TROPHIC STRUCTURE

State of the Scotian Shelf Report

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CONTENTS

1 ISSUE IN BRIEF

Trophic structure refers to the way in which organisms use food resources to get their energy for growth and reproduction, and is often refered to in simple terms as the "food web" or "food chain". A healthy marine ecosystem consists of trophic levels that have complex linkages to form a food web. A food web can be as complex as the connections of the world-wide web, but the concept can be understood if portrayed as a pyramid, with phytoplankton at the base of the pyramid, converting the sun's energy into food for organ-

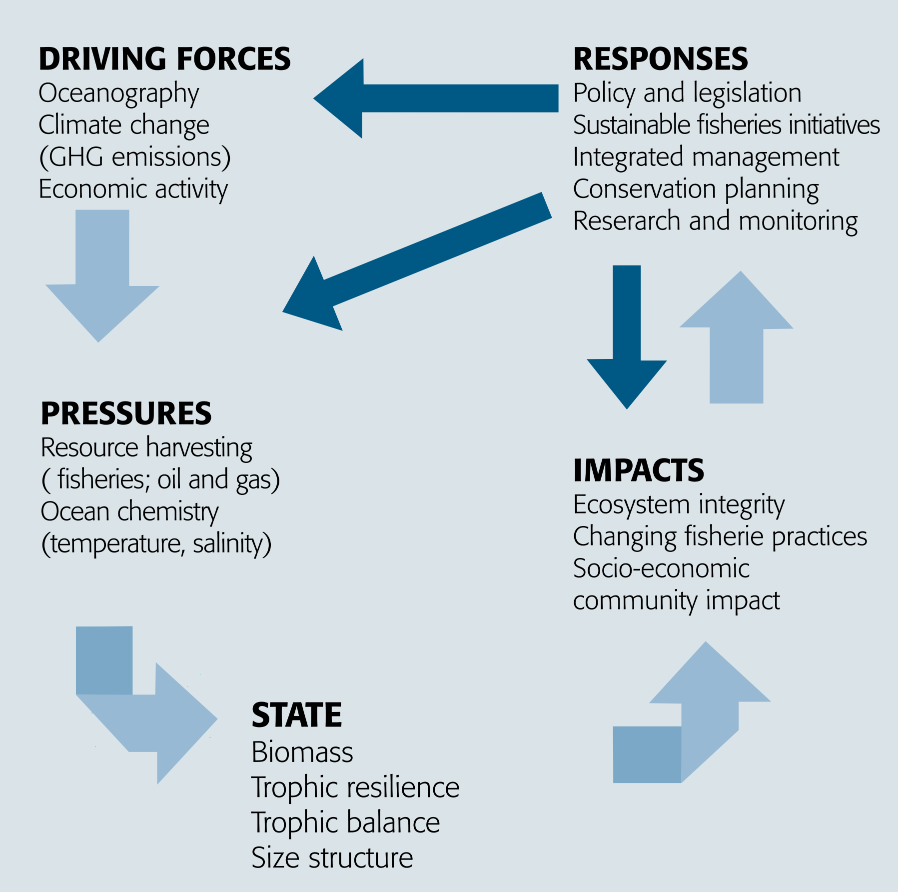


Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) to trophic structure of the Scotian Shelf. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human well-being, ecosystems and materials, which may elicit a societal or government response that feeds back on all the other elements.

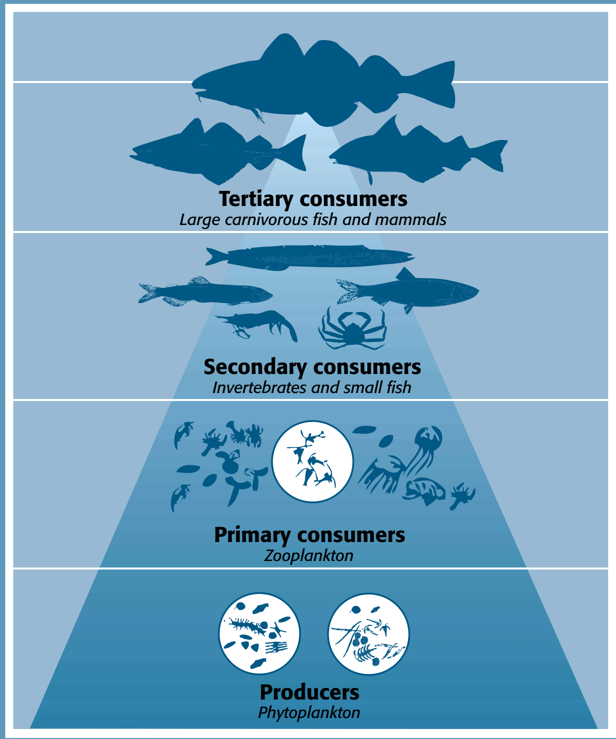
LINKAGES

This theme paper also links to the following theme papers:

- Marine Habitats and Communities
- Incidental Mortality
- Species at Risk
- Primary and Secondary Productivity
- Fish Stock Status and Commercial Fisheries
- Climate Change and its Effects on Ecosystems, Habitats and Biota

ism in the upper levels. The physical oceanography and climate are the natural drivers of these trophic dynamics (**Figure 1**). Regions with higher phytoplankton and zooplankton abundance at the base of the food chain, may have more productive (i.e., increased abundance and size) predator species and higher fishery yields (Ware 2005; Chassot et al. 2010). On the rich Scotian Shelf, over-fishing of large, dominant predatory fish (such as cod) has upset this balance because, in the absence of predators, their prey (e.g., shrimp, herring and sandlance) have increased, resulting in a trophic imbalance in the ecosystem (Worm and Myers 2003; Bundy 2005; Frank et al. 2005). A reduction in predator size on the Scotian Shelf may have also influenced the trophic structure, because smaller predators can not regulate their prey as efficiently (Shackell et al. 2010). The focus of this paper is the groundfish collapse as it has altered the Scotian Shelf trophic structure. By 1992/1993 all fishing regions were declared under moratorium for cod, haddock and pollock, except for the most southerly warmest area in Atlantic Canada, the Western Scotian Shelf. Groundfish recovery and trophic balance since the moratorium on the Eastern Scotian Shelf has been slower than expected partly because herring and sandlance eat groundfish eggs and larvae, and the average groundfish is almost 50% smaller. Lately, some species such as haddock and cod (to a lesser extent) have recovered somewhat, but the fish are still small. The ecological impacts include a restructuring of the ecosystem due to loss of groundfish productivity, which has led to socioeconomic impacts including a decline in the health of coastal communities.

WHAT IS TROPHIC STRUCTURE?



Simplified trophic structure of the Scotian Shelf

The word trophic means "to feed." The trophic structure in a community is the feeding relationships between species. It determines how energy is passed from organism to organism, like from plants to herbivores to carnivores. The pyramid is a useful concept to think about how trophic interactions work, but reality is always more complex. The organisms of the first trophic level are called producers. They exist at the very bottom of the trophic structure and they support all other trophic levels. In the marine environment, these are the phytoplankton (algae).

The first trophic level after the producers is the primary consumer. These organisms are herbivores that eat plants, algae, or bacteria. The next trophic level is composed of secondary consumers, which include invertebrates (e.g., crabs) and small fish. The next level is composed of tertiary consumers, which are larger carnivorous fish and mammals. Detritivores, or organisms that derive energy from dead material like animal wastes, plant litter, or dead organisms, fit in at the very bottom of the trophic structure, but in reality, the food web is far more complex. Consumers at one level can eat at multiple levels and even the prey of one consumer can eat the eggs and larvae of their predators.

2 DRIVING FORCES AND PRESSURES

Every ecosystem experiences natural and anthropogenic forcing, which alters its state, and has a varying impact on both the ecological integrity and resource use. Natural drivers include the natural oceanographic conditions and climate. Anthropogenic drivers include resource use and extraction, which are influenced by increasing populations and expanding economies. In our region, the main activity affecting trophic structure is fishing (resource harvesting). Although other activities (aquaculture, industry, oil and gas) place pressure on the environment (e.g. contamination) so that cumulative changes occur, currently the dominant pressure is fishing.

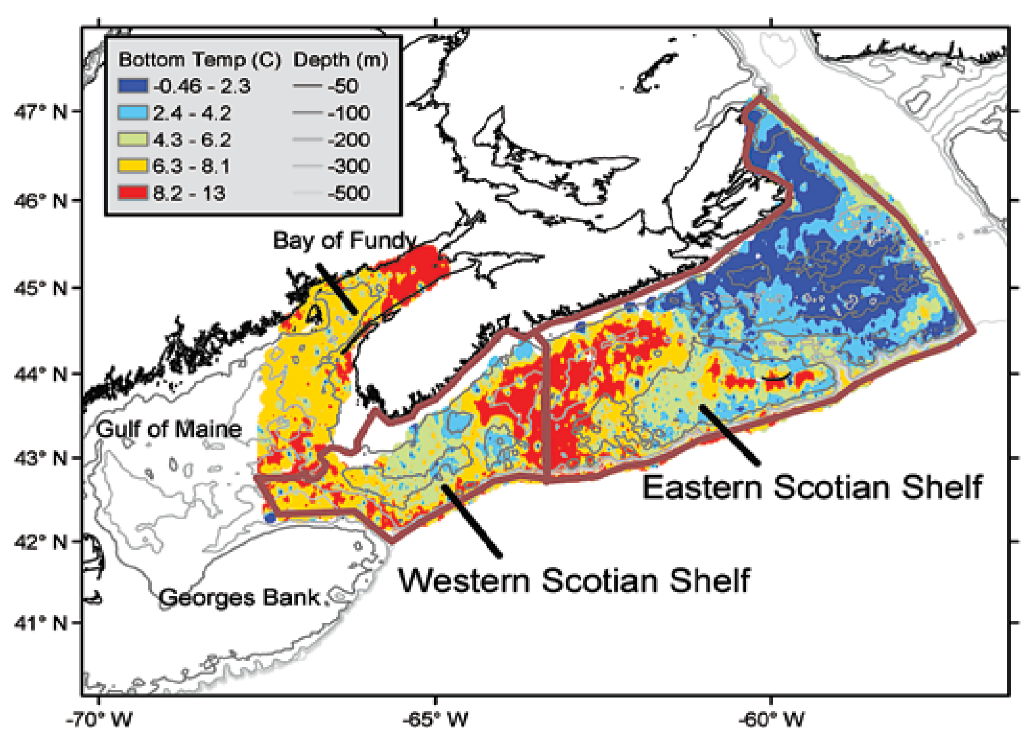


Figure 2: Bottom summer temperature on the Scotian Shelf, delineated into the Eastern Scotian Shelf and the Western Scotian Shelf. These generally correspond to NAFO divisions 4VW and 4X, which are used to compile statistics and regulate fisheries in the Northwest Atlantic.

2.1 OCEANOGRAPHY

The physical oceanography of the Scotian Shelf is described in *The Scotian Shelf in Context*. The Scotian Shelf ocean climate is determined largely by ocean currents. The cold, low-salinity Labrador Current flows past the Grand Banks of Newfoundland and influences the Scotian Shelf. Fresher water also flows in from the Gulf of St. Lawrence. The western part of the Scotian shelf is influenced by the Gulf Stream, which flows north along the edge of the Continental Shelf. The Scotian Shelf is generally divided into two bio-geographical regions, the warmer Western Scotian Shelf, and the colder Eastern Scotian Shelf (**Figure 2**).

2.2 ANTHROPOGENIC AND NATURAL CLIMATE CHANGE

Anthropogenic climate change, principally global warming, due to greenhouse gas (GHG) emissions, is evident at the global scale from ocean circulation models (IPCC 2007a,b,c). These global-scale patterns are modified at the local scale by natural variability, which on the Scotian Shelf is very pronounced due to the strong seasonal cycle and the variable strength of prevailing large scale circulation and atmospheric forcing (e.g. the North Atlantic Oscillation) On shorter time scales (decades), natural variability will be the dominant pressure on shorter time scales (5-10 years), but it is the combined effect of natural variability and antropogenic climate change that will lead to pronounced ecosystem change (J Loder, DFO, pers. comm., 2010).

Temperature heavily influences ecosystems through its effects on physiological processes (growth), timing of migration and population dynamics, all of which influence species distribution. Whether the sea surface temperature (SST) is warming or not depends on the time window. When measured from the early part of the century, SST on the Scotian Shelf as measured near Halifax has shown no long-term increase, but there has been a change of 1 ºC of SST per century as measured at St. Andrew's, New Brunswick in the Bay of Fundy (**Figure 3**). In other words, there are effects of global warming but the natural variability still dominates near Halifax with regards to SST. In both areas, there are distinct naturally derived warm and cold periods that would have affected productivity at all levels.

Recent work documents a decrease in salinity or "freshening" of the Scotian Shelf and Gulf of Maine (Drinkwater and Gilbert 2004; Greene et al. 2008). One of the main reasons for this is the melting of Arctic sea ice. This melting will increase the global input of freshwater resulting in changes in salinity and circulation in the ocean system. As sea ice melts, a large pulse of freshwater increases the strength of the southward flowing Labrador Current and reduces sea surface salinity.

Other expected long-term changes on the Scotian Shelf, due to climate change and GHG emissions, include decreasing oxygen levels in

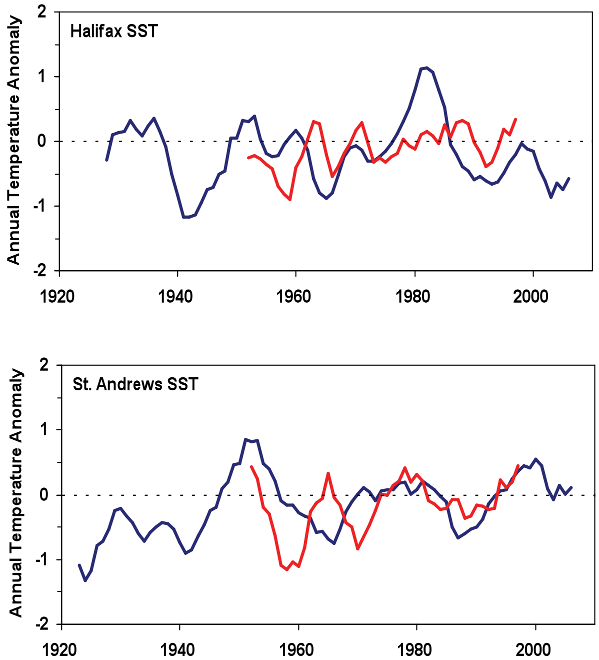


Figure 3: SST as measured at a station called the Halifax line, due to its origin from Halifax, Nova Scotia to the edge of the continental shelf (top panel), and St Andrews, New Brunswick (bottom panel). Units are expressed as Anomalies, where the average is set to 0. The blue line indicates a 5-year running mean based on observations. Red line indicates 5-year running mean based on predictive model (see Petrie et al. 2009a; plot courtesy of Brian Petrie, DFO).

harbours and populated coastal areas (William Li, DFO, pers. comm., 2010) and ocean acidification (see *Climate Change and its Effect on Ecosystems, Habitats and Biota, and Ocean Acidification*).

2.3 COMMERCIAL FISHING

The main economic activity on the Scotian shelf that affects trophic structure is fishing. The Scotian Shelf has always supported vibrant fishing communities (Lotze and Milewski 2004; see also *The Scotian Shelf in Context*). Originally these ecosystems were characterised by productive groundfish such as cod, haddock, pollock and silver hake. European exploitation began around 1560 (Kurlansky 1997). Nova Scotia exports in 1709 of primary target species were about 10,000 t of cod and 4,000 t of mackerel and herring per year, but by 1973, total fish landings were in excess of 750,000 t (Zwanenburg et al. 2006). The majority of the landings were groundfish both on the Eastern Scotian Shelf and Western Scotian Shelf (**Figure 4**). Invertebrates became increasing dominant in the landings during the 1990s.

Cod was once a principal fishery on the Scotian Shelf but was overfished. From 1974-1992, the annual rate of depletion on the Scotian Shelf averaged 49% on the Western Scotian Shelf and 53% on the Eastern Scotian Shelf (Petrie et al. 2009b). The depletion rate increased significantly on the eastern Scotian Shelf spawning stock biomass in the late 1980's, at the same time as certain spawning populations disappeared (Frank et al. 1994). By 1992, a little more than 80% of the available spawning stock biomass on the Eastern Scotian Shelf was being removed.

Since the groundfish collapses in the early 1990s on the eastern Scotian Shelf, the fishery has been dominated by crustaceans such as shrimp, snow crab and lobster (Bundy 2005; Frank et al. 2005). In general, fisheries on lower trophic level marine

ANOMALIES

Anomalies are used often for time series in oceanography and refer to how much an observation deviates from its long-term mean. This is useful when comparing data from different sources. For temperature, data are scaled to have a mean of zero. If the SST is shown as 1°C above the mean, it was a warmer year. Anomalies can also be standardized so as to have a standard deviation of 1. When every data set is scaled to have a mean of zero, and a standard deviation of 1, it is easy to compare how much each series varied over time. For example, if an indicator varied around 0 for the length of the time series, it did not vary much. If an indicator was 3 units above the mean in the earlier part of the time series, and is currently 3 units below, then that indicator has declined well below its long-term mean.

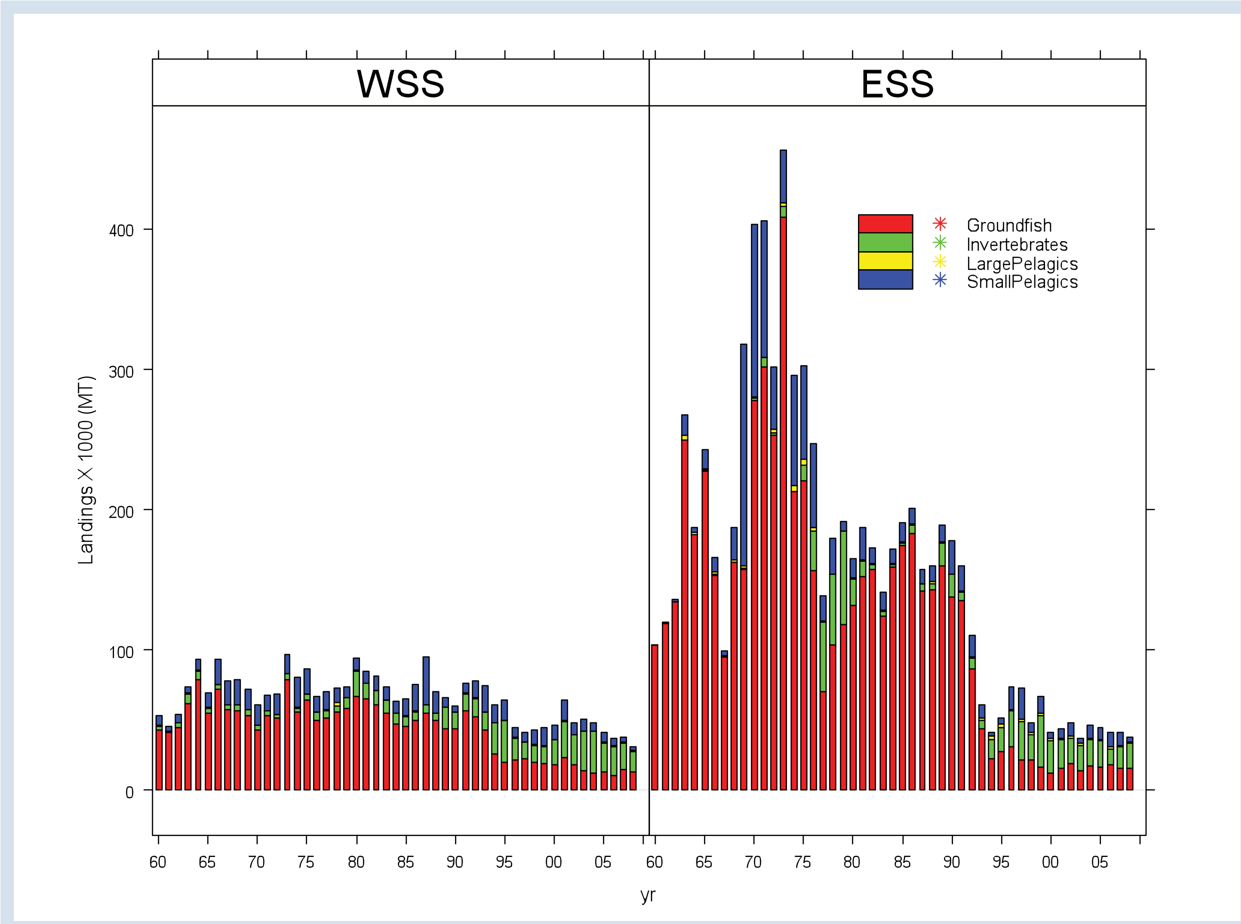


Figure 4: Commercial fisheries landings on the western and eastern Scotian Shelf from 1960- 2008.

invertebrates and plant species expanded (Pauly et al. 2001; Anderson et al. 2008). This resulted in a decline in the mean trophic level of catches starting in 1988 (**Figure 5**).

Fishing not only removes biomass, but can also negatively affect habitat, increase mortality of non-targeted species (bycatch), and selectively target large older fish. In Atlantic Canada, trawling is currently the most widely used method to capture fish and is considered by Atlantic marine professionals (fishermen, scientists, marine conservation professionals, and fisheries managers) to have the greatest ecological impact (Fuller et al. 2008). Trawling will also tend to capture species that co-occur with the target species. For example Thorny skate is not a commercial species but co-occurs with cod and winter skate. The steady decline of thorny skate may be because it was continuously caught as bycatch during the height of the cod fishery (Shackell et al. 2005; see *Incidental Mortality*).

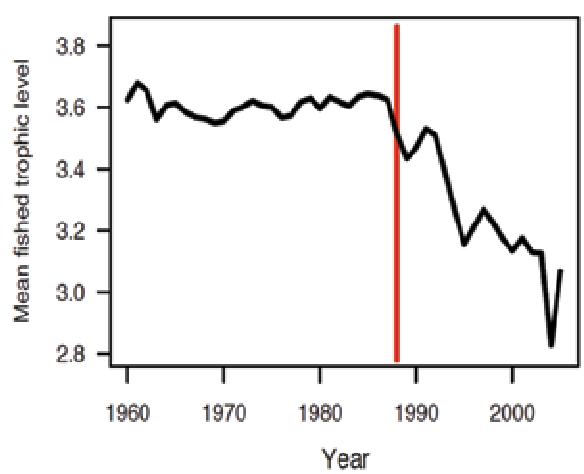


Figure 5: Mean fished trophic level for NAFO Division 4VWX. The red line represents when the trophic level started to decline rapidly in 1988 and was used partly to designate fisheries as established, developing or emerging (adapted from Anderson et al. 2008).

3 STATUS AND TRENDS

The current state of the trophic structure of the Scotian Shelf is an altered structure dominated by the collapse of the traditional groundfish fisheries throughout the Northwest Atlantic. By 1992/1993 all fishing regions were declared under moratoria for cod, haddock and pollock, except for the most southerly warmest area in Atlantic Canada, the Western Scotian Shelf.

3.1 BIOMASS OF THE MAIN TROPHIC LEVELS: TROPHIC BALANCE

When the groundfish moratorium was declared in the early 1990s on the Eastern Scotian Shelf, it became clear that the decline in groundfish was principally due to overfishing, exacerbated by a cold period in the mid 1980's. Importantly, any effect of environmental forcing was dwarfed by the effect of fishing (Bundy 2005; Frank et al. 2005).

Over-exploitation of top predators can create an imbalance between top predator and forage fish prey abundances. Because there are fewer predators, their prey start to increase. If those more numerous forage fish start depleting their main source of food (zooplankton) , there will be fewer zooplankton to eat phytoplankton, and phytoplankton will increase. This is referred to as a trophic cascade because removal of top predators can indirectly affect the dynamics of all the lower trophic levels. Globally, there was strong evidence that a decline in groundfish may cause a trophic cascade through the ecosystem. (Daskalov et al. 2007; Casini et al. 2008, 2009). The decline in groundfish on the Eastern Scotian Shelf initiated an increase in many of their prey species (**Figure 6**). Even the increase in lobster in the Gulf of Maine is likely due to the absence of large cod and other large fish predators (Steneck 1994; Boudreau et al. 2010). In the absence of a strong predation pressure, invertebrates, including shrimp, lobster and forage fish increased (Worm

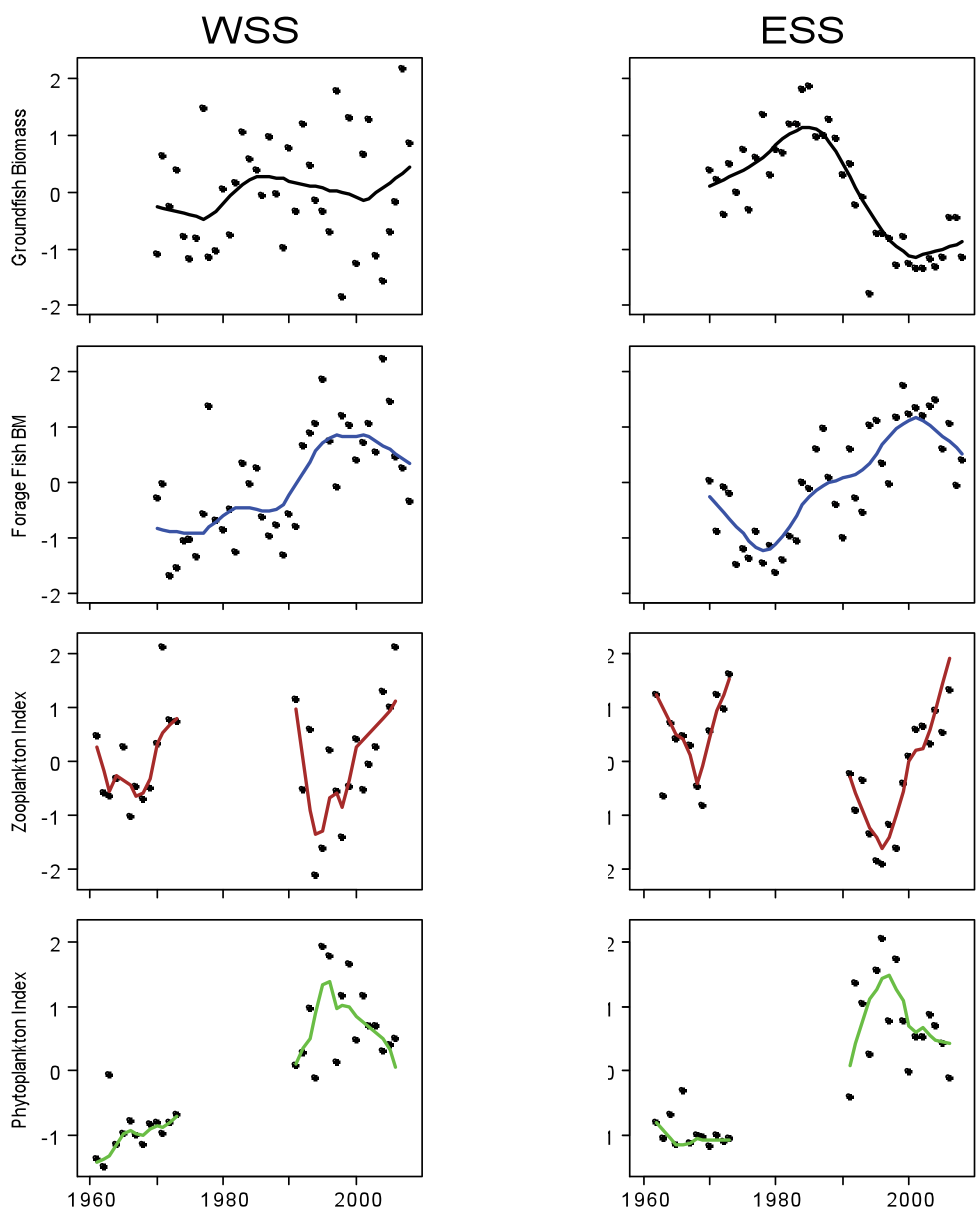


Figure 6: Trophic trends on the Western Scotian Shelf (WSS) and Eastern Scotian Shelf (ESS). From bottom to top panel : phytoplankton (green line); large copepods (brown line); forage fish such as herring, sandlance, argentine and mackerel (blue line), predatory groundfish including cod, haddock, pollock, dogfish, white hake, silver hake redfish etc. (purple line). All units area as anomalies

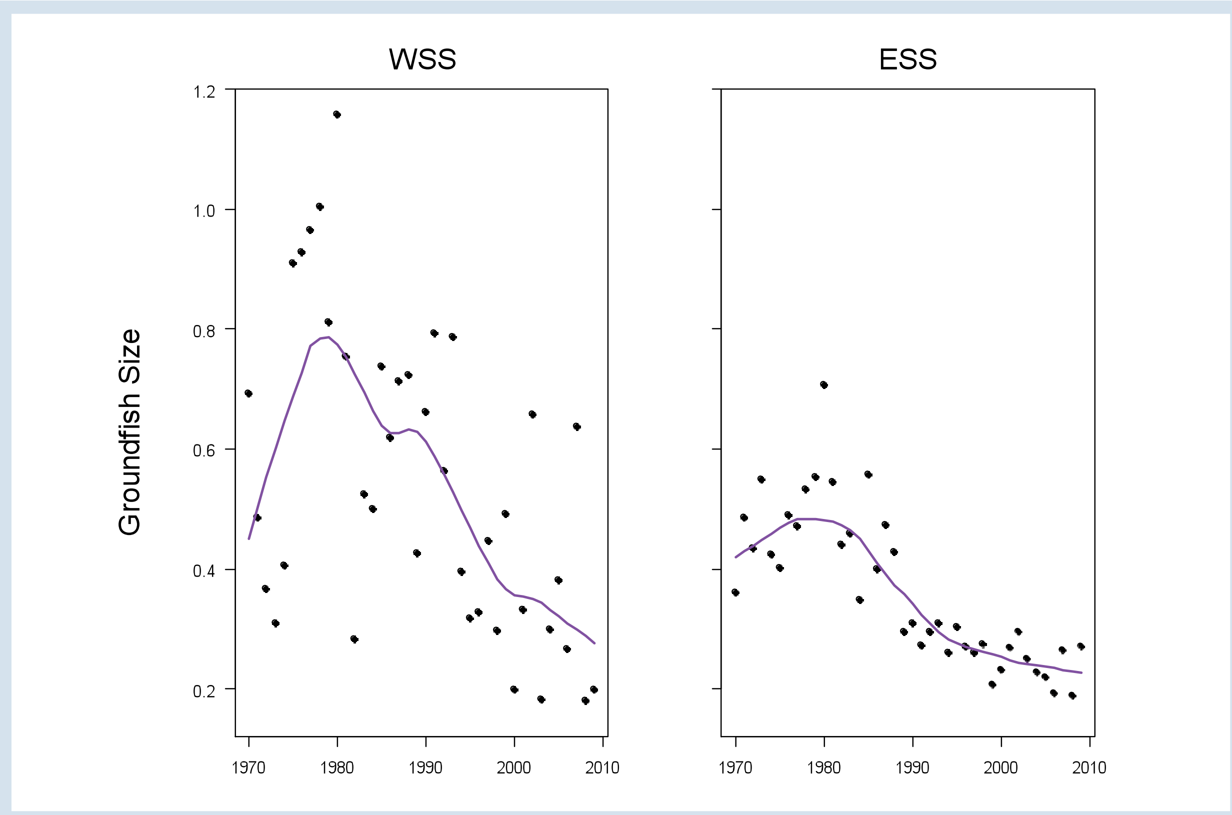


Figure 7: Groundfish size (kg) on the Western Scotian Shelf (WSS) and the Eastern Scotian Shelf (ESS) from 1970-2008. (Source: Shackell et al. 2010).

and Myers 2003; Choi et al. 2005). The increased abundance of forage fish put more predation pressure on zooplankton, and large copepods started to decline in the early 1990s. Since the zooplankton had declined, this allowed the phytoplankton to increase. Thus, the effects of over-fishing the top predatory groundfish have "cascaded" through the ecosystem on the Eastern Scotian Shelf (Bundy 2005; Frank et al. 2005).

As well as a decline in predator biomass leading to an increase in prey, there may also have been other factors affected the changes in the trophic structure on the Eastern Scotian Shelf. For instance, the decline in salinity may have caused the phytoplankton increase from the 1960s to the 1990s. Lower salinity causes increased stratification that traps nutrients in the upper layer of the water column where sunlight is available, resulting in an increase in phytoplankton production (Greene et al. 2008). While the cause of increased phytoplankton throughout the Northwest Atlantic has been questioned (see Head and Sameoto 2007; Greene et al. 2008), it is clear that the ecosystem has changed.

On the adjacent Western Scotian Shelf, the trend in trophic patterns was similar to those on the Eastern Scotian Shelf except for one important difference- biomass of large groundfish. In both areas but to a greater extent in the east, there was an increase in phytoplankton from the 1960s early 1970s to the early 1990s, a decline in large copepods, and an increase in the biomass of forage fish up until the late 1990s (Choi et al. 2005; Frank et al. 2005; Shackell et al. 2010). The major dissimilarity between the two areas was largely in the response of the biomass of large groundfish (see **Figure 6**); not all species declined in the west and when dominant commercial species declined, other species increased (Shackell et al. 2007). The Western

Scotian Shelf showed signs of a weak cascade, but the predation pressure by top predators in terms of biomass, had not declined.

3.2 SIZE STRUCTURE

In marine systems size is important, with larger fish eating smaller fish, which eat smaller fish and so on. Fishing targets and removes the larger, older fish, leaving the smaller, younger and often less fit fish to reproduce (Bianchi et al. 2000; Olsen et al. 2004; Shin et al. 2005; Swain et al. 2007; Darimont et al. 2009). Declining fish sizes have been observed world-wide (Fisher et al. 2010a, b) and specifically on the Scotian Shelf (**Figure 7**; Shackell and Frank 2007; Shackell et al. 2010). Selection pressure of marine harvesting on large fish can be up to 300% higher than natural rates (Darimont 2009). Setting minimum size limits (e.g., 43 cm in cod, haddock, pollock fishery), can exacerbate the problem because the fishing pressure is then concentrated on larger fish.

Given the strong decline in predator size worldwide, it is possible that trophic structure is influenced by size. Larger predators are better hunters and have stronger per capita effects on prey because they need more food to survive. As well, they keep eating smaller prey but also eat larger prey as they get larger (Scharf et al. 2000). Larger hunters are more successful at capturing prey, because they can swim longer and faster, and possess higher visual acuity (Sornes and Aksnes 2004). Finally, larger fish can eat more prey per unit time than smaller predators. As larger fish chase a school of prey, they are able to consume more before that school of prey is able to scatter and escape. Indeed, the diminution of large predator attributes as their size declines would result in a weakening of top predation pressure, and are thought to be responsible for the increase in prey biomass and associated trophic changes observed on the Western Scotian Shelf (Shackell et al. 2010). Size-selective harvesting can occur either because fishers are taking the largest fish or because fish do not grow old enough to be large. Under changing climatic conditions, the decline in body size has initiated a trophic restructuring of the food chain on the Scotian Shelf, the effects of which may have influenced three trophic levels.

The temperature difference between the warmer west and the colder east accounts for the less extreme response in several of the biological indicators. On the Eastern Scotian Shelf, the response of lower trophic levels can be primarily attributed to the absolute loss of biomass of large fish (Frank et al. 2005). On the Western Scotian Shelf, the decline in body size of large fish may have led to different predator/prey dynamics In other words, the indirect effects of size-selective fishing can result in a similar, but less extreme, trophic response as the direct removal of biomass of top predators.

3.3 TROPHIC RESILIENCE

On the Eastern Scotian Shelf, the entire groundfish community declined, but has recently showed signs of recovering. On the Western Scotian, the total groundfish biomass did not collapse because species such as dogfish increased while cod, white hake, cusk and pollock declined (Shackell and Frank 2007). The resilience of a region to overfishing is directly related to its climate regime (Frank et al. 2007). The eastern and western Scotian Shelf share similar species composition, and several populations exhibit coherent trends (Shackell and Frank, 2007). However, the “collapsed” Eastern Scotian Shelf is, on average, 2 ºC cooler than the adjacent Western Scotian Shelf where the cod fishery is still extant. In warmer regions, demographic rates are higher and the targeted stocks can withstand fishing better even though they can experience similar exploitation rates (Shackell and Frank 2007).

4 IMPACTS

Changes in trophic structure can have impacts on the ecosystem and socio-economics. **Table 1** provides a summery of likely impacts of changing trophic structure on the Scotian Shelf.

Table 1: Biophysical and socio-economic impacts of trophic imbalance on the Scotian Shelf

ELEMENT	IMPACTS
BIOPHYSICAL IMPACTS	
Trophic Balance	• Predatory groundfish decline in biomass or size leads to an increase in their forage fish prey • Forage fish, in turn, may suppress groundfish recovery by eating their eggs and competing with their juveniles
Average Size	• Loss of potential accumulation of biomass to beget larger fish, the preferred choice of fisherman • Faster generation times • Lower diversity of size classes • Reduced predatory abilities
Species and ecosystems	• Reduced diversity within species and populations which reduces stability (Portfolio effect) • Transfer of fishing effort to alternate species with unknown consequences due to lack of knowledge of new species being fished (Anderson et al. 2008) • Some of these new species are being fished using gear that destroys habitat or have high rates of bycatch (Fuller et al. 2008)
SOCIO-ECONOMIC IMPACTS	
Commercial Fishery Employment	• In Atlantic Canada, the current invertebrate fisheries are more lucrative, but employ fewer people (Fuller et al. 2008; Charles et al. 2009)
Commercial Groundfishery	• Value has declined reflecting "depreciation of capital" (Charles et al. 2009)
Commercial Invertebrate Fishery	• Effort was transferred to invertebrate fisheries as major groundfisheries were closed. Their sustainability is not predictable. Lobster landings increased through the 2000s but in 2007, were 30% lower than the previous year (Charles et al. 2009) • Transfer of fishing effort to alternate species with unknown consequences due to lack of knowledge of new species being fished (Anderson et al. 2008) • Some of new species are being fished using gear that destroys habitat or have high rates of bycatch (Fuller et al. 2008)

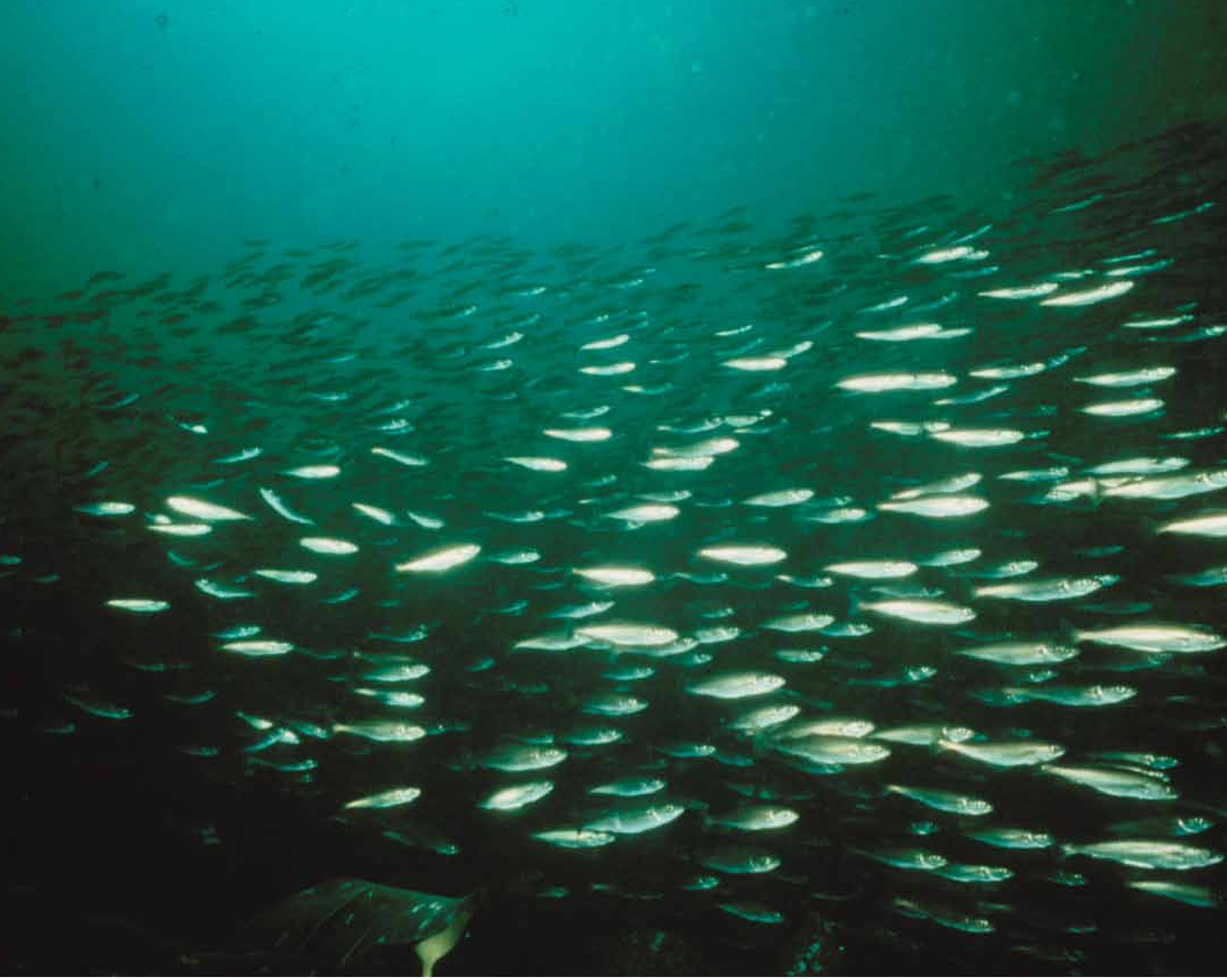
4.1 CULTIVATION EFFECT OR PREDATOR PIT HYPOTHESIS

There are signs of partial recovery of groundfish stocks on the Scotian Shelf (Frank et al. 2007), but not to the extent hoped for. The climate, while unfavourable on the Eastern Scotian Shelf for a brief period, is not the dominant factor the lack of recovery (Choi et al. 2005). In the early 2000s, there were roughly 40 inter-related hypotheses as to why cod were so slow to recover in Atlantic Canada (DFO 2003). Ironically, part of the answer may be that the increase in forage fish such as herring and mackerel delayed groundfish recovery. Herring and mackerel, and likely other forage fish, not only eat groundfish eggs, their young compete with juvenile groundfish for food (Swain and Sinclair 2000). The sustainable abundance of predatory groundfish depends on what has been referred to as the "cultivation effect". When groundfish are abundant, they control the forage fish through predation and so limit their predation on groundfish eggs, and the competition between forage fish and juvenile groundfish. Once groundfish decline, the forage fish can become so abundant that they consume eggs, compete with juvenile groundfish, and suppress recovery. In such conditions, there would be a lagged recovery of groundfish (Walters and Kitchell 2001) and this may have contributed to the lack of groundfish recovery in the Gulf of St. Lawrence as well as other North Atlantic regions (Swain and Sinclair 2000; Walters and Kitchell 2001; Petrie et al. 2009).

Seals have long been suspected of negatively impacting cod populations in Atlantic Canada. On the ESS, grey seals numbered 5000 in 1970 and grew to 64 000 in 1994 but their consumption of cod was not a significant factor in the decline of cod (Mohn and Bowen 1996). The current debate is whether seals are impeding recovery of cod through their shear abundance. There is no consensus on the role of seals on cod recovery (see http://www.dfo-mpo.gc.ca/science/Publications/article/2008/16-09-2008-eng.htm) but if the forage fish are having a greater impact on juvenile cod, then culling the abundant seals, who are predators of forage fish as well (Beck et al. 2007) will further hamper recovery (Swain and Sinclair 2000). When forage fish become far too abundant given their food supply, their rate of population increase slows down, as has happened on both the eastern and western Scotian Shelf in recent years. This decline in forage fish may be beneficial to groundfish recovery (Frank et al., in review)

4.2 SIZE EFFECT

Another part of the answer to delayed groundfish recovery, is the size and condition of the formerly large-bodied community. The average size of groundfish has declined on the Scotian Shelf (Shackell et al. 2010) as has their condition (an index of how fat they are at a given size) (Shackell and Frank 2007). A smaller fish, of the same species, contributes less to the next generation. Younger, smaller, first-time spawning cod are not as successful as second-time spawning cod. "They breed for a shorter period, produce fewer egg batches, exhibit lower fecundity, and produce smaller eggs with lower fertilization and hatching rates; moreover, their larvae are less likely to hatch in environmental conditions favourable for survival…. " (Trippel 1994; 1998). This means that an age-truncated population of the same size does not have the same reproductive potential as an older population. Smaller females of a large-bodied species, in general, produce fewer eggs. When the entire population is smaller, the production potential is reduced (Brander



2007). However, fishery-induced size changes may be reversible (Conover et al. 2009) and the predatory groundfish of the Scotian Shelf may yet regain their former predatory role.

4.3 PORTFOLIO EFFECT

The "portfolio effect" refers to the concept that diversity contributes to stability. Species diversity is one aspect that contributes to ecosystem stability, and likewise diversity within species allows for more stable population dynamics and more resilient populations (Schindler et al. 2010) and within populations (Trippel, 1994). When sub-populations of a species start to disappear, e.g. cod on the Eastern Scotian Shelf (Frank et al. 1994), the entire stability of the population is lower. When a population has reduced age/size/phenotype diversity, its stability is reduced. If many ages/sizes are able to contribute their genes to the next generation, the odds that their offspring survive are greater because they come from a diverse set of spawners; this is referred to as a "bet-hedging life history strategy" and is a reflection of the

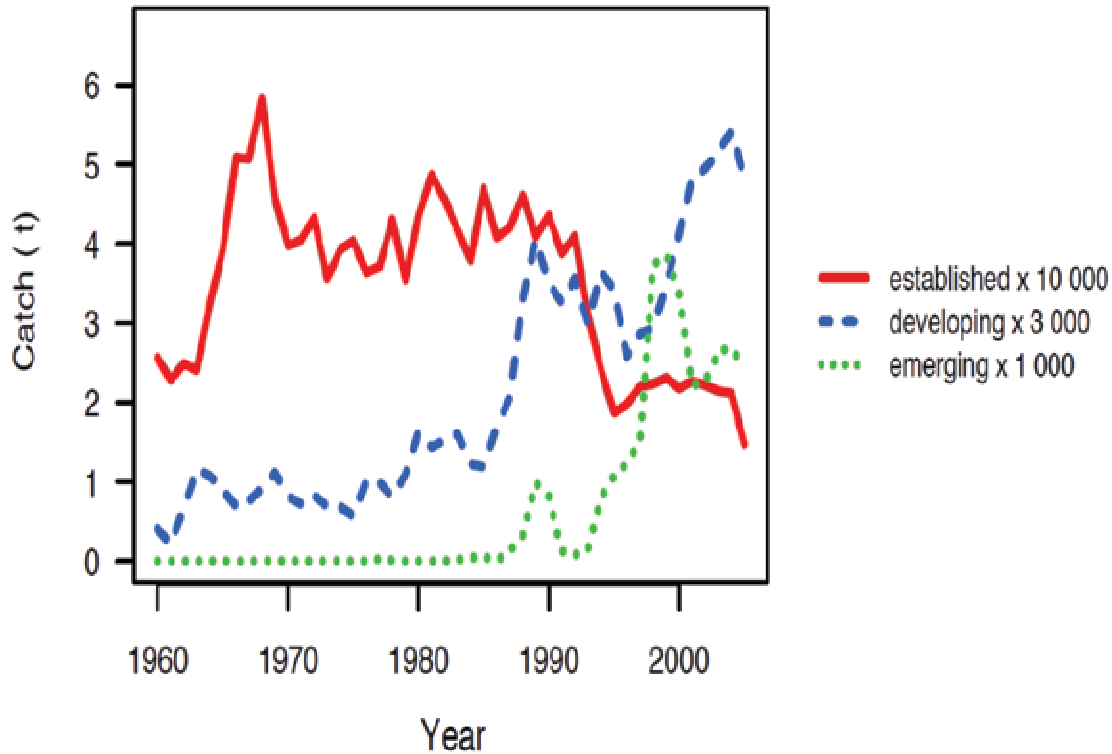


Figure 8: Mean annual catch of fisheries divided into those that are: 1) established: cod, haddock, halibut, redfish, yellow-tail flounder,herring; 2) developing: dogfish, lobster, snow crab, shrimp, scallop, periwinkles, rockweed, and 3) emerg-ing: red crab, rock crab, Jonah crab, quahog, Arctic surf clam, Altantic surf clam, sea urchin, sea cucumber (adapted from Anderson et al. 2008).

DIVERSIFIED ECOSYSTEMS

"One of the most pervasive themes in ecology is that biological diversity stabilizes ecosystem processes and the services they provide to society, a concept that has become a common argument for biodiversity conservation." (Schindler et al. 2010)

gambling approach to life in a highly variable environment. Consider the hypothetical example that in the 1970s, the environment was overly harsh in the early part of the spawning season, when small, young spawners spawn, and few offspring survived. That was not detrimental to the population as the environment favoured offspring that were spawned later in the season by larger fish. In the 2000s, during a similar regime, the odds of high rates of survival would be lower because the population now longer has as many large fish that spawn later in the season.

4.4 ECONOMIC IMPACTS

4.4.1 Harvesting Patterns

The change in the Scotian Shelf ecosystem has caused a fundamental change in the structure of the commercial fisheries in Atlantic Canada. In particular, there has been a decrease in the traditional groundfish fisheries and an increase in developing and emerging fisheries, particularly invertebrates (**Figure 8**).

On the Eastern Scotian Shelf, the principal fisheries are now invertebrate fisheries including lobster, scallop, soft-shelled clam and snow crab (Frank et al. 2005). The snow crab fishery is highly lucrative and there is some question as to whether there is any economic benefit if the groundfish predators resume their ecological role in trophic dynamics. In the long term, however, a biologically diverse system, including healthy invertebrates and groundfish populations is more resilient, would be better able to withstand climate change, and importantly, provides a more diverse option for fisheries. While the current invertebrate fisheries have a higher value than former groundfish, they do not employ as many people in the community (Fuller et al. 2008). As well, invertebrate fisheries are not inexhaustible. Lobster landings increased through the 2000s but in 2007, were 30% lower than the previous year (Charles et al. 2009). Notably, the total value of exports (accounting for 95% of total landings in 2006) peaked at CDN$1.2 billion dollars in 2002, but declined to CDN$ 975 million by 2006 (Pinfold 2007).

4.4.2 Coastal Communities

With the downturn in the lucrative groundfishery, the economic activity and demographics of many coastal communities has changed.

In 2006, 223 licensed fish processing plants were operating. Of those, only 105 were significantly active in actual processing while the remainder was inactive or involved in just shipping, buying, or selling. Of those extant plants, only 50% operated year round while the rest were seasonal. Assuming that the 400-odd plants in the early 1990s were actively processing, there was a 74% decline in the number of fish processing plants in Nova Scotia in 2006 (Pinfold 2007). This has obvious implications for job opportunities in the surrounding communities.

In the early to mid 1990's, the federal government began divesting in public ports, including small craft harbours where 90% of the fish are currently landed. These fishing ports have either been sold or transferred to municipal or provincial governments and private industry, or are maintained by the Small Craft Harbours Branch of DFO. The effect of changes in working waterfronts was addressed in the Nova Scotia State of the Coast Report (http://www.gov.ns.ca/coast/state-of-the-coast.htm; Nova Scotia 2009). A classification scheme of 93 rural coastal communities in Nova Scotia linked to working waterfronts was used to designate whether communities were healthy, transitional or declining. From 1991-2006, the number of healthy communities increased from 28% to 33%, while the number of declining communities increased from 42% to 65%.

DIVERSIFIED FISHERY

"From the human perspective in the fishery, reduced reliance on single fisheries and single fish stocks means not only a more diverse set of fisher livelihood options, thus greater resilience within fisher communities, but also potential insurance against a downturn in fish landings of a particular species". (Charles et al. 2009)

5 ACTIONS AND RESPONSES

The change in the ecosystem on the Scotian Shelf after the cod fishery collapse and the resultant impacts to fishing communities around Nova Scotia have heightened people's awareness of the need for conserving ecosystems as a whole, including the trophic structure. The Canadian government has made significant strides to create a framework, through legislation, policy and program initiatives, for sustainable resource use. As well, there are now numerous fisheries-led initiatives to maintain and conserve trophic resources on the Scotian Shelf. Several key aspects are highlighted below.

Table 2: Key Legislation that is applicable to managing species at risk on the Scotian Shelf.

LEGISLATIVE INSTRUMENT	PURPOSE	COMMENTS
Fisheries Act - 1985	Provides fishing regulations for management of commercial species and also habitat protection.	Managed by Fisheries and Oceans Canada. http://laws.justice.gc.ca/en/F-14/index.html
Oceans Act - 1996	Provides for the management and conservation of marine areas including the establishment of marine protected areas.	Managed by Fisheries and Oceans Canada. http://www.dfo-mpo.gc.ca/oceans/oceans-eng.htm
Species at Risk Act - 2002	Provides for the recovery and protection of species that are endangered or at risk.	Coordinated by Environment Canada in collaboration with Fisheries and Oceans Canada, and Parks Canada. Activities include a Species at Risk Public
Canada National Marine Conservation Areas Act -2002	Allows for the establishment of marine conservation areas within the exclusive economic zone	Registry and Habitat Stewardship Program. DFO is responsible for aquatic species. http://www.dfo-mpo.gc.ca/species-especes/index-eng.htm
The Coastal Fisheries Protection Act C-33	Protects coastal fisheries and migratory fish stocks in Canadian ocean waters.	Managed by Parks Canada http://www.pc.gc.ca/eng/progs/amnc-nmca/pr-sp/index.aspx
Fisheries Development Act (R.S., 1985, c. F-21)	Provides for the efficient exploitation of fishery resources and for the exploration for and development of new fishery resources and technology.	Managed by Fisheries and Oceans Canada http://laws.justice.gc.ca/eng/C-33/page-1.html Managed by Fisheries and Oceans Canada http://www.dfo-mpo.gc.ca/reports-rapports/fda/fda2001-eng.htm

Although it is recognised that climate change is a key factor in driving changes in trophic structure, the actions and responses associated with climate change are outlined in the paper *Climate Change and ifs Effect on Ecosystems, Habitats and Biota* and are not discussed here.

5.1 LEGISLATION

There are several pieces of legislation that impact the conservation of species on the Scotian Shelf (see **Table 2**; see also *At-Risk Species* [hyperlink]). Key federal legislation includes the *Fisheries Act, the Oceans Act* and the *Species at Risk Act.* Under the *Fisheries Act*, fishing of Atlantic cod has been under moratorium since 1992.

5.2 SUSTAINABLE FISHERIES INITIATIVES

There are currently several initiatives underway initiated by the Canadian Government, private industry and NGOs that address sustainable fisheries. Although these initiatives are not focused on trophic structure per se, by ensuring sustainable fisheries, the trophic structure of the Scotian Shelf and the healthy functioning of the ecosystem will be conserved.

5.2.1 Sustainable Fisheries Framework

DFO has initiated the Sustainable Fisheries Framework (http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/overview-cadre-eng.htm), which is an ecosystem approach to fisheries management focusing on sustainable resource use. Under this framework, DFO works together with the fishing industry to develop fisheries-specific integrated fisheries management plans (IFMPs). These identify goals related to conservation, management, enforcement, and science for individual fisheries; and they describe access and allocations among various fish harvesters and fleet areas. The plans also incorporate biological and socio-economic considerations that are factored into harvest decisions. IFMPs have been developed for the Maritimes Region for Atlantic Mackerel (2007), Bluefin Tuna (2007, 2008), and Atlantic Swordfish and other tunas (2004-06) (see http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/index-eng.htm).

5.2.2 Industry-Based Initiatives

There are several industry-led initiatives for sustainable fisheries. These include:

- Participation in the certification program of the Marine Stewardship Council – The Marine Stewardship Council is an international organization that provides certification of sustainable fisheries and ecolabelling for marketing purposes (http://www.msc.org/). Information on certified fisheries on the Scotian Shelf is provided at: http://www.msc.org/track-a-fishery/certified/north-west-atlantic.
- *Canadian Code of Conduct for Responsible Fishing Operations* – The Food and Agriculture Organisation (FAO) Code of Conduct for Responsible Fisheries has been adopted by 80 countries, including Canada in 1995. In response, the Canadian fishing industry has adopted the Canadian Code of Conduct for Responsible Fishing Operations, which outlines general principles and guidelines for all commercial fishing operations to ensure sustainable fisheries (available at: http://www.dfo-mpo.gc.ca/fm-gp/policies-politiques/cccrfo-cccppr-eng.htm).

5.2.3 Community-Based Initiatives

There are several community-led initiatives for sustainable fisheries. In general, these include:

- Community-Based Management in Integrated Coastal and Ocean Management in Canada. In the wake of the cod collapse, the Canadian government recognized that increased participatory governance of coastal communities, those with the highest stakes in the fishing industry, would be necessary to ensure sustainable fisheries. The extent of decision-making by coastal community management committees varies across the province. In the mid-1990s DFO worked with the some members of the fishing community on the Scotian Shelf to introduce community quota

management (Fanning 2007). During this time, policies were adopted to move away from a top-down approach to fisheries management to a more participatory approach (DFO 2004).

- Development of fishing co-operatives - A recent initiative in Nova Scotia includes a joint effort by Ecology Action Centre and Fishers to connect consumers to small-scale hook and line fishers in the Bay of Fundy (see http://www.offthehookcsf.ca/). If this is successful, it may be expanded to other fisheries. The benefits to the fishers is that they sell directly to the consumer, bypassing the costs of middle man. The benefit to the consumer is the option to buy fish that are caught with gear that has relatively less impact on the benthic habitat.

5.3 INTEGRATED OCEANS MANAGEMENT

Integrated oceans management includes a variety of activities to manage the oceans in a holistic manner for the future sustainability of its resources. Some key initiatives include the development of integrated management plans, conservation planning and implementation of ecosystem approach to management .

5.3.1 Integrated Management Plans

Under the *Oceans Act,* the Eastern Scotian Shelf has been designated as a large ocean management area. The Eastern Scotian Shelf Integrated Management (ESSIM) Initiative is a collaborative ocean management and planning process being led and facilitated by DFO. The *Eastern Scotian Shelf Integrated Ocean Management Plan* (see http://www.dfo-mpo.gc.ca/Library/333115.pdf) has been developed as a blueprint for action for this area. Nothing similar is available for the Western Scotian Shelf.

One of the major implementation tools for the ESSIM Plan is marine spatial planning (see Ehler and Douvere 2009). Currently work is being done on the authority required for marine spatial planning on the shelf and the information and tools that will be required for its implementation.

5.3.2 Marine Protected Areas and Conservation Planning

Designation of fisheries closures and marine conservation areas are accepted methods to limit the impact of anthropogenic activities on marine organisms. Fisheries closure can be found at: http://www2.mar.dfo-mpo.gc.ca/fishmgmt/vo/search/index.asp. Conservation areas on the Scotian Shelf and slope include the Lophelia Coral Conservation Area, The Gully Marine Protected Area and Roseway Basin Whale Sanctuary. Another marine protected area is currently being designated on the Eastern Scotian Shelf. DFO Maritimes region is actively involved in a larger project to develop a Canadian network of marine protected areas.

5.3.3 Ecosystem Approach to Management

Ecosystem approach to management is an environmental management approach that recognizes the full array of interactions within an ecosystem, including humans, rather than considering single issues, species, or ecosystem services in isolation (Christensen et al. 1996, McLeod et al. 2005). In order to practically implement ecosystem-based management in the Maritimes Region, the DFO is currently developing an ecosystem approach to management through an Ecosystem Approach to Management (EAM) Framework (Fisheries and Oceans 2010). The EAM framework identifies key strategies for ecosystem management and critical thresholds or limits for indicators associated with these strategies. Pilot implementation were due to begin in 2010.

5.4 ECOSYSTEM MONITORING

Developing an understanding of the ecosystem is key to managing it in an integrated and holistic manner. Research is an ongoing mandate for DFO Science Branch. Of particular interest is that, in response to the downturn in the cod fishery, the DFO established the Atlantic Zonal Monitoring Program (AZMP) in 1999 (http://www.bio.gc.ca/monitoring-monitorage/azmp-pmza/index-eng.htm). The main objectives of AZMP are to collect and analyse biological, chemical, and physical data to characterise and understand the causes of oceanic variability at different time scales; and to provide the multidisciplinary data sets that can be used to establish relationships among the biological, chemical, and physical components, including the various trophic levels.

INDICATOR SUMMARY

INDICATOR	POLICY ISSUE	DPSIR	ASSESSMENT	TREND
Climate Change				
SST	Global warming is occurring, but no direct indication on Eastern Scotian Shelf yet, but we are currently in a warm period	Pressure	Good	/
Salinity	Salinity is decreasing due to freshwater from melting Arctic, may enhance/disrupt regular patterns of plankton growth.	Pressure	Fair	-

INDICATOR SUMMARY (continued)

INDICATOR	POLICY ISSUE	DPSIR	ASSESSMENT	TREND
Fishing				
Trophic Level of Landings	Fishing lower down the food chain is considered unsustainable because fishing options have been reduced.	Pressure	Poor	/
Trophic Balance	Trophic balance can be upset by overfishing one trophic	State	Fair	+
Fish Body Size	Size-selective fishing can cause decrease in long- term average size of fish.	State	Poor	/
Coastal Communities				
Fishery jobs	Employment levels in fishing industry	Impact	Poor	/
Health of Coastal Communities	Economic vibrancy and well-being	Impact	Poor	-
Fish Plants	Number of operational fish plants has declined	Impact	Poor	/
Fisheries Management				
Policy and legislation	All relevant policy and legislation are in place	Response	Fair	/
Practice	Implementation of policy is lagging	Response	Poor	/

Key:
Negative trend: -
Unclear or neutral trend: /
Positive trend: +
No assessment due to lack of data:?
*see more about the DPSIR framework at
http://coinatlantic.ca/index.php/state-of-the-scotian-shelf/217

Data Confidence:
Good data are available for climate indicators and upper trophic levels of fish. There is a gap of information for lower trophic levels, phytoplankton and zooplankton and for invertebrates. Good data for all trophic levels, from phytoplankton to predatory groundfish is ideal to study trophic dynamics.

Data Gaps:
- Since the start of the AZMP (Atlantic Zonal Monitoring Program) in 1998 (http://www.bio.gc.ca/monitoring-monitorage/azmp-pmza/index-eng.htm), researchers have had access to region-wide data on lower trophic levels and climate. To investigate trophic structure before 1998, researchers have had to patch together lower trophic level data from the CPR program (http://www.sahfos.org), and have only scant information on regional abundance and distribution of macroinvertebrates. However, data on upper trophic levels, including forage fish and their predatory ground fish has been available since 1970 from the Canadian Department of Fisheries and Oceans (DFO) annual, scientific research vessel (RV) surveys. Integrated management is difficult under the current governance.
- Some data on impact of cod fish collapse on fishing communities is available in Chapter 5 of http://www.gov.ns.ca/coast/state-of-the-coast.htm

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