stock contraction into the western Gulf of Maine, where cod are relatively more abundant, or whether distinct spawning populations have been greatly reduced in eastern Gulf of Maine.

Information on cod movement patterns obtained from a large-scale tagging effort in the Gulf of Maine support the picture of stock structure informed by genetics (*Figure 4*). The distribution of recaptures of fish released on Georges Bank suggested that Georges Bank fish are a self-sustaining offshore population. Cod tagged in the western Gulf of Maine were predominantly recaptured within this area, suggesting this is a distinct population. Cod tagged in the Great South Channel were recaptured within this region as well as to the northwest in the western Gulf of Maine. This agrees with the view of a complex of inshore winter spawners distributed from Ipswich Bay to southern New England, including the Great South Channel. Information from more traditional

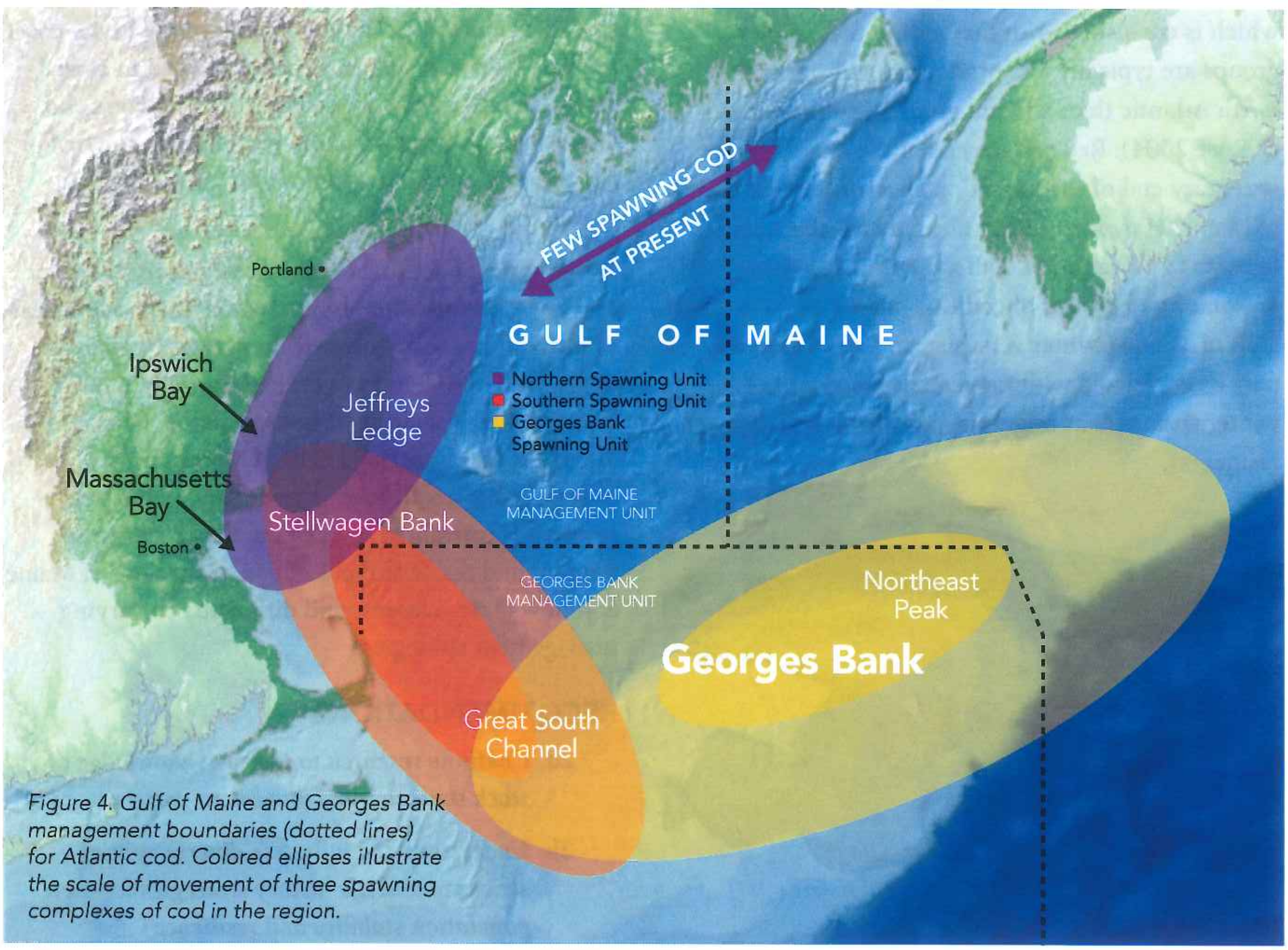

Figure 4. Gulf of Maine and Georges Bank management boundaries (dotted lines) for Atlantic cod. Colored ellipses illustrate the scale of movement of three spawning complexes of cod in the region.

stock identification techniques also generally supports the genetic perspective on stock structure, including additional tagging work (Hunt et al. 1999, Groger et al., 2007, Howell et al. 2008) and examinations of life history parameters (Begg et al 1999, Tallack 2009), larval dispersal (Lough et al. 2005, Huret et al. 2007, Churchill et al. 2011), and body morphology (Sherwood and Grabowski 2010, 2012).

Even within these stocks, there is considerable variability in life history that has implications for the productivity and spatial management of the fishery. Sherwood and Grabowski (2010) described the ecological characteristics of "red" cod that appear to be a highly resident form of cod (*Figure 5*). Red cod tend to use shallow kelp habitats (mostly inshore but also at Cashes Ledge in the center of the Gulf of Maine), whereas "normal" cod roam over larger, deeper areas. Furthermore, red cod are smaller at age which is consistent with the finding that resident groups are typically less productive throughout the north Atlantic than migrant groups (Robichaud & Rose 2004). Red cod may be at the extremely sedentary end of the migration spectrum in the Gulf of Maine. However, within normal cod, there also appears to be variation. Differences in spawning season of two groups of cod that spawn in the western Gulf of Maine (winter versus spring, discussed above) may be correlated with movement behavior (i.e., winter spawners as migrants and spring spawners as residents).

Figure 5. Normal and "red" cod.

Given the variability in migratory behavior that exists both among and within cod stocks, is it possible that fishing and fishery management practices have favored the proliferation of residents over migrants? In the Gulf of Maine and Georges Bank, five year-round closed areas may be favoring "stay-at-home" individuals (i.e., cod that reside within the safe confines of areas protected from bottom trawling, which collectively represent 22,000 km^2 of habitat) (Sherwood and Grabowski, in prep). In addition, under the previous days-at-sea management system, a day of fishing in the western Gulf of Maine counted as two days under the management rules. This may have created a de-facto closed area that favored resident cod (i.e., spring spawners, Runge et al. 2010) over cod that presumably only migrated there to spawn (i.e., winter spawners, Runge et al. 2010). Thus, past conservation measures may be inadvertently favoring non-migratory cod, possibly to the detriment of the stock's productivity. These potential productivity costs must be balanced against benefits accrued in closed areas, such as robust age structures (Sherwood and Grabowski, in prep.), to fully evaluate the value of closed areas as a management tool for the Gulf of Maine cod population.

While some of the links between migratory behavior and stock performance are uncertain, it is nonetheless of interest that many historical migratory pathways in the Gulf of Maine have broken down and failed to recover (particularly in eastern Maine, i.e. Ames 2004). At the same time, Gulf of Maine cod are experiencing record lows in abundance. Further research is warranted to examine the existence of migrant and resident types of cod in the Gulf of Maine and how these may respond differently to varying management strategies.

RECOMMENDATIONS

- *2a. Continue research to improve knowledge of stock structure and movement patterns*
- *2b. Understand the influence diverse spatial structure and life history strategies have on population stability and resilience*

3. Stock Assessments and Management

The discussion above presents a range of processes that could explain poor performance of Gulf of Maine cod, or, in the case of complex stock structure, could complicate the assessment and management of the stock. Accounting for these processes in assessment and management efforts is essential to establish the long-term viability of the stock.

The need for accurate stock assessments is now even stronger due to the mandate to assign annual catch limits (i.e. quotas) under sector management. As discussed above, the stock boundaries used in the assessments are uncertain. Changing the boundaries to more accurately reflect the true biological stock boundaries of this species may improve the assessment and subsequent management decisions. Although easy in principle, such a change would not be simple and would require considerable work to construct and parameterize the assessment models.

The impact of physical conditions on cod has important implications for sustainable management of this species, particularly in the context of climate change. While these ecological interactions are widely recognized, it remains challenging to incorporate them formally into fishery management processes. Implementing standards of the Magnuson Act often relies on historical stock conditions as baselines against which current biological reference points are assessed. Although there are provisions in the Act to change reference points in response to short-term and long-term environmental conditions, it is difficult to use these provisions effectively due to limitations in our ability to predict how physical changes will affect individual stocks. Incorporating environmental influences into stock assessment models and coupling stock perspectives with broader ecosystem changes that will affect species' distributions and productivity are critical advances for successfully managing cod in the context of environmental variability and climate change.

Sector management offers fishermen the flexibility to define when and where they target a particular species. However, in the absence of other management tools such as time or area closures, sector management does not protect some of the unique aspects of cod biology, including spawning behavior, spatial structure, and age-specific reproductive value, that are important to the sustainability of the resource. The spawning behavior of Atlantic cod is complex and occurs in discrete space and time, requiring dense aggregations of fish for maximum recruitment success (Dean et al. 2012). The aggregation of fish for spawning makes them susceptible to intense fishing pressure and even complete removal from an area when protective provisions are not in place (e.g., spawning closures to fishing activity). Spatial structure can have a stabilizing influence on recruitment variability, and failure to protect stock structure may result in a resource that is less resilient to perturbation (Berkeley et al. 2004). Together these biological features are important to maintaining a healthy cod stock, and when the stock is depleted to very low levels, these biological attributes can be critical to stock recovery.

Closed areas have been identified as one of the most effective approaches to protect age structure, spatial structure, and the spawning behavior of cod (Berkeley et al. 2004, Dean et al. 2012). Closed areas in the Gulf of Maine were established primarily to reduce mortality of groundfish including cod and haddock (Murawski et al. 2005), and recent work has shown that they are indeed effective at protecting older, larger cod (Sherwood and Grabowski, in prep). From the outset of sector management, many industry members called for opening areas previously closed to fishing, arguing that under a quota-based system, closed areas were no longer necessary to control catch levels. With the severe cuts to cod catch limits, calls for opening closed areas have grown even louder as fishermen fear the cod reductions will severely limit their ability to harvest other, more abundant, stocks. However, catch limits do not conserve age structure and life history diversity, both potentially crucial to population resiliency and long term productivity. Thus, the use of closed areas as a management tool still has value under sector management, if for no other reason than to provide a backstop for over-optimistic assessments and subsequent quota determinations (e.g., as was the case following the 2008 assessment).

RECOMMENDATIONS

- *3a. Develop stock assessment models that incorporate environmental influences, including changes in temperature and prey*
- *3b. Conduct an interdisciplinary evaluation of population structure for definition of appropriate fishery management units*
- *3c. Incorporate knowledge of life history and age structure when modifying closed areas.*

4. Improving Profitability

New England's groundfish fishery is facing a steep challenge of how to make do with less cod. Cod typically accounts for 30-40% of the annual groundfish landings (Sun, 2013a). The reduction in cod quota will have a direct impact on the bottom-line of the industry, but the complexities associated with the mixed fishery will amplify the loss. Even at the current low abundance, it is difficult to avoid cod altogether. It is likely that many fishermen will reach their limit of cod well before they reach their limit for other groundfish. When a fisherman reaches his quota of cod, he must buy quota from someone else or stop fishing to avoid the steep penalties associated with exceeding the quota. The challenge for the industry is how to maximize profits from more limited fishing opportunities. Innovations in fishing gear, fishing operations, and marketing can each help either reduce costs or increase revenue.

Will cod survive in a warmer Gulf of Maine?

Cod are a subarctic species, and the stocks in the Gulf of Maine and on Georges Bank are at the southern limit of their range. While cod are found in the mid-Atlantic region, their abundance is low and the species is not commercially important. Given the strong consensus among climate scientists that global temperatures will rise, an obvious question is whether cod will persist in the Gulf of Maine through the coming century.

Two studies have attempted to answer that question. Drinkwater (2005) analyzed how temperature changes have impacted cod stocks from around the North Atlantic. For stocks in cold water, such as those off of Newfoundland and Norway, an increase in temperature increased the productivity of the stock. For stocks in warm water, such as those in the Irish Sea, warming resulted in fewer cod. The Gulf of Maine is in the middle. He then used these relationships to project how increases of 1-4°C would impact each stock. These projections indicate that warming of 3°C or more would lead to a reduction in cod production in the Gulf of Maine but would not lead to a collapse. In contrast, any warming is expected to lead to a collapse of cod in the Irish Sea, but increased abundance off of Newfoundland.

Drinkwater's analysis shows the range of possible outcomes, but he did not attempt to determine which outcome (1° vs. 4°C) is more likely. Fogarty et al. (2008) used the output from several global climate models to estimate the changes in bottom temperature on Georges Bank and in the Gulf of Maine. Their work suggests that the Gulf of Maine will warm by 2°C by the end of the 21st century and that Georges Bank will warm by more than 3°C. Based on Drinkwater's calculations and their own, Fogarty et al. (2008) suggest that the Georges Bank stock will decline, but the Gulf of Maine stock should remain productive. One important caveat with these simple forecasts is that it difficult to estimate the confidence interval around them. For example, if we assume that the 2°C forecast for the Gulf of Maine has a 1° margin of error, then there is a 16% chance that the mean temperature will actually exceed 3°C, severely challenging the viability of the stock (of course, there is also a 16% chance of an increase of less than 1°C).

The stock predicted to be less productive and will not be able to support the same level of fishing effort. Even if the change in mean temperatures is not enough to threaten cod, we can expect to see an increase in the frequency of years with temperatures warm enough to stress the population. For example, the mean temperature in 2012 was 3° warmer than normal and was likely very stressful for cod. In order for cod and the fishery to survive, managers will need to be able to rapidly respond to these events in order to avoid overfishing. Understanding the impact of extreme years in addition to the impact of the long-term warming trend is important for devising effective management approaches to sustain fisheries under changing climate patterns.

The type of fishing gear and how it is deployed influences the composition of the catch and the cost of fishing. The GEARNET program, funded by NOAA's Cooperative Research Program, is currently working with the fishing industry to develop gear that is more selective. The eliminator trawl, for example, is designed with large mesh netting in the lower belly and has demonstrated an excellent ability to allow cod to escape while retaining haddock and pollock (Beutel et al., 2008). Reducing the netting on the top of the trawl could successfully avoid catching cod while maintaining catches of yellowtail flounder (Tallack, unpublished). Presently, diesel fuel is a fisherman's largest operating cost. In recent tests, a new net with 7 inch mesh and smaller diameter twine reduced drag and yielded a 22% fuel savings with no loss of commercial catch (S. Eayrs, pers. obs.). The use of semi-pelagic doors is another fuel saving option. Designed to operate clear of the seabed, these doors are more hydrodynamically efficient than traditional trawl doors and can reduce fuel consumption by at least 10% while also reducing seabed impacts.

Where and when a fisherman chooses to fish also influences the volume, composition, and quality of his catch. Most fishermen have a good understanding of fish behavior, including preferred habitats, timing of movements into particular fishing grounds, and response to fishing gear; however, there is always a high degree of uncertainty about what will come up in the net. Sharing knowledge, experience, and real-time observations within a sector or across the industry would allow fishermen to avoid areas where cod are currently aggregating and target areas where other species are abundant. Since each of the individual groundfish sectors is too small to have an impact in the marketplace, a coordination across sectors would be needed to develop generic marketing strategies to increase the value of the catch. For example, coordination could allow the industry to optimize the timing of their landings to take advantage of periods when price is high or to smooth out their landings to build up a consistent supply of better quality fish. Eventually, such planning could extend to more sophisticated arrangements between fishermen and dealers, possibly including forward contracts (Sun, 2013a; Sun, 2013b).

One of the steep barriers facing the industry is the relative inelasticity in the price of groundfish. Basic economics suggests that the price of a product should go up if supply decreases. Although there is some increase in groundfish prices when supplies are limited, the increase is unlikely to be large enough to compensate for the reduction in quota. This is due to the fact that cod and most of the other groundfish in New England are part of a global market for generic whitefish. Thus, one solution is to aggressively market Gulf of Maine cod and other groundfish to distinguish them from other whitefish. Consumers are becoming more sophisticated about where their food comes from, creating opportunities for local sourcing of seafood. Local sourcing has the potential to raise prices but likely only for high quality fish. This would require building markets for under-appreciated and more abundant Gulf of Maine species by connecting local fishermen, restaurants, and food service providers.

RECOMMENDATIONS

- 4a. *Encourage the development and use of fishing gear that avoids cod and reduces fuel consumption*
- 4b. *Explore business planning and marketing strategies to maximize value of each fish caught*

Conclusions

Cod remains an iconic species in the waters of the Gulf of Maine, not only for its historic prevalence in the ecosystem but also for the cultural significance of its fishery. However, recent developments highlight the challenges facing cod. The unexpectedly low abundance revealed by the last stock assessment is compounded by apparent biological, distribution, and ecosystem changes that may constrain cod recovery. Further, the effects of rising water temperature and food web shifts will be exacerbated as climate change progresses.

Sustaining cod in the Gulf of Maine will require focused efforts to understand the ecological factors that are impacting cod as well as innovative approaches to enhance management and profitability of the fishery. Building the scientific information base from which assessment and management approaches can be refined is a key step, as are efforts to encourage data sharing among fishermen, increase fishing selectivity, reduce fuel use, and broaden markets.

The challenges facing Gulf of Maine cod are not unique. Fisheries around the world are struggling to avoid overfishing and to develop management structures that ensure their long-term sustainability. This struggle is taking place against the backdrop of economic changes due to globalization and high fuel prices and an increasingly unpredictable physical environment. Although the challenges for the Gulf of Maine cod population and fishery are steep, they present an opportunity to develop and test strategies that will allow fisheries to adapt to climate and economic changes.

Acknowledgments

This paper is a joint effort between the Research and Community Programs at the Gulf of Maine Research Institute. This is our attempt to characterize the state of knowledge of Gulf of Maine cod and to begin a process to develop solutions to the severe challenges facing the fishery. We recognize the valuable contributions of our partners in the federal, state, academic, and NGO communities and in the fishing industry to understanding this species and its fishery. We look forward to continued collaborations and believe that moving forward will require the engagement of the entire community.

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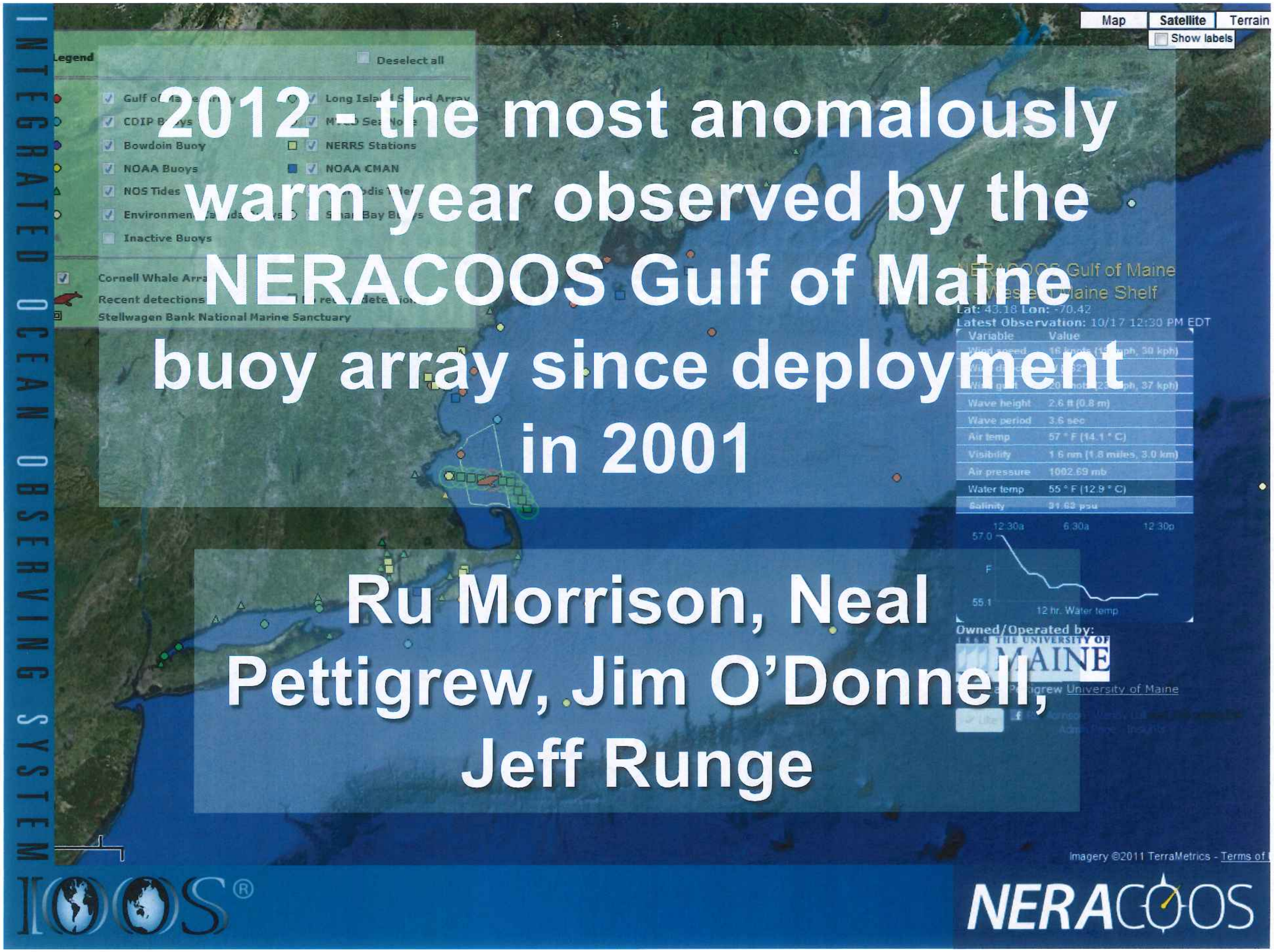
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NOAA Buoys
NOS Tides
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NERRS Stations
NOAA CMAN
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Stellwagen Bank National Marine Sanctuary
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Latest Observation: 10/17 12:30 PM EDT
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Wave period
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Air temp
57 ° F (14.1 ° C)
Visibility
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Air pressure
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Water temp
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University of Maine
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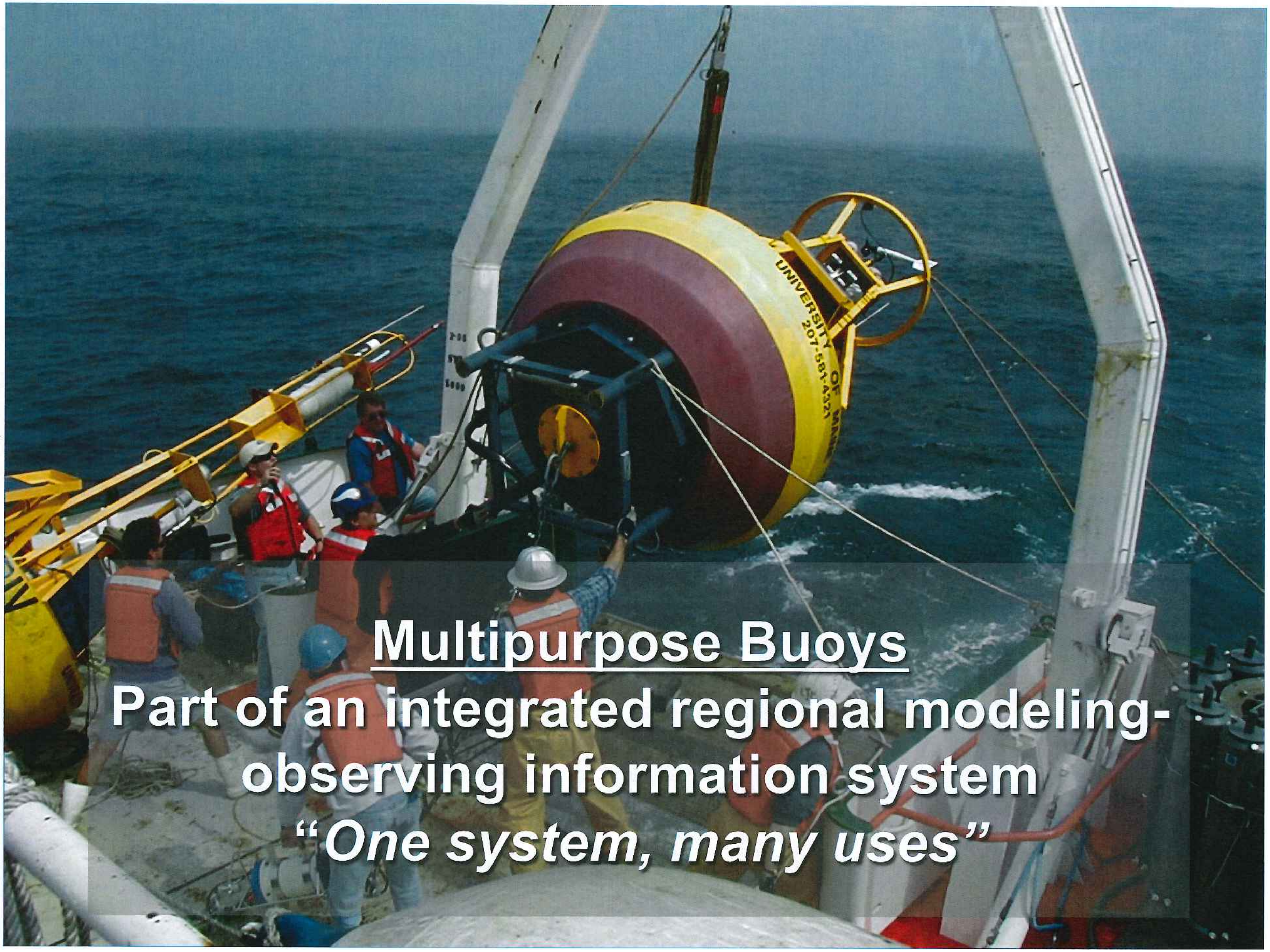
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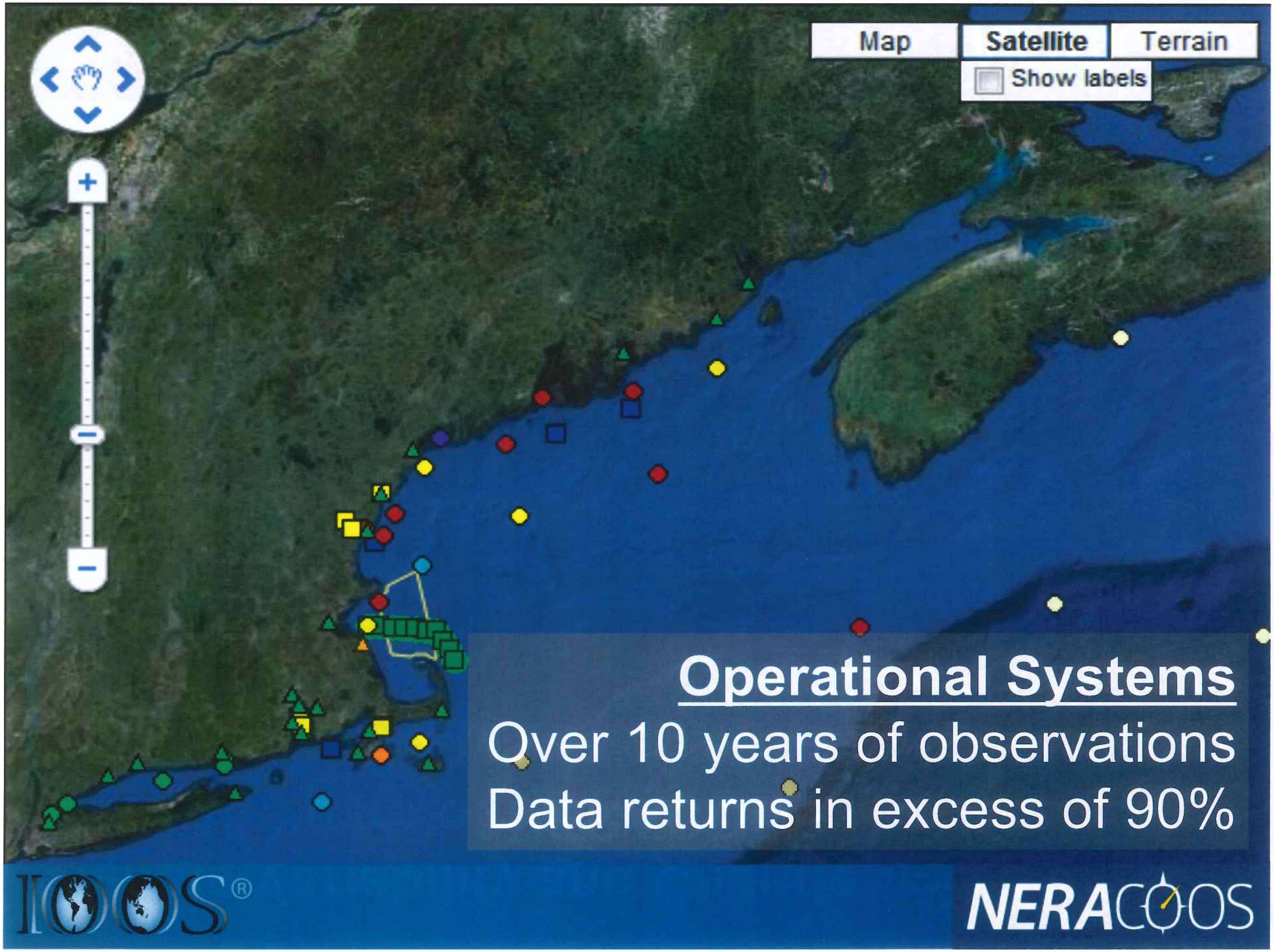
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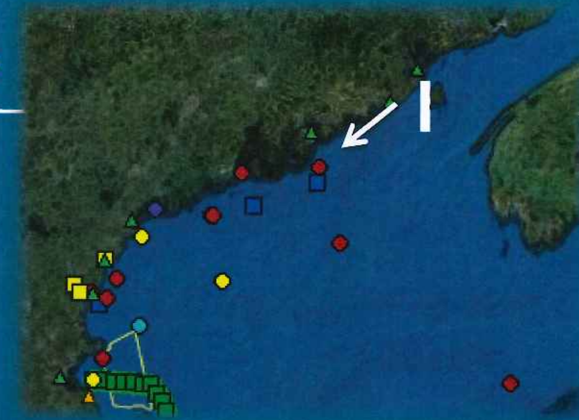

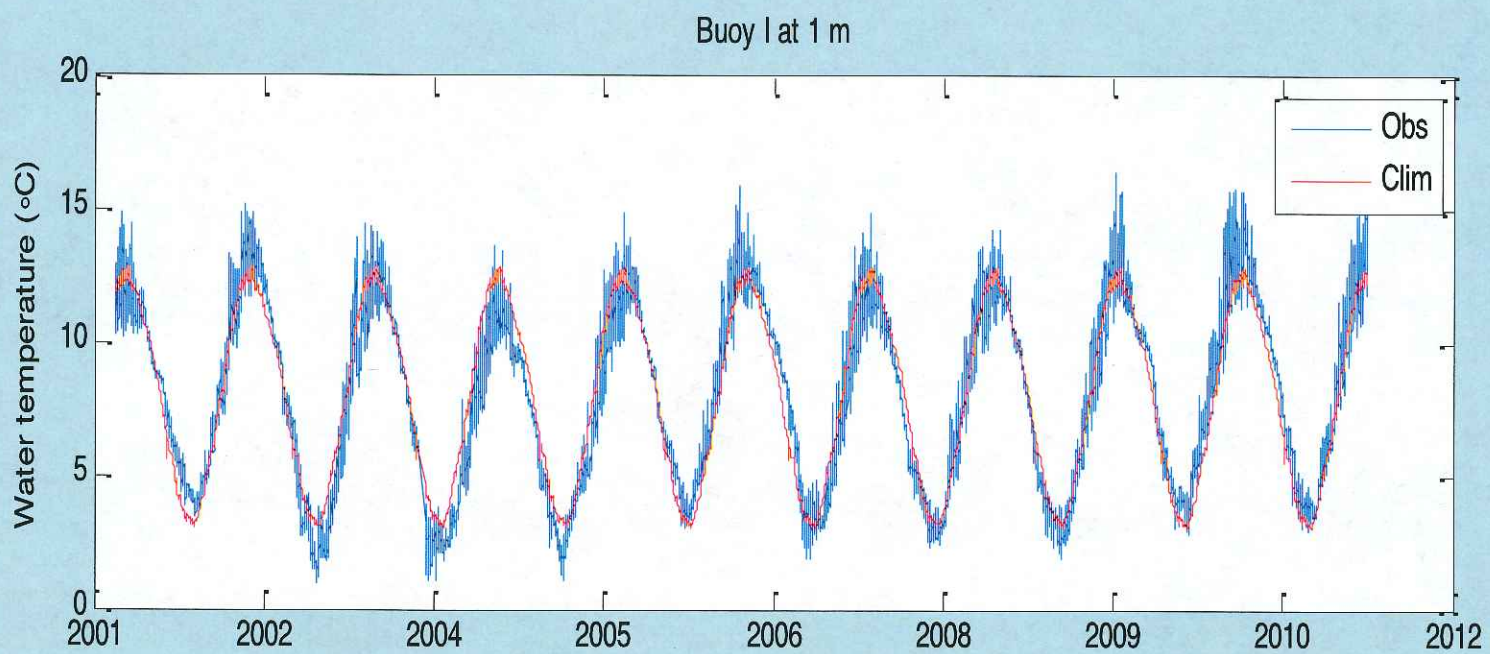

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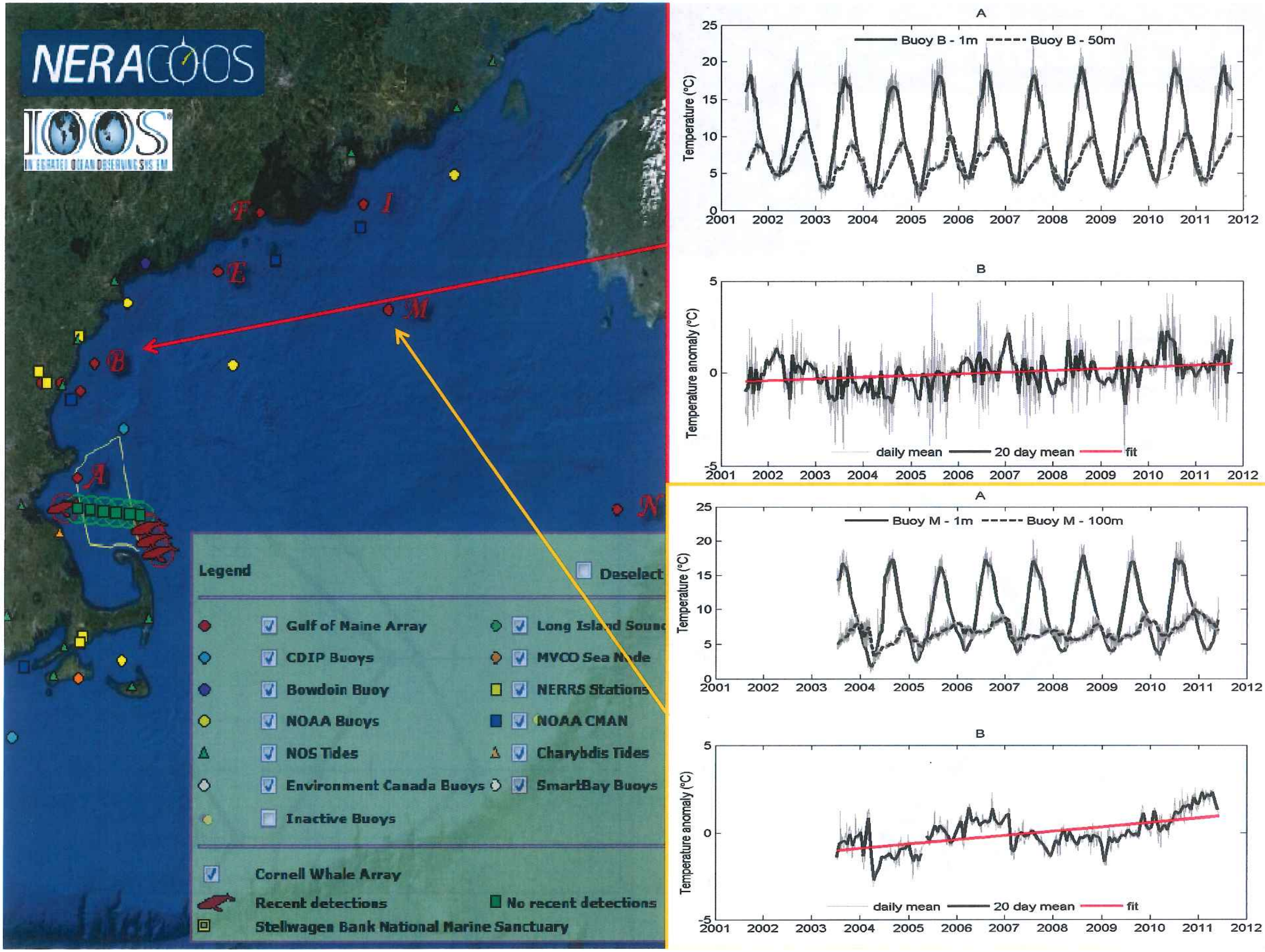
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Environment Canada Buoys
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NERRS Stations
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Charybdis Tides
SmartBay Buoys
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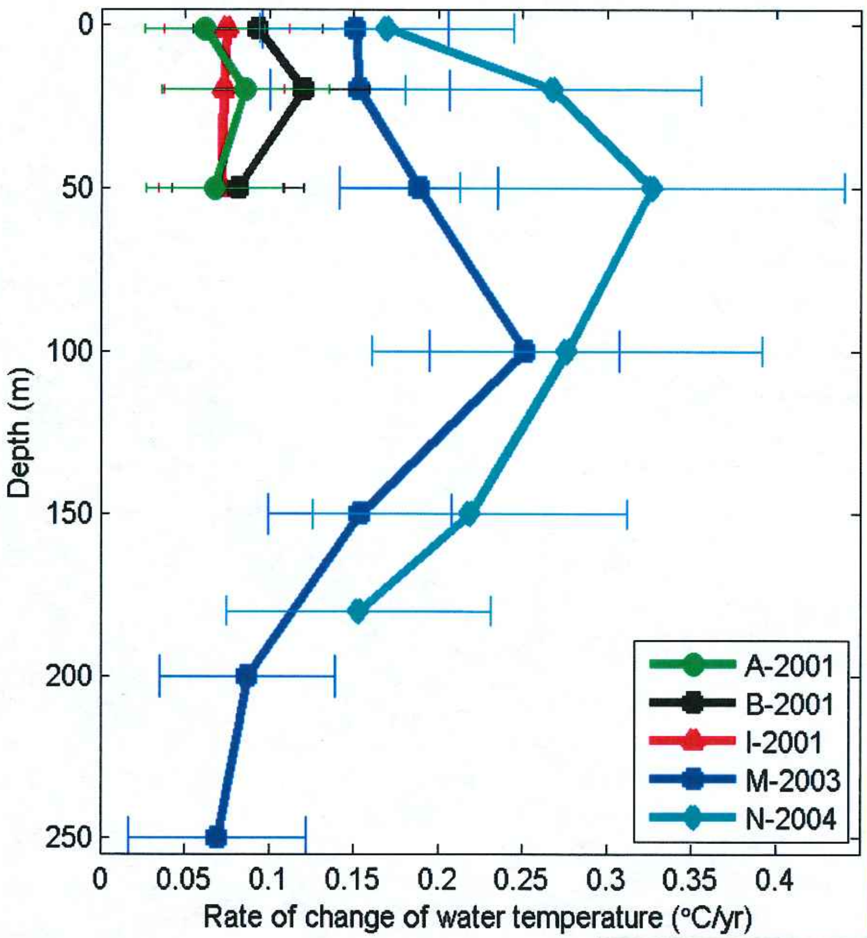

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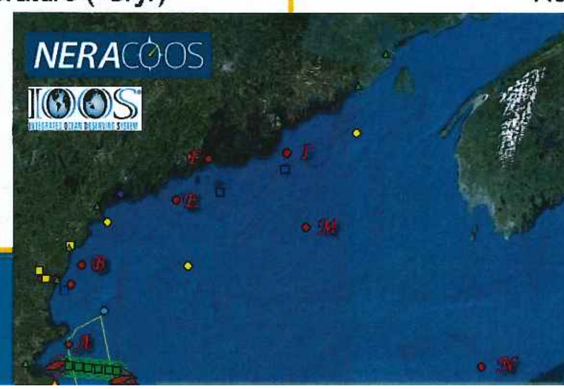

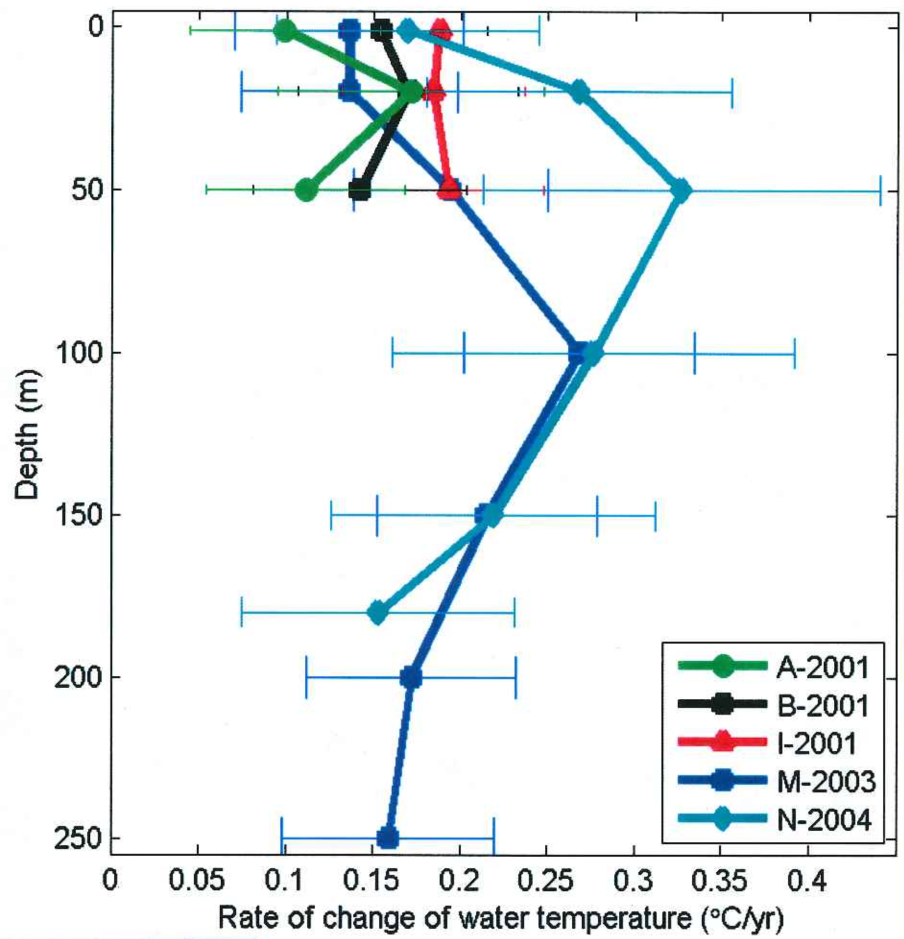

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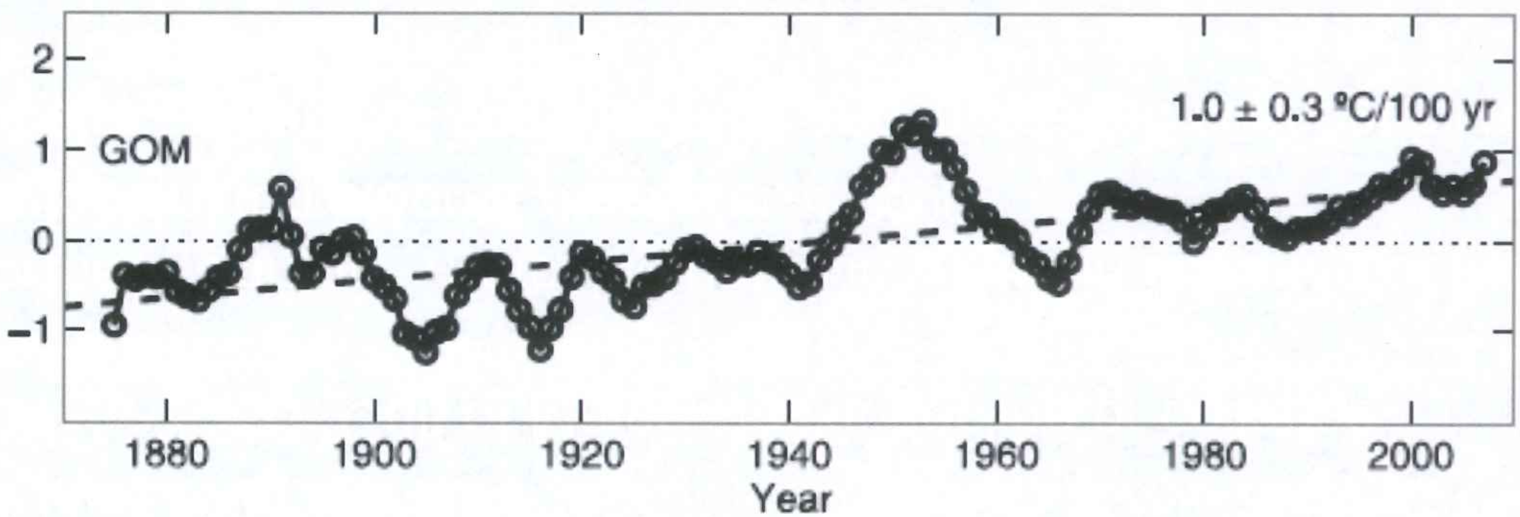

FIG. 8. Composite average SST anomalies (black) for GOM, MAB, SAB, and FL, smoothed with a 5-yr running mean, plus regional surface air temperature anomalies (gray) for the northeast United States, southeast United States, and Labrador. Best linear fits are plotted (thick dashed lines), and trends with 95% confidence intervals are noted.

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Potential Ecosystem Impacts

- Physical forcing – alterations to primary production cycles, timing of prey availability, predator-prey interactions and composition of species assemblages *(MERCINA 2001, Greene and Pershing 2007, Nye 2010, Ji et al. 2010, Lucey and Nye 2010)*
- Cod – >2-3°C, Gulf of Maine stocks decline or collapse *(Drinkwater 2005, Fogarty et al. 2008)*
- Northern Shrimp – hatching dates in winter in advance of the phytoplankton blooms *(Koeller et al. 2009)*
- Lobster – timing of summer molt and increased susceptibility to shell disease *(Steneck et al. 2011)*
- *Calanus finmarchicus* – key prey for forage species such as herring, sand lance, mackerel, as well as for the northern right whale. Projected to disappear from GoM *(Reygondeau and Beaugrand 2011)*

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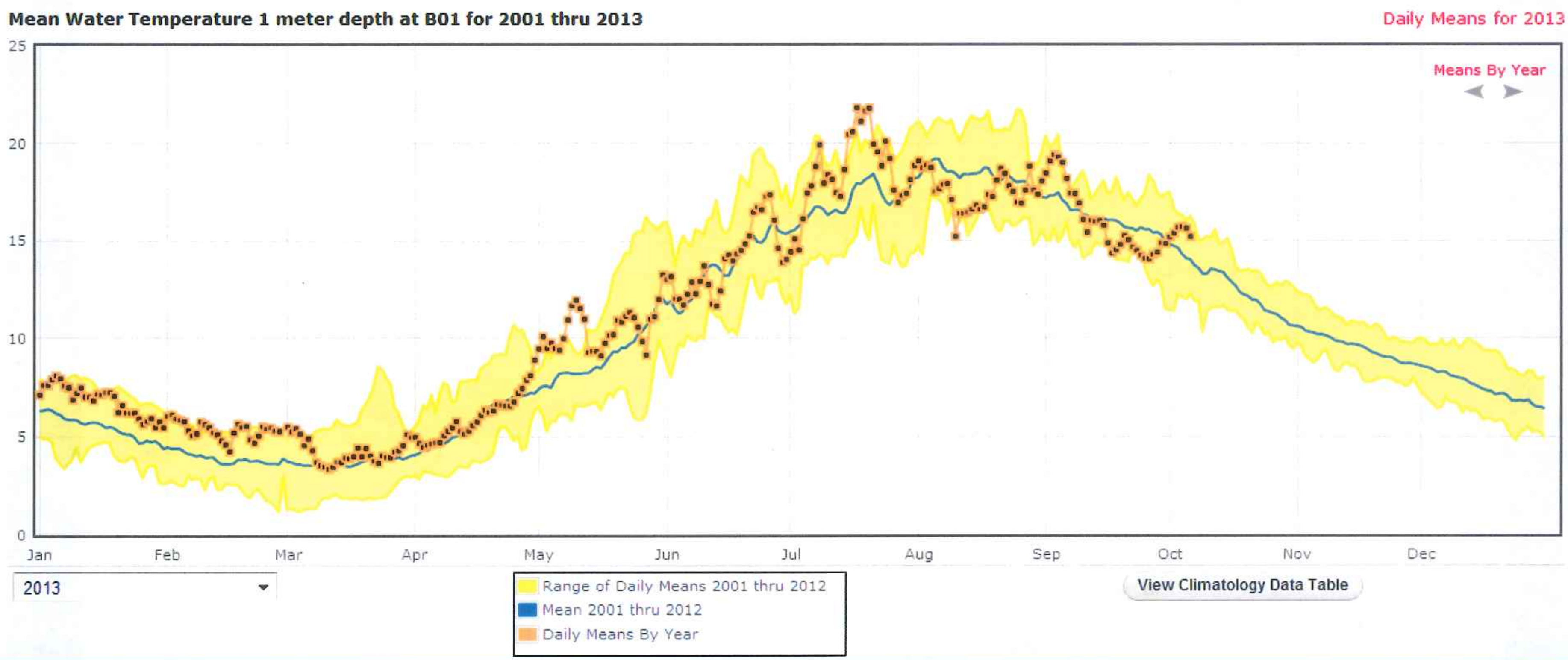

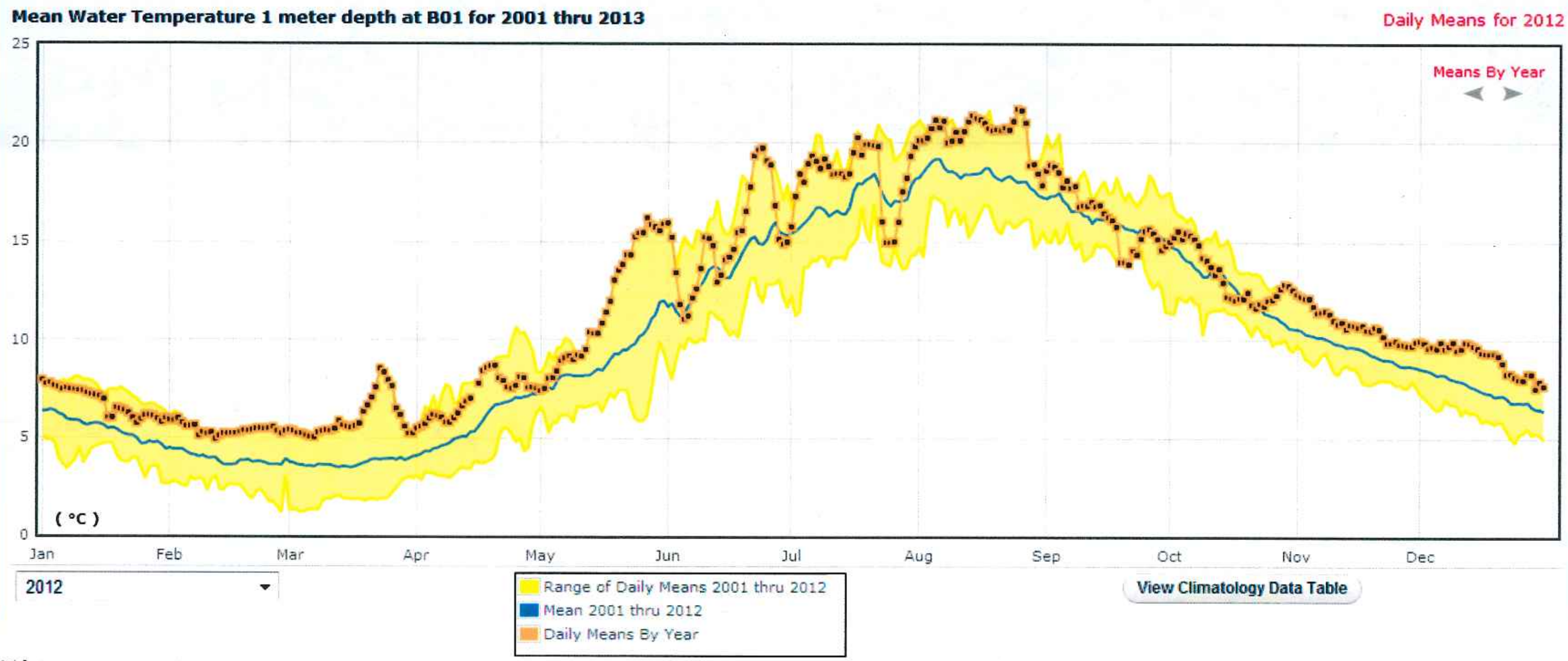

Mean Water Temperature 1 meter depth at B01 for 2001 thru 2013
Daily Means for 2012
Means By Year
25
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(°C)
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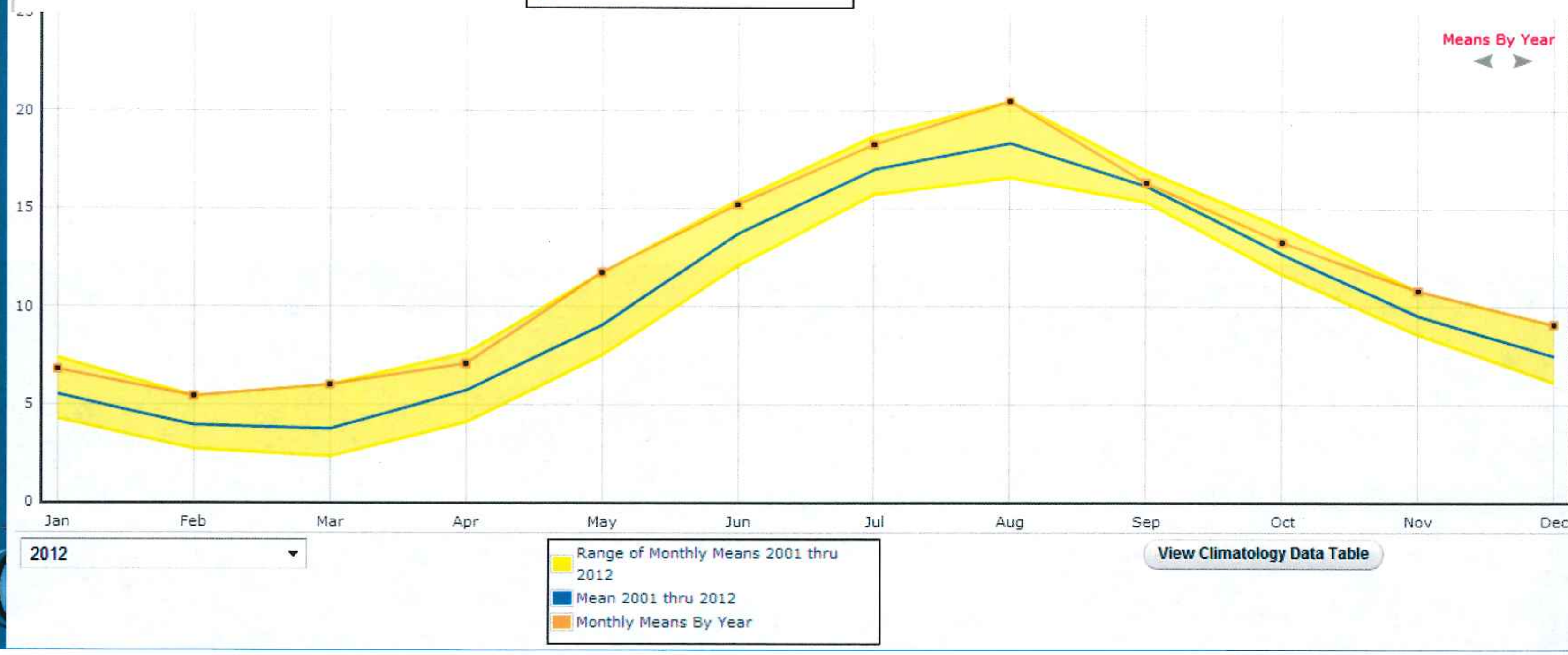
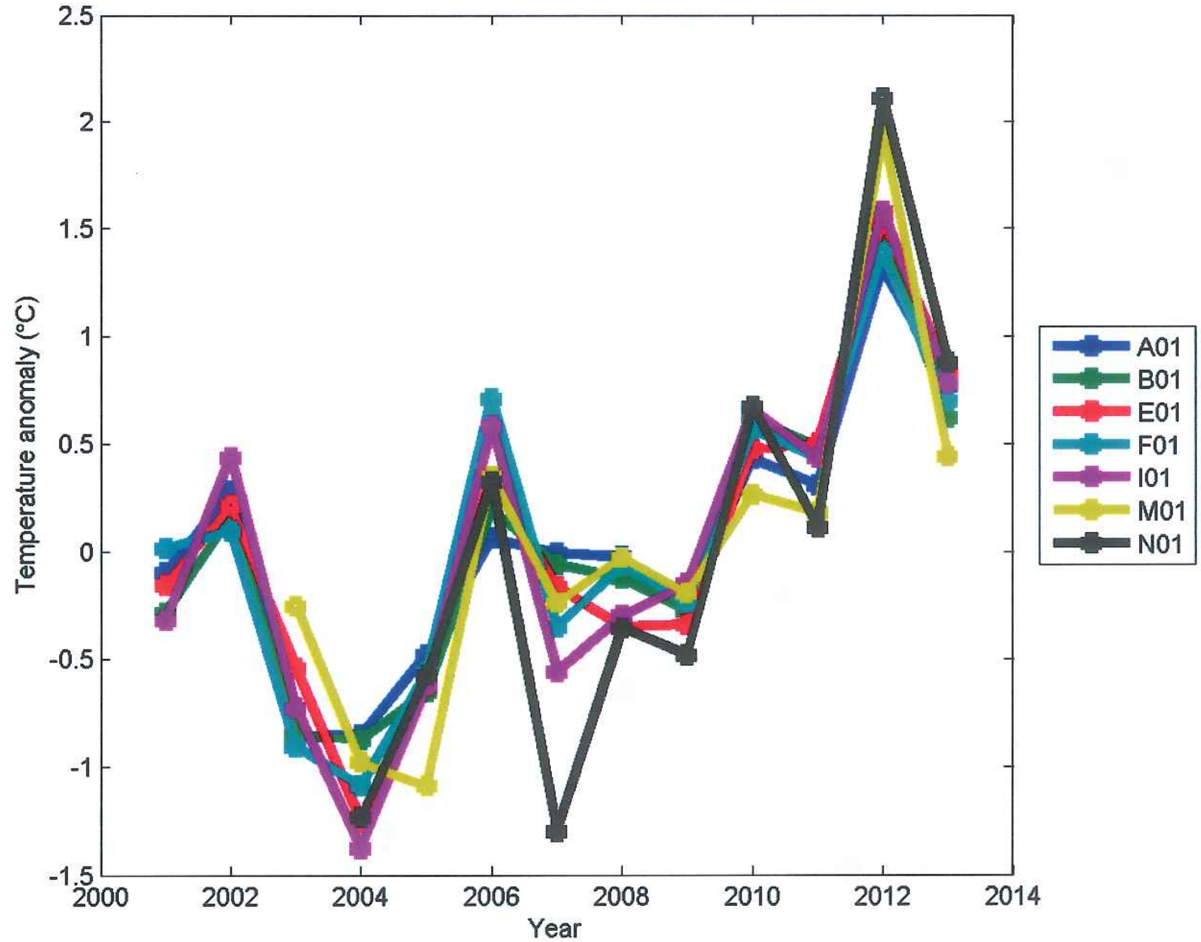
Range of Daily Means 2001 thru 2012
Mean 2001 thru 2012
Daily Means By Year
View Climatology Data Table



Means By Year
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2012
Range of Monthly Means 2001 thru 2012
Mean 2001 thru 2012
Monthly Means By Year
View Climatology Data Table

Temperature Anomaly at 1 m



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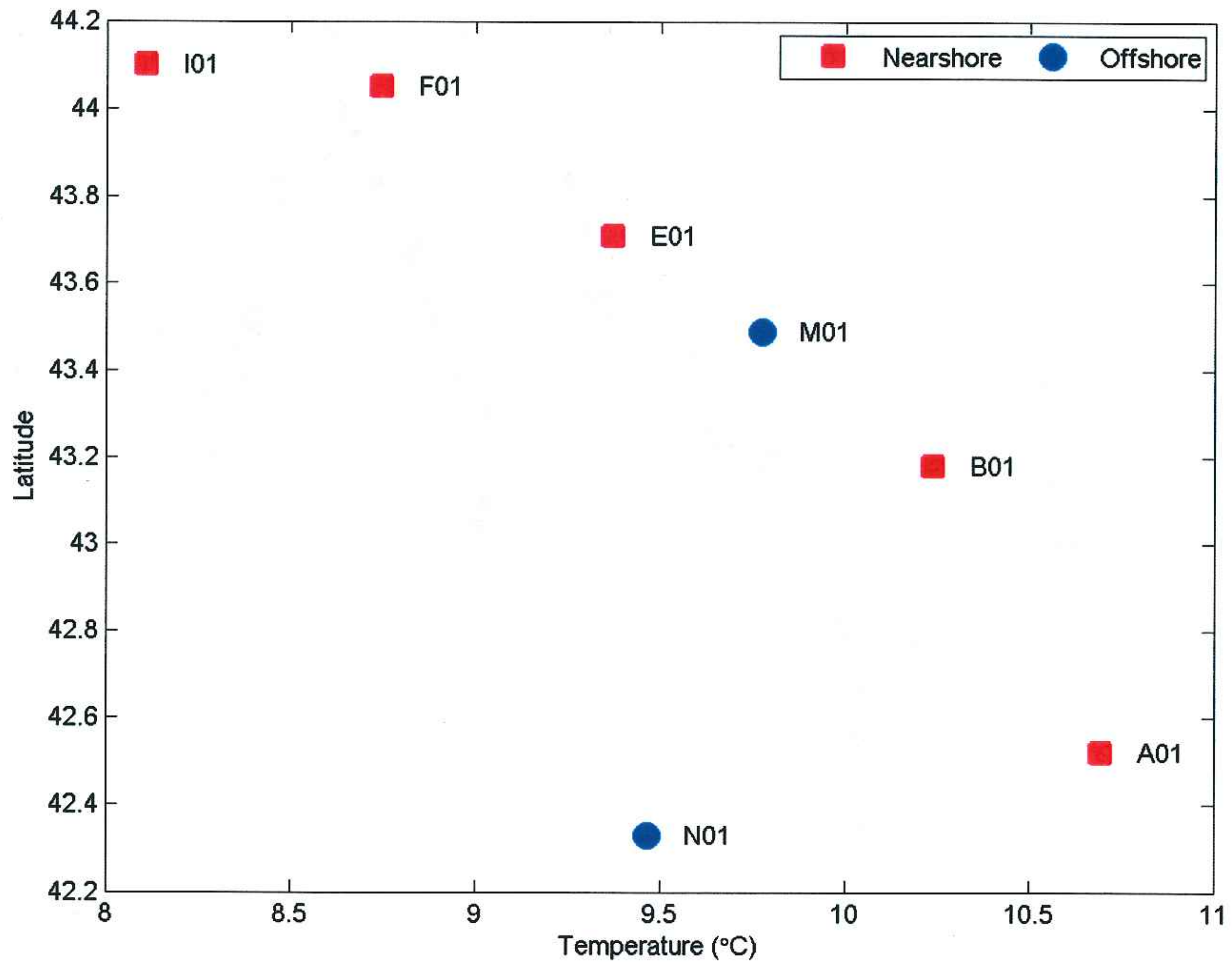
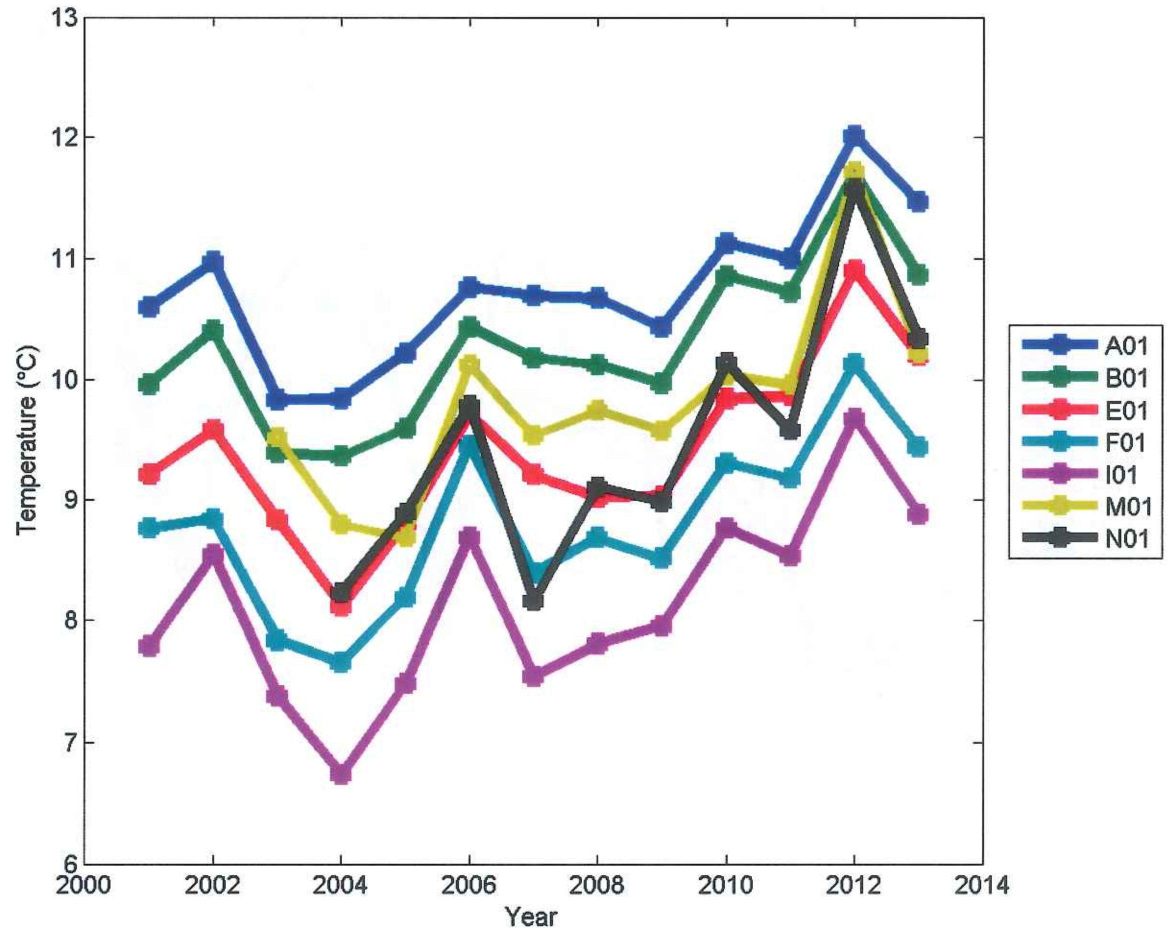
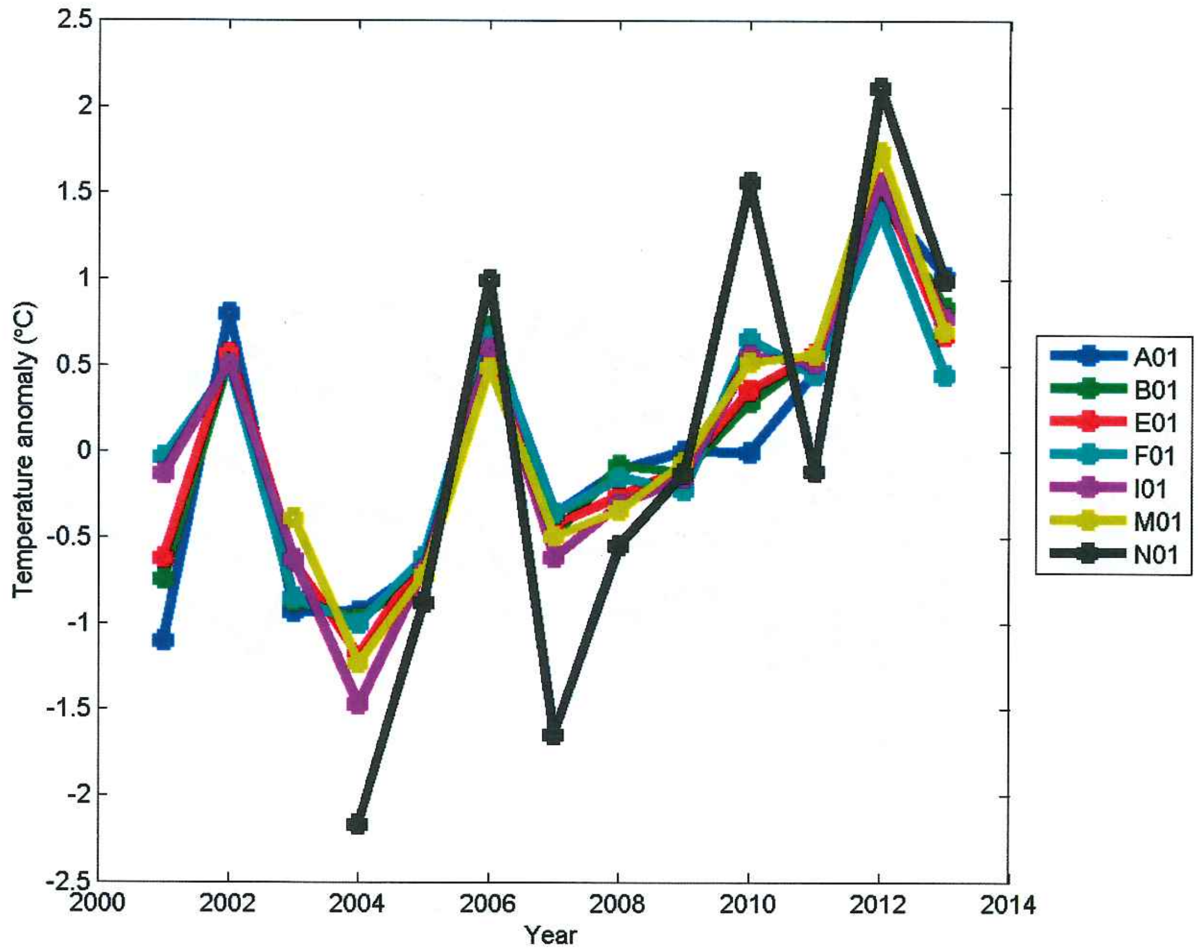
Mean Temperature at 1m with latitude



Annual Average Temperatures at 1m



Temperature Anomaly at 50 m



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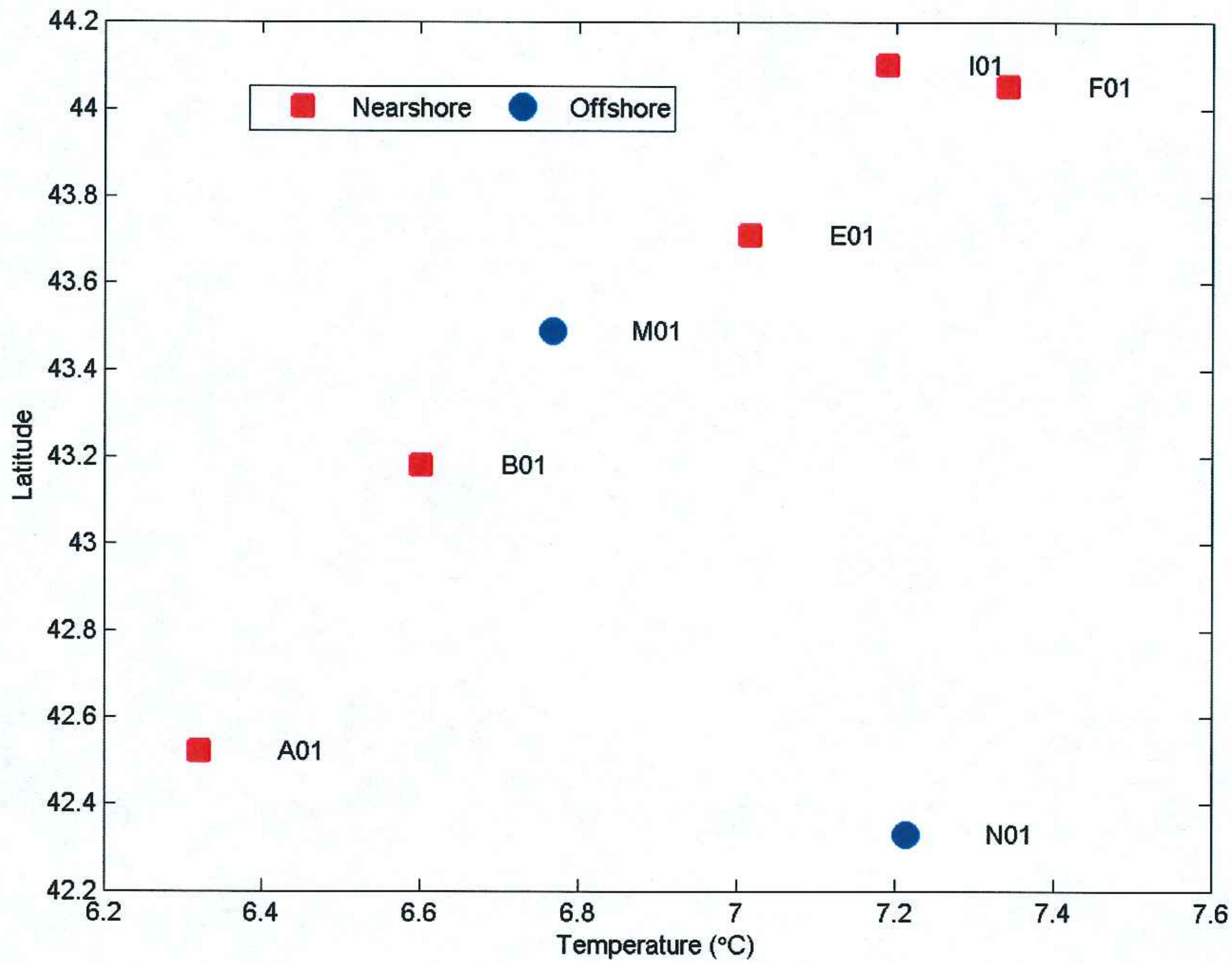
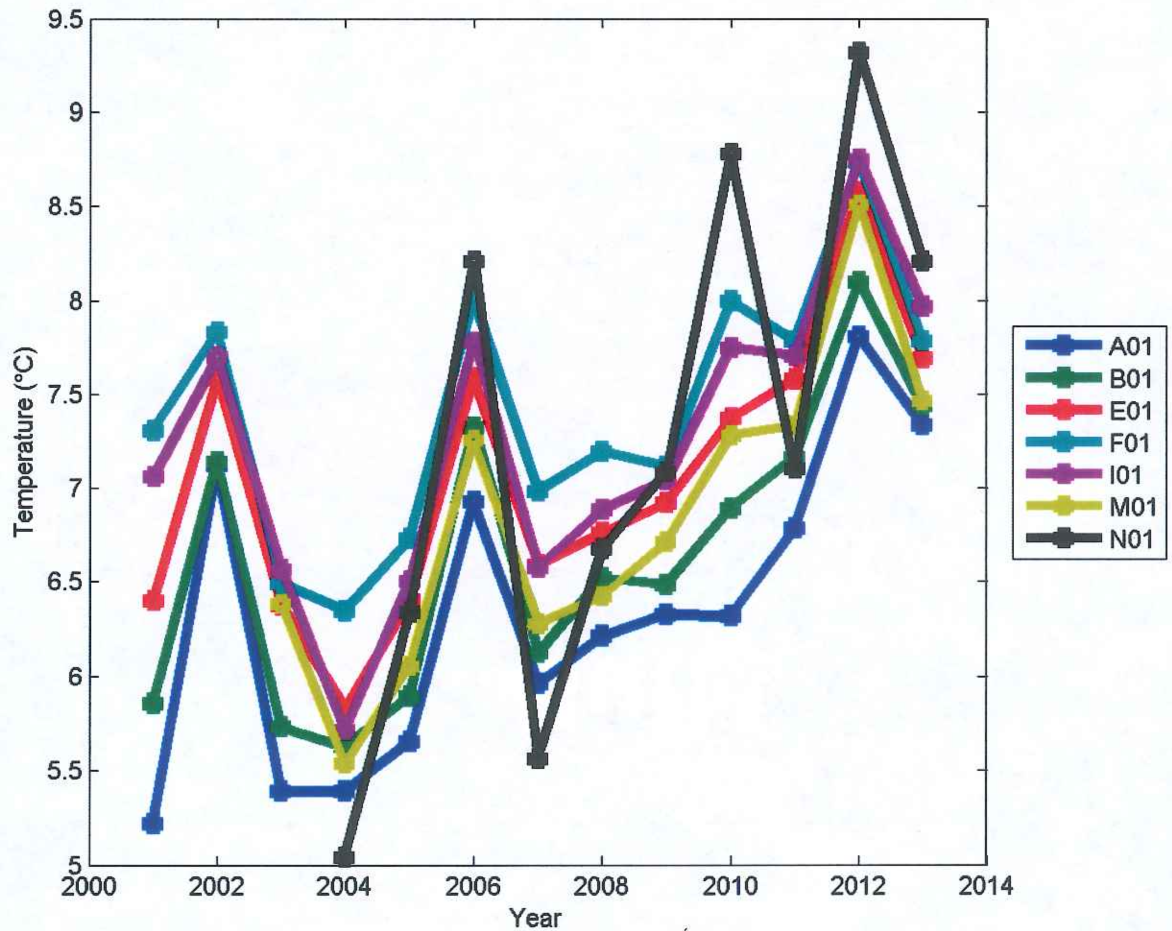
But!

Mean Temperature at 50m with latitude

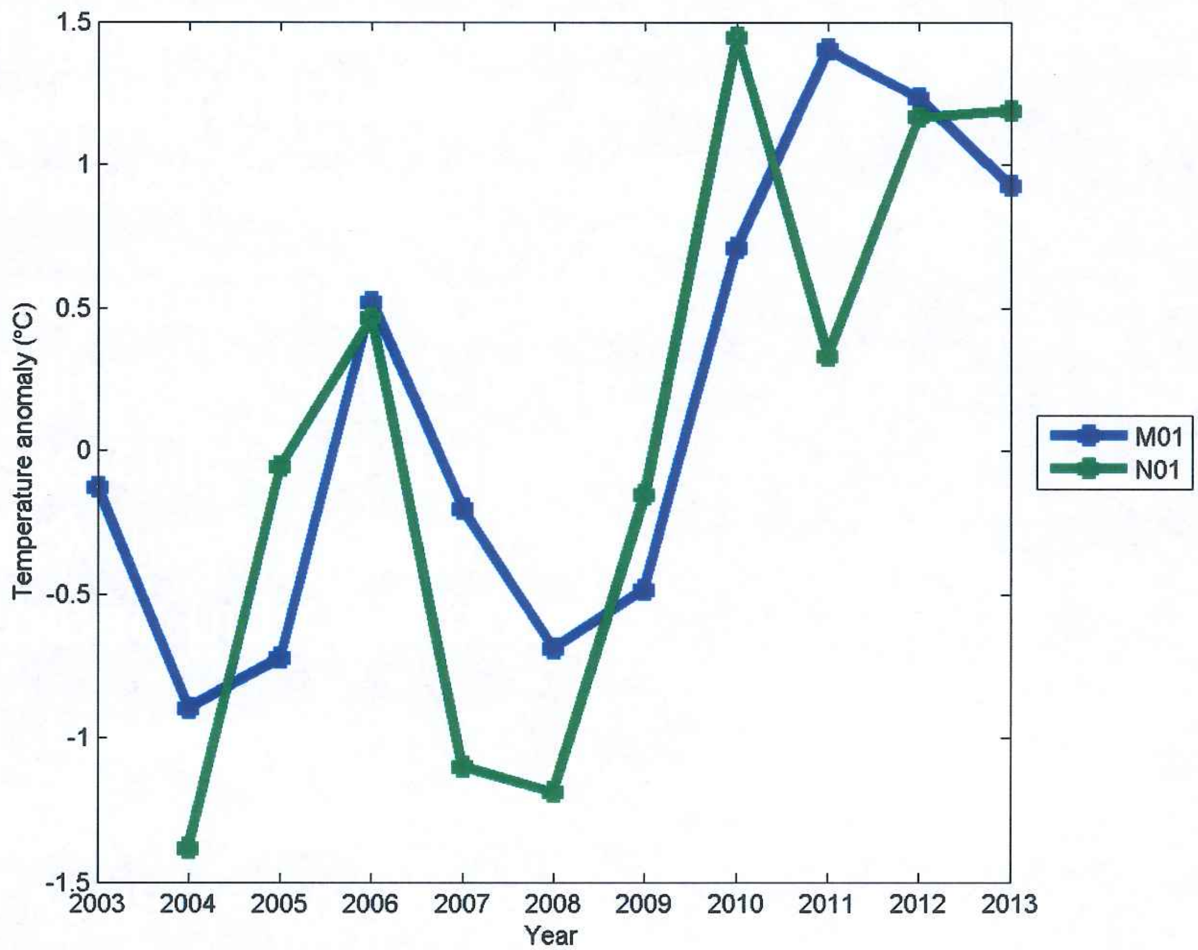


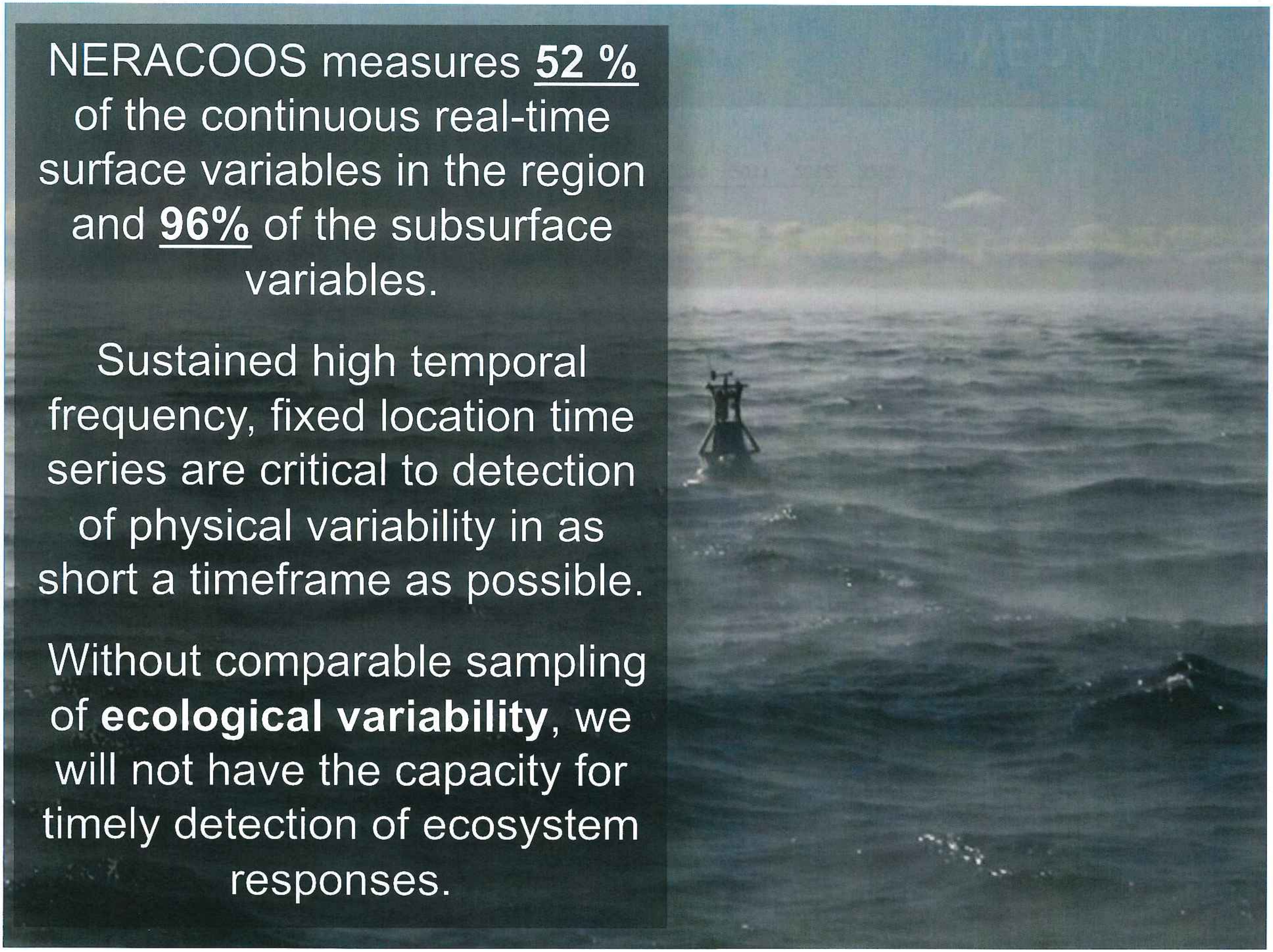
Annual Average Temperatures at 50m



But!

Temperature Anomaly at 150 m




NERACOOS measures 52 % of the continuous real-time surface variables in the region and 96% of the subsurface variables.
Sustained high temporal frequency, fixed location time series are critical to detection of physical variability in as short a timeframe as possible.
Without comparable sampling of ecological variability, we will not have the capacity for timely detection of ecosystem responses.

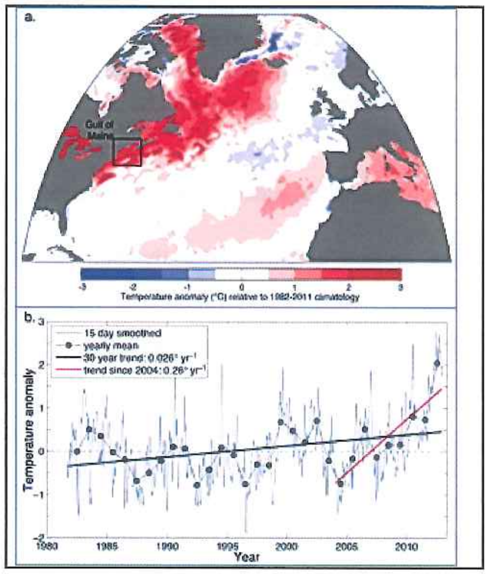
August 2013 Volume 18, No. 8

FISHERMEN'S VOICE

News and Comment for and by the Fishermen of Maine

Marine Heat Wave Research at GMRI

The Gulf of Maine Research Institute (GMRI) has published a paper on the abrupt change in water temperatures seen in the Gulf of Maine in 2012. Kathy Mills a scientist at GMRI said the higher than average temperatures from Cape Hatteras to Iceland in 2012 demanded that scientists look at the scale – in both area and magnitude – and their effects on fisheries.



Note the lower panel and 30 year temperature trend line (gray) compared to the 9 year trend line (red). Also the yearly mean for 2012. *GMRI Chart*

Temperatures were higher in 2012 but they had also developed three weeks ahead of schedule. This change effected inshore lobster migration, spawning and shedding. The timing of lobster landings was off as well which disrupted processors who were unable to handle the unexpected surge in product volumes.

Mills noted two objectives. First, while the 2012 temperature spike was one event it is very likely to be part of future weather patterns. Scientists work from models but they have not been studying how the effects of what their models tell them are impacting environmental systems and people. Second, addressing how management may have to adapt in order to be better prepared for future weather pattern impacts on fisheries.

Andrew Pershing and Janet Nye are scientists at GMRI and authors of papers on long range temperature changes in the Gulf of Maine (GOM).

There are two proposals in the pipeline looking at the water temperature problem said Pershing.

1. A project to look at the impact of warming events like 2012 and the general global warming trend on lobsters and the lobster fishery. This one is likely to start this fall, but until it's official, it's probably best to characterize it as something we hope to start.

2. A project to develop models to predict the timing of the peak lobster season and the composition of the catch (hard vs. soft shells) based on buoy temperatures. The idea is that these forecasts would be issued in the spring and updated as the season develops. Pershings initial stab at this is at: http://www.seascapemodeling.org/seascape_projects/2013/06/predicting-temperature-and-lobster-phenology.html

There is more information and graphs at Pershings website: seascapemodeling.org

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B.C. Fish Heating Up

Evidence of more southerly fish being found in the GOM is an indication of more sensitive fish on the move. When southern fish are seen in the GOM we know where they came from. A species of hake previously know to inhabit the continental shelf off New York is now in the GOM and Georges Bank.But when temperature sensitive historically native to the GOM fish disappear we don't necessarily know where they specifically went to find cooler water.

Research Institutes at Boothbay Harbor and the Woods Hole Oceanographic Institute have ocean temperature records back 100 years. The records that scientists in the GOM use begin in 1981. That was when the first satellites were launched to record sea surface temperatures. It was in the late 1990's that rising temperatures were seen to be impacting marine ecosystems.

Within the long-term trend of rising water temperatures there are decade long periods of more dramatic temperature changes both rising and falling. The water temperature event of 2012 is believed to be a part of a decadal period of change. Pershing noted that in the period from 1981 to 2012 sea surface temperatures rose .026 degrees C per year. Sea surface temperatures have risen .26 degrees C per year from 2004 - 2012. This translates to 0.05°F and 0.5°F. A 1/4 of a degree per year or a 10% rate of increase since 1981.

A similar figure to the one in the paper is in a blog post on potential impacts of warming on cod:
http://www.seascapemodeling.org/seascape_projects/2013/02/cod-in-the-gulf-of-maine.html

Pershing said it is very difficult to predict how temperatures will change. Predicting 5 days out or 20 years out is less difficult than making predictions for next year.

Temperatures on land that are 10 degrees above normal and last 3 to 5 days qualify as a heat wave. These temperatures can suddenly drop back to normal and things go back to normal. However, a one or two degree increase in sea temperature is a big deal. The higher temperature lingers longer. Water heats up and cools down more slowly than land.

The water temperatures in the GOM are affected by a more complicated natural system than the land areas. The normal seasonal melting of part of the ice cap sends cold fresh water into the GOM. That cold water flow has established stable patterns, currents, salinity changes, comfort and discomfort levels for marine life that rely on them.

How fisheries will be more broadly effected by sea water temperature changes and what kind of changes are needed on the management side to more effectively respond to these changes is what the GMRI proposals aim to study and draw conclusions.

Kathy Mills and Andrew Pershing have joint appointments with the University of Maine and the Gulf of Maine Research Institute.