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Monitoring Pelagic Marine Cold Water Ecosystems

Surveillance des écosystèmes marins pélagiques en eau froide.

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Abstract
Fisheries management traditionally has been based on a single stock approach. More recently, a holistic approach to management and decision making has been called for in the marine environment. Issues such as groundfish stock collapse and lack of recovery, trawl impacts on benthic habitats, marine biodiversity and climate change require an ecosystem approach. Defining marine ecosystems and determining which components should be monitored in long term observational programs (LTOP) is an important starting point for fisheries science. Spatially, marine ecosystems occur at large scales of biomes and provinces with smaller scale structure embedded within. Vertically, the pelagos and benthos vary independently across these marine spatial scales. Monitoring such systems will require carefully planned programs capable of detecting important signals of change. One of these signals is the annual production of fish which occur as pelagic juveniles for a relatively short period of time each year. Measuring the production of fish at the pelagic juvenile stage is an important step towards untangling confounding relationships in traditional fisheries recruitment data.

Résumé
La gestion des pêches est depuis toujours fondée sur une approche axée sur un seul stock. Dernièrement, il a fallu adopter une approche de gestion et un processus décisionnel plus globaux en ce qui concerne le milieu marin. Des problèmes tels que l'effondrement des stocks de poisson de fond, qui ne montrent aucun signe de rétablissement, les incidences de la pêche au chalut sur les habitats benthiques, la biodiversité marine et le changement climatique exigent une approche axée sur l'écosystème. La définition des écosystèmes marins et l'identification des éléments à surveiller dans le cadre des programmes d'observation à long terme (POLT) est un point de départ important pour les sciences halieutiques. À l'échelle spatiale, les écosystèmes marins se manifestent aux grandes échelles des biomes et des provinces et comprennent une structure plus petite. À l'échelle verticale, le pélagos et le benthos varient de façon indépendante d'un bout à l'autre de ces échelles spatiales marines. La surveillance de tels systèmes nécessitera des programmes planifiés méticuleusement, capables de détecter d'importants signaux de changement. Un de ces signaux est la production annuelle de poissons pendant la période relativement courte où ils sont des juvéniles pélagiques. L'évaluation de la production de poissons à ce stade est une étape importante pour arriver à démêler des relations déconcertantes dans les données de recrutement issues des pêches traditionnelles.

Introduction

Traditionally, marine fisheries have been managed on a single species, single stock basis (VPA). Attempts at multispecies management (MSVPA) have largely failed due to the complexity of species interactions which can change unpredictably over relatively short periods of time. In Atlantic Canada, a more holistic approach to marine management has been advocated since the collapse of groundfish stocks (Harris 1990, FRCC 1995). Issues of groundfish stock collapse and non-recovery, habitat degradation, marine biodiversity and climate change are themes that demand a new approach to fisheries science.

Within an ecosystem framework, the primary scientific question is whether or not the ocean's carrying capacity is changing over time. When it does, then multiple states will exist within fish populations that require different realizations of their ability to produce young and to withstand fishing mortality. To detect change it will be necessary to establish long term observational programs (LTOP) monitoring key components of marine ecosystems. The most significant components will be in the species compositions of the higher trophic levels (Cushing 1982). The relevant scales of study will be regional, rather than global or local (Steele 1995). A fundamental question is whether changing productive capacity is driven by top down control by predators or bottom up production by plankton.

It is convenient to divide marine ecosystems into pelagic and benthic components. The pelagos is primarily where production occurs while the benthos is where this production is stored. Of particular interest to fisheries scientists is how annual production in the plankton is transferred to fish and invertebrates of commercial importance. This transfer occurs during larval stages of fish and invertebrates as well as during the pelagic juvenile stage of most species. The pelagic juvenile stage is ephemeral, embracing the critical period of metamorphosis and extending through the summer production period to autumn (Figure 1). Pelagic juveniles are the survivors of complex processes occurring during the first few months of life. We can regard their annual success, in terms of survival and growth, as a biological integration of these processes. When the annual response is similar across species lines then we begin to understand ecosystem responses when it occurs. Density dependent processes which effect survival during the multi-year juvenile pre-recruit period can modify year-class strength. We regard these as second order effects. Therefore, a key component of any LTOP would be the annual success of the pelagic juvenile (0-group) stages, before density dependent processes occur. Monitoring changes in pelagic juveniles over time and understanding the trophic linkages should be the guiding principles of our scientific research programs.

Recruitment of fish into fishable populations is a primary input into single species stock assessments. This is particularly true of populations recovering from overfishing or suffering the effects of excessive fishing mortality. Increasingly, it is being demonstrated for many species of fish that year-class strength is established relatively early in life. Atlantic cod (*Gadus morhua*) and capelin (*Mallotus villosus*) are key components of boreal ecosystems (Tjelmeland and Bogstad 1998). Understanding recruitment dynamics of cod and capelin has been an important scientific question confronting fisheries scientists (Akenhead et al. 1982). For Atlantic cod, year-class strength is established by the pelagic juvenile (Sundby 1989, Assthorsson et al. 1994, Jakupsstovu and Reinert 1994, Helle et. al. 2000). For capelin, it is established during the larval and 0-group stages shortly after their release and dispersal from beach and bottom sediments (Leggett et al. 1984, Gundersen and Gjøsæter 1998, Anderson et al. 2000). Targeting these early life stages should be a primary focus of any attempt to understand processes effecting the production of fish. Measuring the abundance and biomass at these pelagic juvenile stages is critical to disentangling bottom up versus top down control mechanisms.

Perhaps the exception to the pelagic production/benthic storage model is the role played by multi-aged populations of forage fish. In the Newfoundland region, the primary forage fishes are capelin, sandlance (*Ammodytes* sp.) and Arctic cod (*Boreogadus saida*). Capelin is a keystone species (Figure 2). As planktivores, they rely on zooplankton for their well being. As prey, they are an important and preferred component of all dominant piscivore and mammal predators. It is estimated that capelin provided on the order of 6.7 Mt of prey to the marine ecosystem in the early 1980's (Bundy et al. 2000). Current estimates suggest this consumption is now less than 2.0 Mt (Carscadden et al. 2001). However, the current uncertainty in the status of capelin off Newfoundland and Labrador (Anon 2000) precludes any understanding of processes at work. Interactions between species of forage fish, and with their environment, should be a primary goal of ecosystem research. Monitoring the abundance, distribution and biomass of the dominant forage fishes will provide important measures of ocean carrying capacity. Linking the status of forage fish to Atlantic cod population dynamics is a necessary step in understanding and monitoring the re-building of these stocks during fishing moratoria.

Definition of an Ecosystem

Marine pelagic ecosystems can be defined at different spatial and temporal scales. Spatially, the Atlantic Ocean has been divided into four "biomes" comprising 21 biological "provinces" (Longhurst 1998). Atlantic Canada is comprised to two provinces from two different biomes. From the Atlantic Coastal Biome, there is the Northwest Atlantic Shelves Province, which extends from Cape Hatteras to the northern Grand Banks, including the Gulf of St. Lawrence and Flemish Cap. Within the Atlantic Polar Biome, there is the Boreal Polar Province, which extends from the Northeast Newfoundland Shelf to the Arctic. Of particular importance is the boundary between Arctic and Temperate systems within Canada's Atlantic zone in the waters off Newfoundland. Measuring ecosystem response at this boundary should be a key component of any LTOP in Atlantic Canada.

Temporally, the ocean exhibits red noise at all observed frequencies in the range of seconds to years (Wunsch 1981). This can be used to explain why marine pelagic organisms are more closely coupled to their physical environment than terrestrial ones (Steele 1991). However, we have no direct information on the exact nature of biological variance at decadal to century scales (Steele 1995). The important question is how will marine communities respond at these longer time scales? Clearly, LTOP's must operate over many decades before we can answer this question.

Spatially, marine ecosystems differ in vertical structure. The pelagos is composed of plankton and nekton living in a dynamic and advective environment. In contrast, the benthos is composed of sessile organisms which spend most of their lives constrained to relatively small areas. In between these two communities exists a third component, the semi-demersals, species which are largely dependent on the benthos as prey and on seabed habitats as refugia. The horizontal structure of these ecosystem components is different. The pelagos is characterized by relatively little structure over large spatial distances in contrast to the benthos which is highly structured over smaller distances (Figure 3). Lying between these two extremes is the horizontal structure of semi-demersal species. Different monitoring programs will be required for the these different components of marine ecosystems.

Ecosystem Science for the Newfoundland Region

Geographical Area

The shelf waters off the coasts of Newfoundland and Labrador are unique. To the north they are dominated by the cold, low salinity, ice infested waters of the Labrador Current. The influence of the Labrador Current propagates onto the Scotian Shelf and into the Gulf of St. Lawrence, having a significant impact on these systems. In the south of the Newfoundland region, the ocean is strongly influence by the warm, high salinity waters of the Gulf Stream and North Atlantic Current. Within a relatively small geographic area, these currents meet to form a distinct cline in biological regimes that range from Arctic to Temperate. Many species are at the northern, or southern, limits of their range. Monitoring ecosystem dynamics in the Newfoundland region, where the Arctic influence on the marine ecosystems is strongest, should best detect signals of ecosystem change in Atlantic Canada.

Monitoring Ecosystem Components

The marine ecosystem can be summarized into eight components (Figure 4). Currently we are monitoring five of these components in the Newfoundland region. Long term temperature and salinity observations extend over a 50 year period. Demersal fish have been monitored using research trawl surveys on the Grand Banks for 30 years and on the Northeast Newfoundland Shelf, Southern Labrador Shelf and St. Pierre Bank for 20 years. Harp seals have been censuses over several decades while components of seabird colonies have been monitored on decadal time scales by researchers from the Canadian Wildlife Service and Memorial University. Monitoring of the plankton began in 1993 and continues under the Atlantic Zone Monitoring Program (AZMP).

The major components not monitored within the Newfoundland region are the nekton which includes the pelagic fishes, the benthos and other large predators. Exclusion of these major groups from long term monitoring programs will preclude any fundamental progress in monitoring ecosystem changes when they occur and understanding of linkages among the primary components of marine ecosystems. We propose that new programs be initiated that would include the long term monitoring of the missing components of the marine ecosystems off Newfoundland and Labrador. The most important of these programs would be a long-term survey of the nekton.

Components of an Ecosystem Survey

Surveys designed to monitor marine ecosystems should meet several criteria. These criteria include measures of:

1. Absolute estimates of abundance and biomass at population scales;
2. Biological responses in growth and condition of populations;
3. Distributional shifts in spawning time and location of populations;
4. Many species of the ecosystem(s);
5. Boundary conditions among adjacent ecosystems.

The most meaningful surveys will be those that measure the response of important fish, and invertebrate, populations to a changing physical and biological environment. How the annual production of plankton affects higher trophic levels is of fundamental importance to our understanding of how marine ecosystems are changing. In temperate and boreal systems, most marine species disperse their progeny into the pelagic zone as larvae and juveniles where they graze on the annual production of zooplankton. In cold water systems this annual production is compressed into a single pulse. The confinement of fish larvae and juveniles to the upper water column in late summer provides a key opportunity to quantitatively sample the ecosystem. This is a gate-way through which most marine species must pass.

Pelagic Juvenile Fish Survey 1994-1999

A large-scale survey of the pelagic ecosystem was conducted off Newfoundland from 1994-1999. This survey, the Pelagic Juvenile Fish Survey, was designed to measure the pre-recruit abundance of Atlantic cod and capelin, as well as provide measures of abundance, distribution and biomass of all components of the plankton and nekton from southern Labrador to the southern Grand Banks (2J3KLNO) as well as the large inshore bays along the northeast coast of Newfoundland. The survey sampled over three order of magnitude in size, from macrozooplankton (0.2 mm) to 3+ year old capelin (200 mm) using plankton (bongo) and mid-water (IYGPT) trawls. In recent years, splitbeam acoustic sampling was incorporated (EK500) to assess biomass throughout the water column to approximately 400 m depth. The results from these surveys have been presented at regional and zonal assessment meetings (eg. Dalley et al. 2000). In summary, the survey has measured large scale changes over the six years the survey was conducted. These changes include:

- expansion of spawning range, for many species;
- order of magnitude increases in abundance
- doubling of plankton and nekton biomass
- increased fish condition (eg. capelin)
- earlier spawning dates (eg. capelin, cod)

These changes have occurred within a warming ecosystem, following the extensive ice cover and record low temperatures of 1991.

The pelagic ecosystem can be divided into three biological regimes based on the nekton (Figure 5). In the north are Arctic species, dominated by Arctic cod (*Boreogadus saida*) and including such cold water species as Arctic squid (*Gonadus fabricii*) and Arctic alligatorfish (*Aspidophoroides olriki*). In the south are Temperate species, dominated by sandlance (*Ammodytes* sp) and including such warm water species as yellowtail flounder (*Limmanda ferruginea*), haddock (*Melanogrammus aeglefinus*) and white hake (*Urophycis tenuis*). In between are Boreal species, dominated by capelin (*Mallotus villosus)* and including Atlantic cod (*Gadus morhua*) from the northern stock (2J3KL) and American plaice (*Hippoglossoides platessoides*). To date, 74 species of fish have been identified from survey collections. Unidentified are species of lanternfishes and, no doubt, rarer species of sculpins, shannies and blennies.

Beginning in 1994, zooplankton biomass increased linearly, reaching a peak in 1997 before declining moderately in 1998 and again in 1999 (Figure 6). Nekton biomass reached a minimum in 1995 and increased only moderately until 1997, after which biomass had approximately doubled by 1999 (Figure 6). A large component of the increase in nekton biomass was due to large jellyfish (eg. *Aurelia* sp.). A lag between the increase in zooplankton and the nekton is apparent. The reason(s) for this lag remain unknown. Individual species of fish remained low or declined from 1994 until either 1996 or 1997. In 1998, there were order of magnitude increases in fish abundance, although these occurred primarily over the Grand Banks. The most dramatic increase was haddock, which did not occur within the survey area until 1998. However, other species exhibited logarithmic increases in abundance. In 1999, a similar large increase in abundance was observed to the north along the northeast coast of Newfoundland, of which the most dramatic was Atlantic cod. Taken together, the large increases in abundance of pelagic juvenile fish did not occur until 1998 and 1999 (Figure 7), one year after the peak in zooplankton biomass. Finally, the increases in abundance are reflected in distributional changes, where ranges tended to contract until 1996 or 1997 before increasing to maxima by 1999. Together, these data suggest an increase in carrying capacity within the pelagic ecosystem and are suggestive of a biological regime shift.

Our ability to detect changing carrying capacity in the ocean must extend from measures of physical change and plankton production to production at higher trophic levels. Measuring the production of fish at the pelagic juvenile stage is an important step towards untangling confounding relationships in fish population dynamics. Only by measuring change, when it occurs, will we begin to understand significant events in marine ecosystems.

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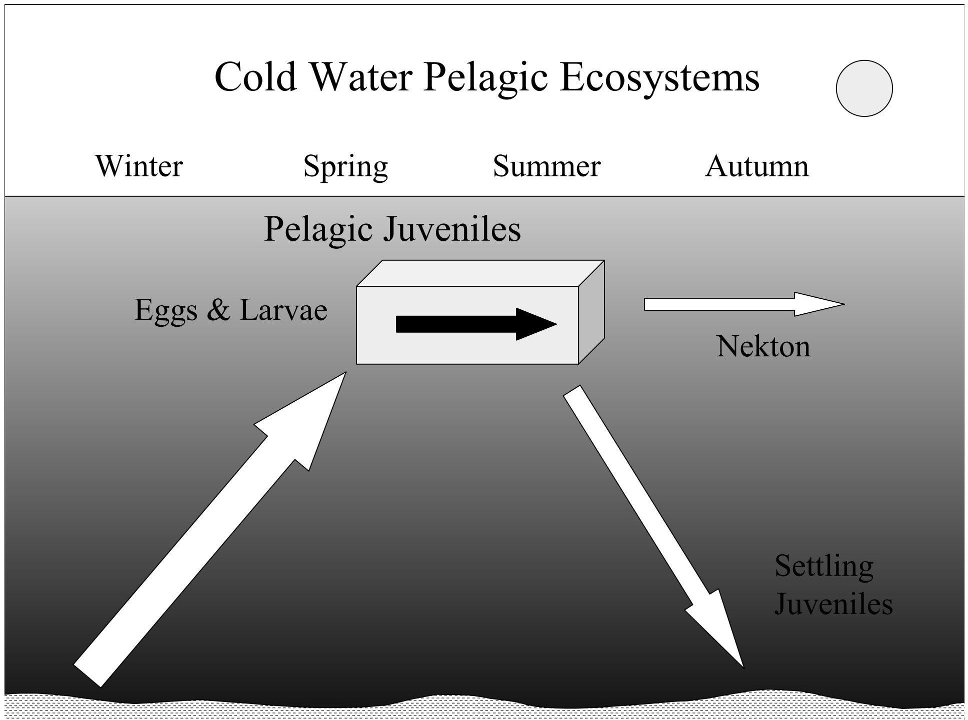

Figure 1. Schematic representation of pelagic ecosystem, where spawning occurs in late winter and spring, followed by the summer period of growth and metamorphosis to pelagic juveniles. In the autumn much of the fish and invertebrate biomass settles to the bottom while a smaller component remains pelagic as forage fishes.

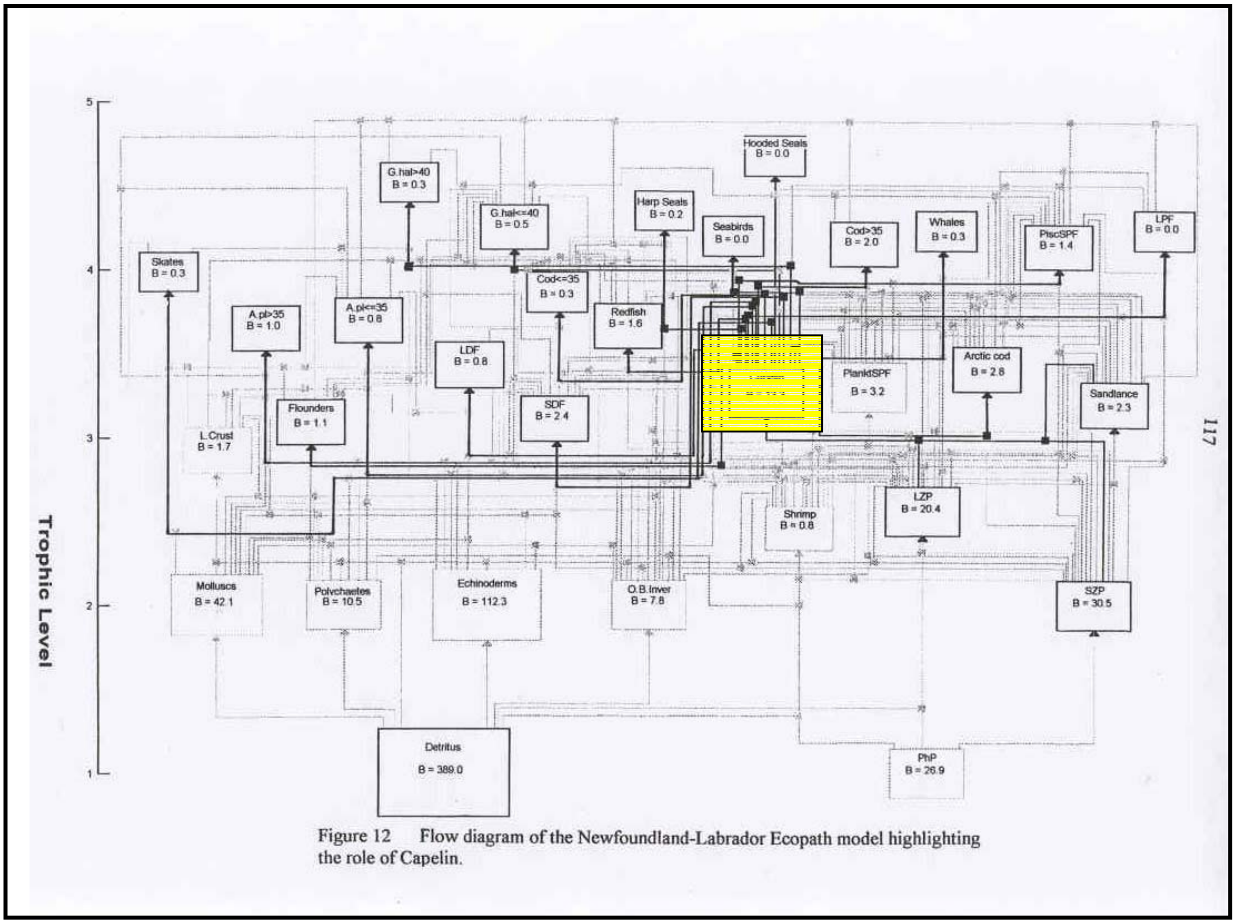

Figure 2. Flow diagram of the Newfoundland-Labrador Ecopath model highlighting the role of capelin as an important keystone species in the ecosystem (Bundy et al. 2000).

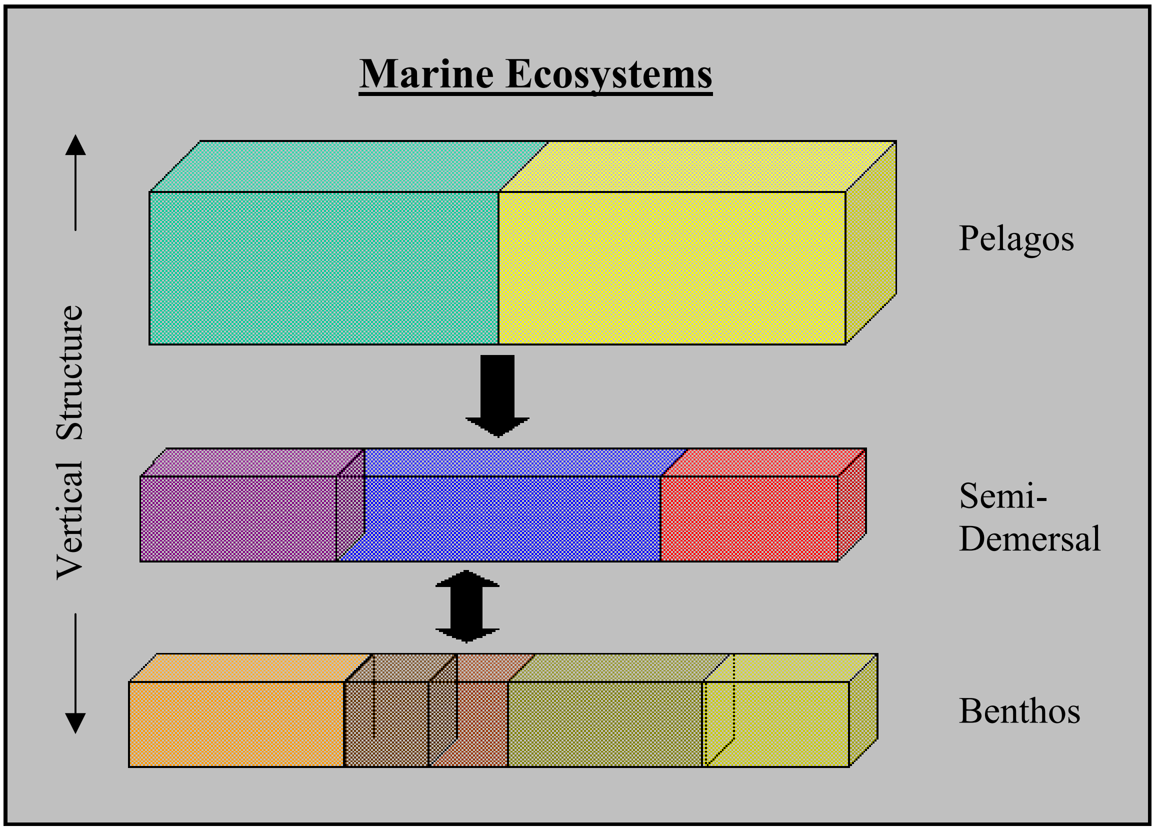

Figure 3. Schematic representation of ecosystem spatial structure for the different components that occur in the pelagic zone, the benthic zone and the semi-demersal interface zone between the pelagos and benthos.

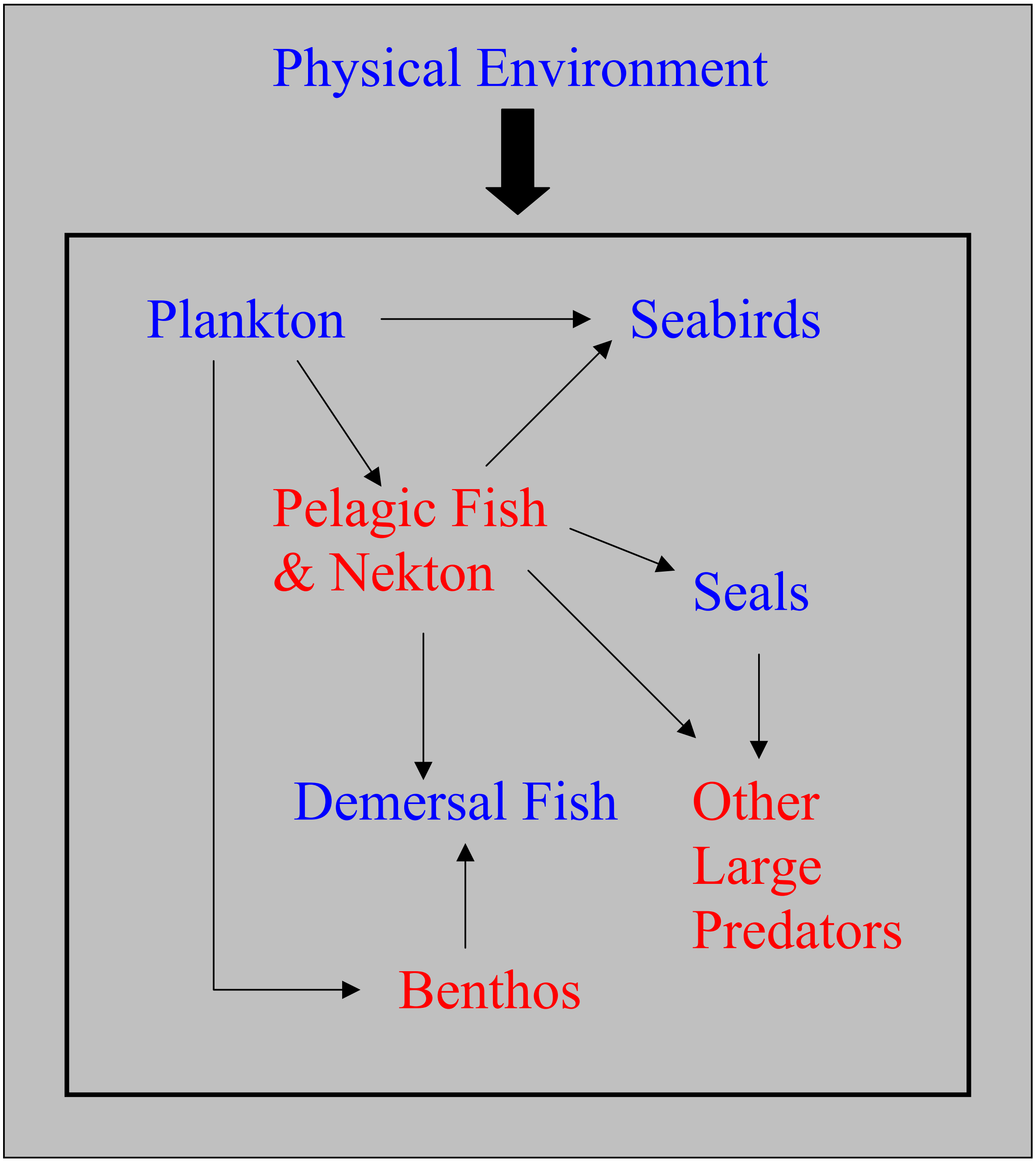

Figure 4. Schematic representation of relationships among key components of temperate and boreal marine ecosystems.

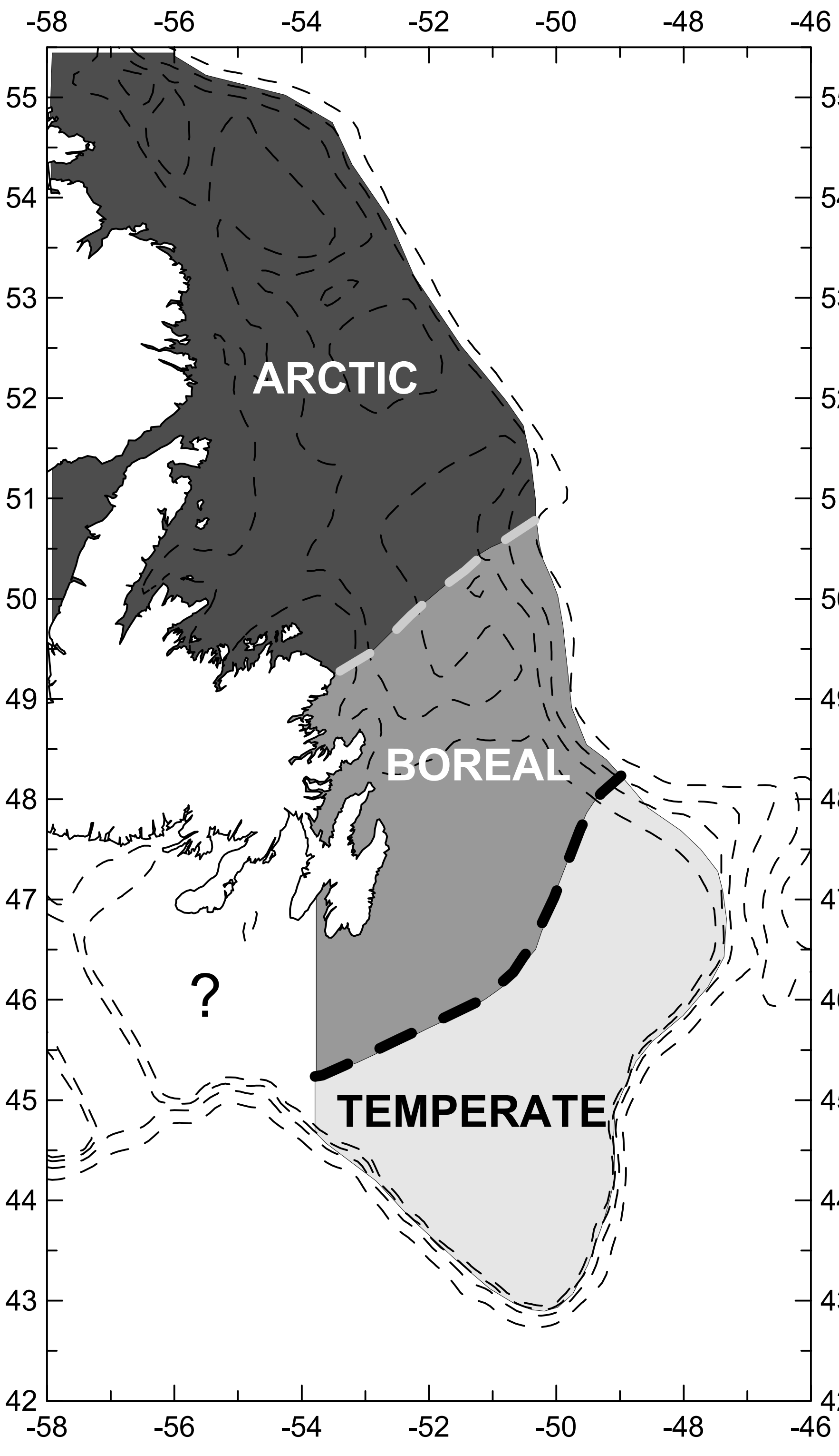

Figure 5. Oceanic regimes defined by nekton sampled during the annual Pelagic Juvenile Fish Surveys, 1994-1999.

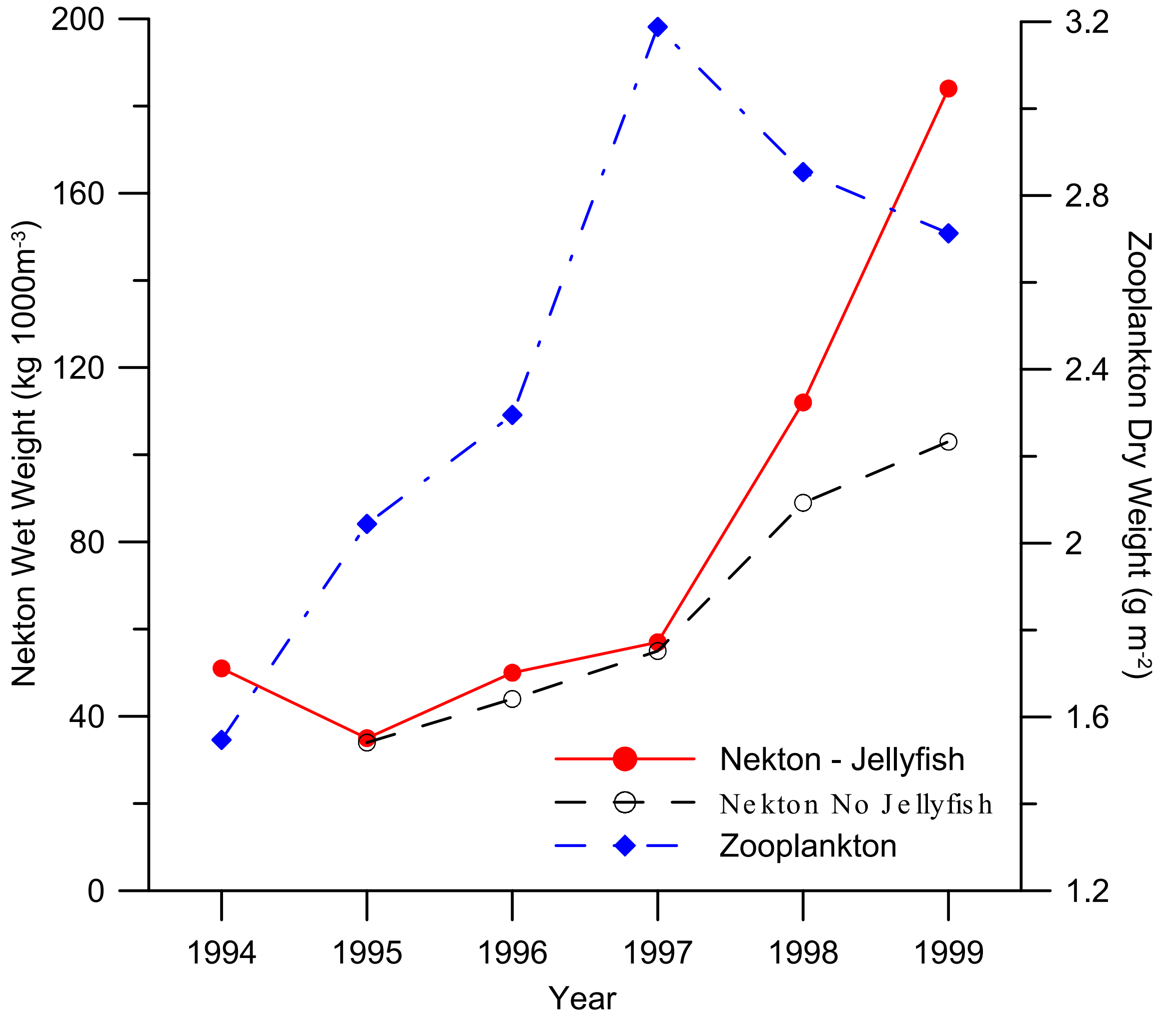

Figure 6. Temporal change in biomass of invertebrate zooplankton and nekton both with and without jellyfish as sampled during annual Pelagic Juvenile Fish Surveys, 1994-1999.

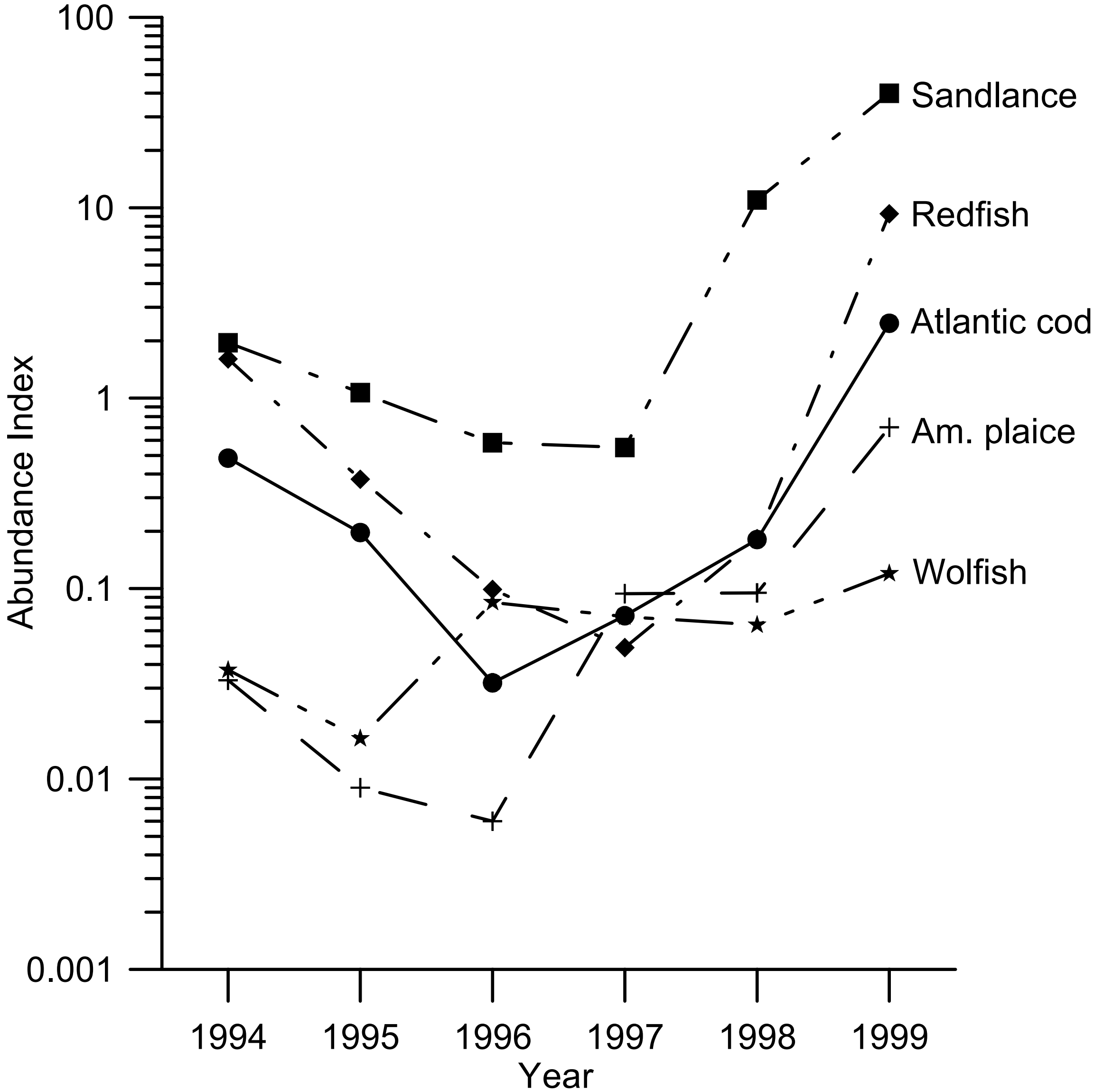

Figure 7. Abundance of different species of pelagic fish sampled on the Northeast Newfoundland Shelf and Grand Banks (2J3KLNO) during annual Pelagic Juvenile Fish Surveys, 1994-1999