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LARGE-SCALE CLOSED AREAS AS A FISHERY-MANAGEMENT TOOL IN TEMPERATE MARINE SYSTEMS: THE GEORGES BANK EXPERIENCE

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ABSTRACT

Seasonal closed areas have been an element of fishery management in New England waters since 1970 but before 1994 had limited impact on the conservation of groundfish stocks for which they were designed. Beginning in December of 1994, three large areas of historic importance to groundfish spawning and juvenile production on Georges Bank and in Southern New England, totaling 17,000 km^2, were closed year-round to any gears capable of retaining groundfish (trawls, scallop dredges, gill nets, hook fishing). In the ensuing five years, the closed areas contributed significantly to reduced fishing mortality of depleted groundfish stocks. Placements of the closed areas afforded the greatest year-round protection to the shallow-sedentary assemblage of fishes (primarily flounders, skates, and miscellaneous others) and bivalve molluscs. Although the closures afforded less year-round protection to migratory age groups of Atlantic cod, *Gadus morhua*, and haddock, *Melanogrammus aeglefinus*, additional new regulations in open areas and in the Canadian portions of Georges Bank also contributed to the observed reductions in stock-wide fishing mortality rates. The areas were closed to dredge gear designed for sea scallops, *Placopecten magellanicus*, because of groundfish by-catch (particularly of flounders). Scallop biomass increased 14-fold within the closed areas during 1994–1998. In July 1998, total and harvestable scallop biomasses were 9 and 14 times denser, respectively, in closed than in adjacent open areas. A portion of the closed areas was designated a "habitat area of particular concern" on the basis of patterns of occurrence of juvenile groundfish in gravel/cobble sediment types. Managers reopened portions of one closed area to sea-scallop dredging in 1999, but restrictions on gear and areas fished were used to minimize groundfish by-catch and impact on juvenile cod and haddock on gravel substrates. Results from these reopenings have encouraged managers to contemplate a formal 'area rotation' scheme for scallops intended to improve yield per recruit. Closures of large portions of Georges Bank have proved to be an important element leading to more effective conservation of numerous resource and nonresource species, despite selection of the closed areas on the basis of seasonal spawning grounds of haddock and the distribution of yellowtail flounder, *Limanda ferrugineus*, in southern New England. In the future, factors other than fishing mortality reduction, including optimal placement to enhance larval production and to protect nursery areas and spawning concentrations, may well influence the selection of closed-area boundaries.

Cuius regio, eius religio
(Proverb: He who controls the area controls the religion)

Interest in the use of the use of marine protected areas as a primary fishery-management tool has increased as many species have become overfished and depleted while regulated under traditional direct and indirect control systems (Agardy, 1994; Lauck et al., 1998; Allison et al., 1998; National Research Council, 1999). The recent focus on 'simpler' fishery management measures such as areas closed to all fishing stems in part from implementation failures (inability to meet biological goals of management programs)

Table 1. Common and scientific names of some important groundfish species managed under the New England Fishery Management Council's Multispecies Fishery Management Plan (marked with *) and other important Georges Bank finfish and invertebrate species found in the Georges Bank and Nantucket Lightship closed areas.

Common name	Scientific name
Atlantic cod*	*Gadus morhua*
Haddock*	*Melanogrammus aeglefinus*
Pollock*	*Pollachius virens*
Yellowtail flounder*	*Limanda ferrugineus*
Winter flounder*	*Pleuronectes americanus*
Windowpane flounder*	*Scophthalmus aquosus*
Acadian redfish*	*Sebastes marinus*
White hake*	*Urophycis tenuis*
Silver hake*	*Merluccius bilinearis*
Red hake*	*Urophycis chuss*
American plaice*	*Hippoglossoides platessoides*
Witch flounder*	*Glyptocephalus cynoglossus*
Ocean pout*	*Macrozoarces americanus*
Atlantic halibut*	*Hippoglossus hippoglossus*
Winter skate	*Raja ocellata*
Little skate	*Raja erinacea*
American lobster	*Homarus americanus*
Atlantic sea scallop	*Placopecten magellanicus*

in fisheries management. Even when appropriate biological goals for fisheries have been specified, fisheries have failed because of significant harvest overcapacity, combined with the lack of proper enforcement of regulations, inability of management to react in a timely way to changing stock conditions, the relatively rapid pace of technology development in fishing, difficulties in addressing allocation issues, and other problems. Properly designed and implemented closed areas offer at least the potential for improved fishery management as a hedge against ineffective direct controls and as mitigation for potentially destructive habitat modifications by various fishing methods (Lauck et al., 1998). Use of closed areas has been advocated primarily for tropical reef systems, where habitat attributes structure the fish community and rates of movement across closed-area boundaries by adults are modest (Bohnsack, 1994, 1998). Examples are fewer of the use of large-scale closed areas to manage temperate marine (gradient) systems (Horwood, 2000), and the effects of those that do exist are little documented (Peit and Rijnsdorp, 1998; Brown et al., 1998).

In the U.S. northwest Atlantic, closed areas have become important elements of fishery management programs for regulated groundfish (Table 1) and sea scallops, in part because of earlier implementation failures of fishery management programs for these species. Their use, in combination with more aggressive direct controls in these fisheries, has resulted in major changes in the fishing mortality rates, abundance and geographic distributions of resource and nonresource species, and fishing effort. This paper examines the historical evolution of closed areas as a management tool in this temperate marine system. Biological and economic effects of current closed areas are discussed, and optimal placement of closed areas for enhancing recruitment and fishery yields is considered.

Evolution of Fishery Closed Areas in New England

> "We therefore recommend that the taking of fishes, excepting shellfishes, by means of otter trawl . . . or by any other apparatus drawn over the bottom by a vessel in motion, be prohibited on all bottoms . . . north of the 40th degree of N latitude, excepting Georges Bank, South Channel and Nantucket Shoals east of the meridian of Sankaty Head on the Island of Nantucket" (Alexander et al., 1915)

The introduction of the otter trawl to the New England groundfish fishery at the turn of the 20th century was not greeted with unanimous acclaim (Alexander et al., 1915). Concerns about economic competition with existing fixed-gear (predominantly hook-and-line) fleets, by-catch mortality of large numbers of juvenile fishes, and the potential for destruction of bottom faunal communities were articulated and studied (Alexander et al., 1915). Comparative observer data were obtained from otter-trawl and hook-and-line vessels ('line trawlers') and used to characterize catches, document by-catch, and conduct crude evaluations of the impacts of mobile gears on megabenthic plant and animal communities. On the basis of these early studies, researchers recommended, among other things, that the new trawl technology be deployed only on the broad continental shelf off southern New England and on Georges Bank (Fig. 1). The study recommended against the use of the otter trawls in the Gulf of Maine and adjacent 'hard-bottom' areas, because of competition with line trawlers and the greater abundance of flounders, which could not be as readily caught by line trawl, on the offshore banks—the recommendations were never followed. The banning of particular gears or all fishing in specific areas was not again considered in New England until the late 1960s (Halliday, 1988).

During the 1960s the arrival of large distant-water fleets and ensuing overfishing of groundfish and other resources resulted in calls for various protections, including the seasonal closure of areas on the Northeast Peak and Great South Channel of Georges Bank (Fig. 1; Halliday, 1988). Two seasonal closures were established on Georges Bank, beginning in 1970, under the authority of the International Commission for the Northwest Atlantic Fisheries. The areas were closed to most gears capable of catching groundfish (although hook gear and scallop dredges were allowed), originally from March through April (Halliday, 1988; Gerrior et al., 1994, 1996; Brown et al., 1998). The two areas were configured explicitly to protect the two spawning components of Georges Bank haddock, so as to minimize disruption of breeding activities, a policy widely supported by fishers as an appropriate management measure (Halliday, 1988). The area boundaries changed over time in response to perceived fluctuations in the spawning grounds occupied by the stock, management concerns for other resources, and changing political geography including the resolution of the U.S.-Canada maritime boundary in 1985 (see Halliday, 1988, for plots of closure boundaries over time). These temporary spawning closures had little effect in arresting the decline of the haddock stock in the early 1970s; seasonal closed areas were determined to be working only marginally to meet fishery-management-plan goals, when assessed in 1988 (Serchuk and Wigley, 1987; Technical Monitoring Group, 1988).

Although the closed areas protected spawning aggregations that would otherwise have resulted in higher haddock catches and exploitation rates, reduction of fishing mortality was not the explicit reason for establishing the closures. Improvement in the efficiency of reproduction was the purpose: such an effect could not be demonstrated in the time series of recruitment-survival data for years when the closed areas were in force. Fish generally

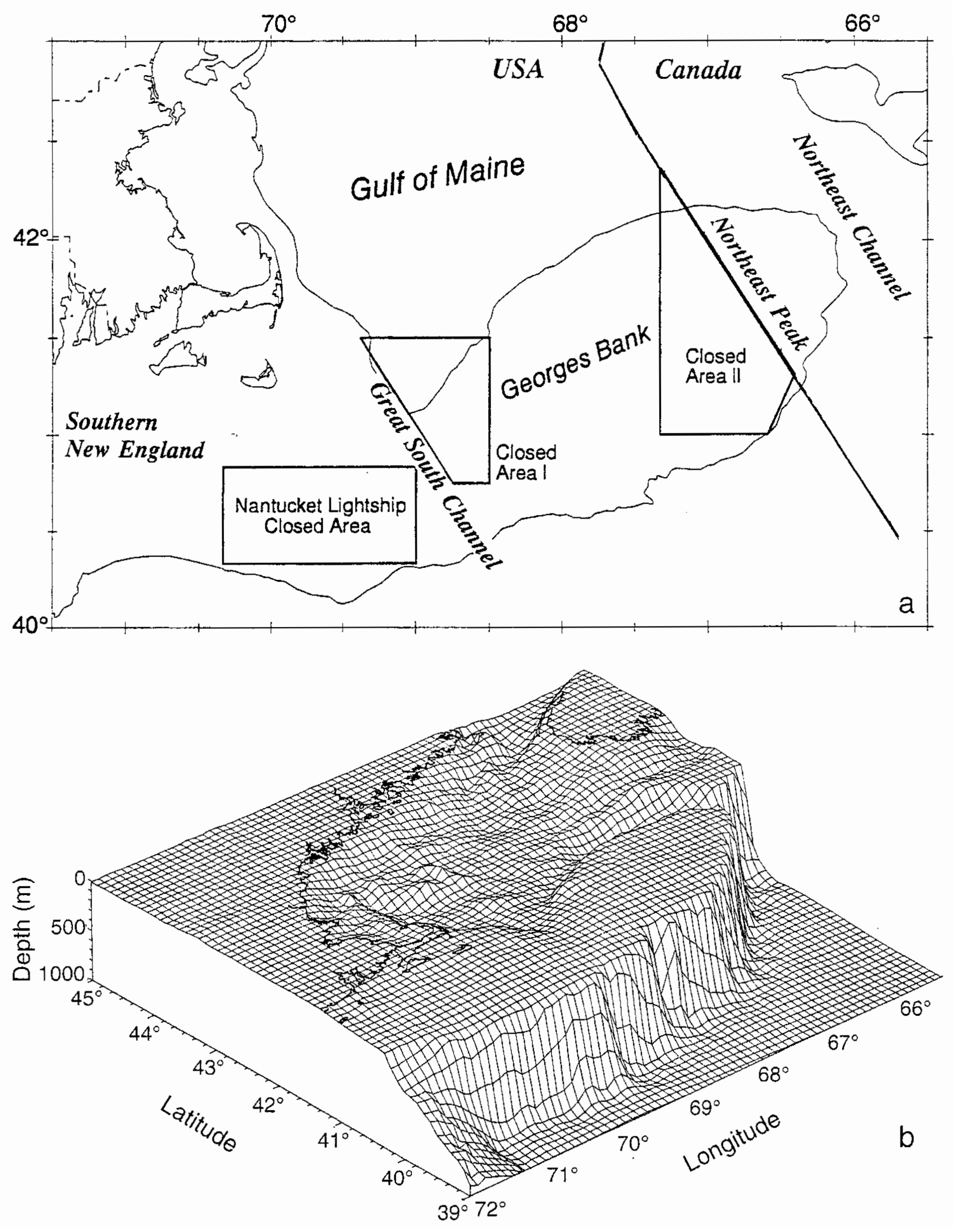

Figure 1. Fishery closed areas in the Georges Bank–Southern New England region (a) and bathymetry of the Gulf of Maine region (b).

remained aggregated after the temporary closures were lifted, resulting in relatively high catch rates on postspawning adults (usually in early June). In some years, the majority of the annual U.S. haddock catch was landed just after the lifting of the seasonal closures. Haddock aggregations, particularly on the eastern side of Georges Bank, would then disperse into deeper waters off the Northern Edge of Georges Bank (Overholtz, 1985; Brown et al., 1998).

Partitioning of Georges Bank into U.S. and Canadian zones by the World Court in 1985 resulted in changing configurations of closed areas (Halliday, 1988). The closed areas in U.S. waters were extended spatially in some years and temporally from January through June. Area I (Fig. 1) was not closed in 1994, because of the very low abundance of haddock in the Great South Channel area and the perception that there were few spawning fish left in that area to protect. On Canadian portions of Georges Bank, all groundfish fishing has occurred in recent years during the second half of the year (June–December) under restrictive total-allowable-catch quota regulation.

Closed areas for the protection of yellowtail flounder were instituted with the advent of the Northeast Multispecies Fishery Management Plan in 1986 (see Table 1 for a list of species currently regulated under this plan). A seasonal closure was established from March through May in an irregularly shaped area off the southern New England coast, extending from east of Nantucket Island westward to the waters south of eastern Long Island, New York. The original yellowtail closure area off southern New England was intended to reduce fishing mortality and to protect the stock during spawning. As with the Georges Bank areas intended for haddock, the southern New England seasonal closures were not particularly effective as a conservation measure for the target species (Technical Monitoring Group, 1988), because aggregations of yellowtail could be effectively exploited before and after the seasonal closure. An alternative yellowtail protection area (Fig. 1) was identified in the Nantucket Lightship area as a contingency measure in Amendment #5 to the Northeast Multispecies Fishery Management Plan. This area was originally intended to be implemented only when the abundance of southern New England yellowtail flounder, as measured by standardized surveys, was high enough to justify closure to protect identified concentrations of small fish from being killed as by-catch. The measure was intended to minimize the potential by-catch mortality of abundant yellowtail flounder year classes, which had been problematic for the stock virtually since the advent of the fishery in the 1930s. The irony, of course, was that in the absence of the closure and other direct fishery controls, conditions that would have triggered closing the grounds (i.e., high abundance of small yellowtail) became less and less probable with progressive declines in spawning biomass.

Promulgation of Amendment #5 to the Northeast Multispecies Fishery Management plan in 1994 marked a change in philosophy of groundfish management in New England to more direct controls on effort and fishing mortality. Days at sea by fishing vessels were to be cut gradually to 50% of the fleet total in the early 1990s, and other, more restrictive measures were enacted, but the deteriorating condition of groundfish resources in the mid-1990s resulted in recommendations from the scientific community for immediate reductions in fishing mortality on groundfish stocks to avert wide-spread fishery collapse (NEFSC, 1994). As a result, the Secretary of Commerce, acting under his emergency authority, closed Areas I and II on Georges Bank and the Nantucket Lightship area to all gears capable of retaining groundfish (trawls, gill nets, hook gear, and scallop dredges), effective December 1994. The only gears that could be deployed in the closed areas were lobster traps and, later, mid-water trawls for small pelagic species. Given that the secretary's emergency authority could only be extended for up to 180 days, the New England Fishery Management Council, in early 1995, amended its fishery-management plan to incorporate year-round closures of the areas. The New England Council implemented, in 1996, Amendment #7 to the fishery-management plan, to accelerate days-at-sea reductions, and added additional restrictions on the fishery. Under Amendments #5–

Table 2. Areas of the closed areas discussed in the present paper.

Closed area	Area (km^2)
Area I	3,960
Area II	6,927
Nantucket Lightship	6,275
Total	17,162

7 of the plan, effort was reduced by 50% for most of the mobile-gear fleets, the three large areas on Georges Bank and in southern New England were closed, minimum mesh sizes were increased to 6 in, a moratorium on new vessel entrants was enacted, and trip limits for haddock, and later cod, were implemented, as were a number of additional regulatory and administrative measures.

DESCRIPTION OF THE CLOSED AREAS.—The three closed areas on Georges Bank and in southern New England total about 17,000 km^2 (Table 2). For Georges cod, haddock, and yellowtail flounder, Areas I and II represent about 21, 17, and 29%, respectively, of the area occupied on Georges Bank. The Nantucket Lightship area represents about 22% of the southern New England yellowtail flounder's range. Habitat types represented in the three closure areas represent a wide range of surficial sediments occurring in these glacial-outwash areas (Fig. 2; Fogarty and Murawski, 1998). Area I is dominated by gravelly sand and gravel, interspersed with extensive fields of glacial erratics. Area II has a northern component of gravel pavement and gravelly sand and has broad expanses of sand and sand waves in the south (Valentine and Lough, 1991). The Nantucket Lightship Area is composed of gravel-sand-boulder areas in the northeast and sand in the central portion, grading to silt-clay in the west. Sediment type, seasonal bottom temperature conditions and depth are the primary factors that structure complex finfish assemblages in the region. On the basis of their preferences about these factors, some species occupy the closed areas year-round (i.e., yellowtail, windowpane, and winter flounders, little and winter skate), and others occupy them seasonally (i.e, cod, pollock, haddock, silver hake; Overholtz and Tyler, 1985; Gabriel, 1992; Murawski, 1993).

Passage of the Magnuson-Stevens Fishery Management Act of 1996 focused new attention on the incorporation of habitat protection as an explicit consideration in fishery management. The new statutes require the designation of essential fish habitat (EFH) and provide for the recognition of "habitat areas of particular concern" (HAPCs) for various stocks or communities. Regulations pertaining to designated HAPCs are developed within the context of approval of fishery management plans.

In the spring of 1998 the New England Fishery Management Council identified a specific HAPC in the northern portion of Closed Area II (Fig. 2), designated to include a portion of the gravel-cobble pavement that extends across the Northeast Peak and Northern Edge of Georges Bank (Valentine and Lough, 1991; Collie et al., 1997; Fig. 2). The gravel pavement areas of the Bank have been identified as a facultative nursery area for juvenile cod and haddock (Lough et al., 1989), although the growth and survival of juveniles in the gravel-cobble habitats, relative to those on other sediment types, is not known. Comparative benthic surveys of gravel pavement areas disturbed by mobile fishing gear (trawls and scallop dredges) and nearby undisturbed sites revealed a number of differences in the biological community (Collie et al., 1997). These areas were sampled in 1994, before the year-round closures. Undisturbed sites had higher numbers of megabenthic organisms, biomass, species richness, and diversity than disturbed sites (Collie et al.,

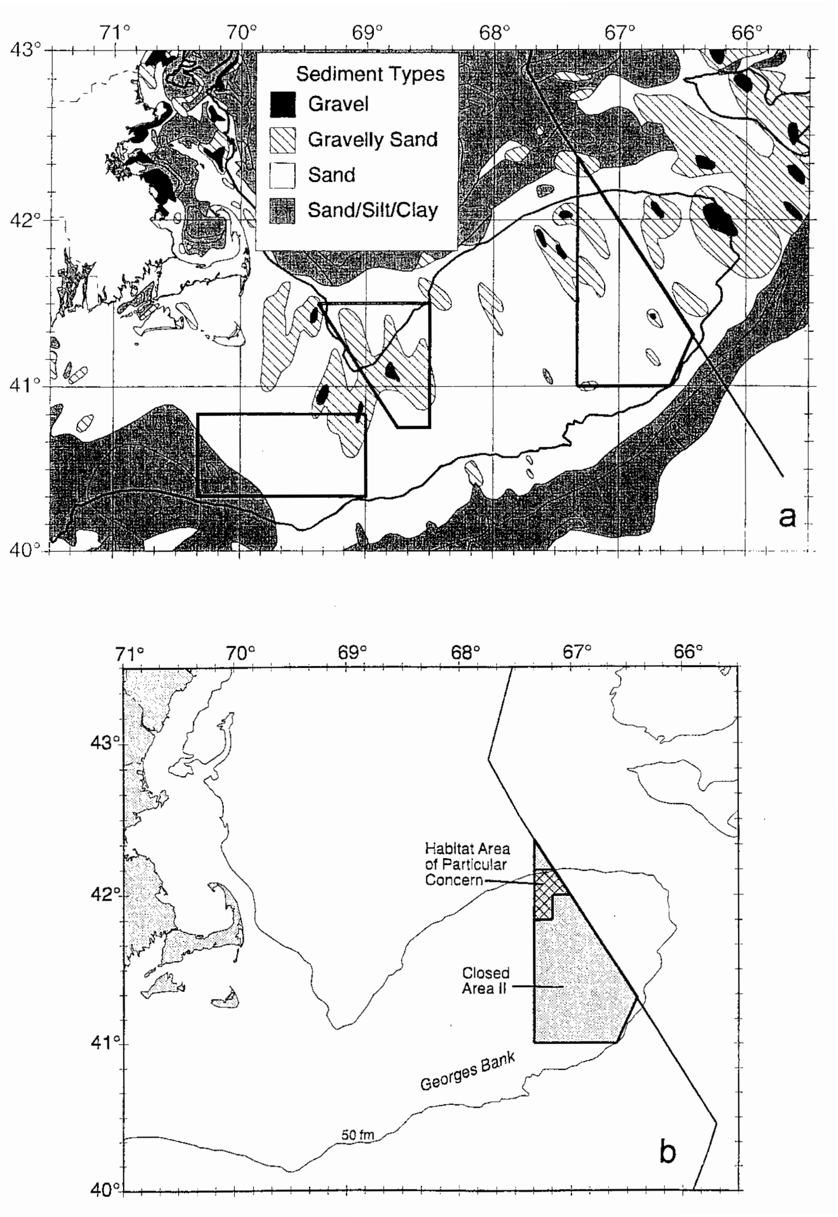

Figure 2. Bottom sediment types in the Georges Bank–Southern New England region (a) and location of the 'habitat area of particular concern' designated by the New England Fishery Management Council (b).

1997). In particular, undisturbed sites were dominated by taxa such as bryozoans, hydroids, and worm tubes. Faunal communities of disturbed sites were dominated by larger shelled molluscs, crabs, and echinoderms. Studies of the composition of benthos at previously disturbed sites that are now located in Closed Area II and specifically in the HAPC have been continued and expanded. On the basis of the gradient of disturbances observed in 1994 and the life histories of various plants and animals common in the area, Collie et

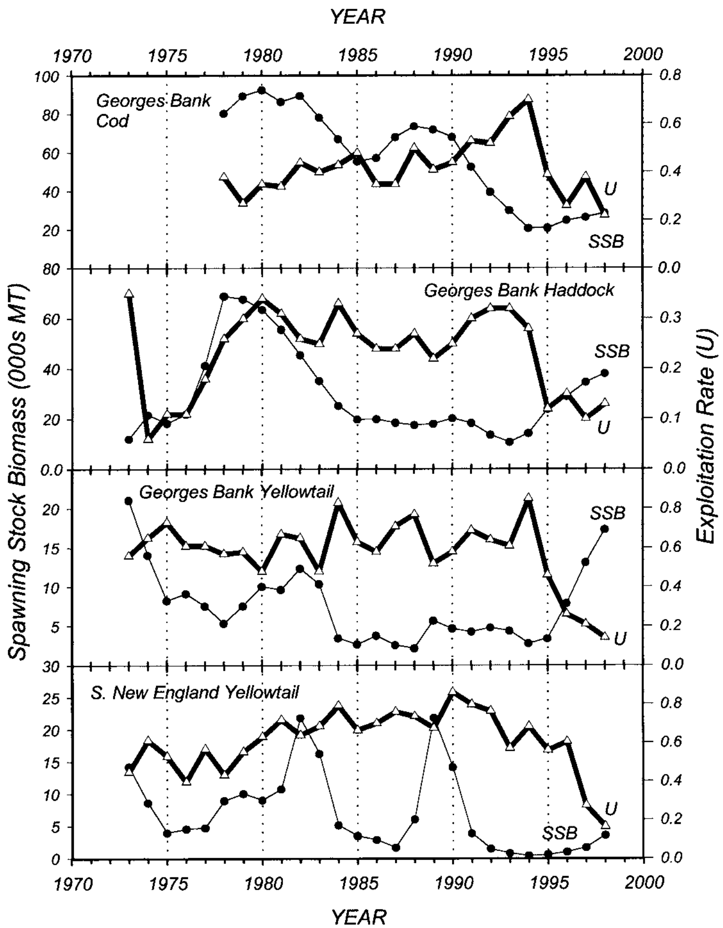

Figure 3. Trends in spawning-stock biomass (SSB, in metric tons) and exploitation rate (U) for four groundfish stocks in the Georges Bank–Southern New England region, 1973–1998.

al. (1997) speculate that it would take 5–10 yrs for the benthic communities in the closed areas to resemble those of undisturbed sites after cessation of trawling and dredging.

Changes in Fishery Resources and Effects of Closed Areas

The level of protection from fishing afforded to various fishery stocks by closed areas is determined by (1) the proportion of the particular stock encompassed by the closures, (2) the extent of movement by vulnerable sizes out of closed areas (either random or seasonal directed movements), and (3) the level of fishing-effort and other regulations in adjacent open areas. In the following sections we describe changes in important groundfish stocks and Atlantic sea scallop and relate the observed changes to the protections afforded by year-round closures and other measures used to conserve the stocks.

Groundfishes.—The three designated areas were closed year-round because of the declining abundance and landings and high exploitation rates of Atlantic cod, haddock, and yellowtail flounder, among other key groundfish species (NEFSC, 1994). A total of 14 groundfish species comprising 24 identified stock groups are regulated under the Northeast Multispecies Fishery Management Plan (Table 1); all regulated species are found at some time or life stage within one or more of the closed areas (Gabriel, 1992). After the year-round closure, exploitation rates (proportion of the stock at the beginning of the year killed by the fishery during the year) declined and spawning-stock biomasses increased for four of the most important regulated groundfish stocks (NEFSC, 1999; Fig. 3). Exploitation rates for Georges Bank cod declined from about 0.7 to 0.5, those for haddock from 0.3 to 0.10, and those for yellowtail flounder from 0.8 to 0.4, between 1994 and 1995 (Fig. 3). Exploitation rate of the southern New England yellowtail flounder stock declined from about 0.7 in 1994 to <0.6 in 1995 and continued to decline to <0.2 in 1998. Spawning-stock biomasses have increased slightly for cod and southern New England yellowtail and significantly for Georges Bank haddock and yellowtail, since 1994 (Fig. 3). Growth in spawning-stock biomasses of the stocks is primarily attributable to increased survival of adults, combined with relatively high rates of somatic growth observed in these populations (NEFSC, 1999). Recruitment during 1994–1998 was poor for Georges Bank and southern New England yellowtail and moderate to good for Georges Bank yellowtail and haddock. The 1998 year class of haddock is the third highest since 1963, and the largest since 1978. Survival of recruits (indexed as recruits per unit of spawning-stock biomass, R/SSB; Fig. 4) has improved since the mid-1990s; in the case of haddock and cod 1998 recruitment survival was above the long-term mean.

To what extent are changes in exploitation rates and spawning biomasses for groundfish stocks attributable to imposition of closed areas? Eastern and western components of Georges Bank cod and haddock stocks are protected differentially by the imposition of Closed Areas I and II. During the winter and spring both Areas I and II are inhabited by adult and juvenile cod and haddock. In the winter and spring, cool water temperatures preferred by cod and haddock extend to shallow portions of Area II (Murawski and Finn, 1988; Murawski, 1993), but in summer and autumn, when conditions warm, Area II is virtually devoid of adults and larger juveniles of both species, which have moved to the north and east into deeper, cooler waters (Figs. 5,6). In summer and autumn, Area II retains age-0 cod and haddock, spawned the previous spring. In contrast, Area I retains significant numbers of cod and haddock in all seasons, because of its steeper depth gradient and, on average, cooler waters throughout the year.

Both Areas I and II and the Nantucket Lightship area retain significant quantities of yellowtail flounder in all seasons; the species is one component of the shallow-water sedentary assemblage of the Bank and shelf, which also includes winter flounder, windowpane flounder, winter skate, and little skate, among other species (Murawski, 1993).

Closed Areas I and II, then, have contributed significantly to the reduction in exploitation rates and improvement in spawning-stock biomasses of Georges Bank cod, haddock, and yellowtail flounder, as well as other components of the regulated groundfish community. Part of the reduction in fishing effort on the eastern Georges Bank spawning components of cod and haddock is also due to reductions in days at sea, which have made fishing trips to the vicinity of Area II relatively more costly in steaming time. The exact proportion of the reduction in exploitation rates attributable to the year-round closed areas cannot be determined, because several other important management controls were implemented about the same time, but some general conclusions can be drawn. Otter-trawl effort (the primary gear used for groundfish stocks) expended by U.S. fishers on Georges Bank and in southern New England declined 41%, from 29,519 d at sea in the

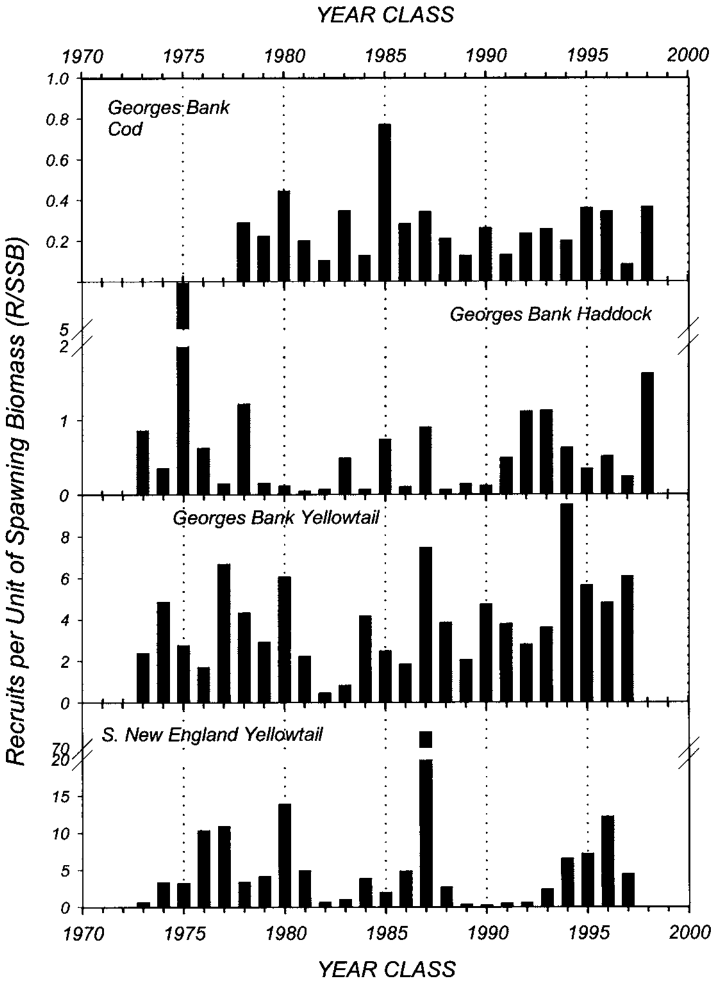

Figure 4. Trends in recruit survival indexed as the ratio of age-1 recruits per unit of spawning stock biomass (R/SSB) for four groundfish stocks in the Georges Bank–Southern New England region, 1973–1998.

1994/1995 fishing year (1 May 1994 to 30 April 1995) to 17,511 d at sea in 1997/1998. Instantaneous fishing mortality rates (a measure of exploitation rate proportional to fishing effort) declined by 66, 62, and 88%, respectively, for Georges Bank haddock, cod and yellowtail flounder from 1994 to 1997. The differences between effort reduction and mortality-rate reduction, particularly for cod and yellowtail, are probably attributable primarily to the lower average catch per day fished (cpue) in open areas, where average stock densities were lower than in the closed areas. For haddock, reductions in Canadian fishing effort (not influenced by the year-round U.S. closures) were the most significant contributing factor to reduced exploitation rates (Canada took over 90% of the Georges Bank haddock catch in 1994, which declined to about 75% in 1997).

Area II effectively protects the majority of the eastern spawning components of cod and haddock while they are distributed in U.S. waters. Landings by U.S. fishers from the

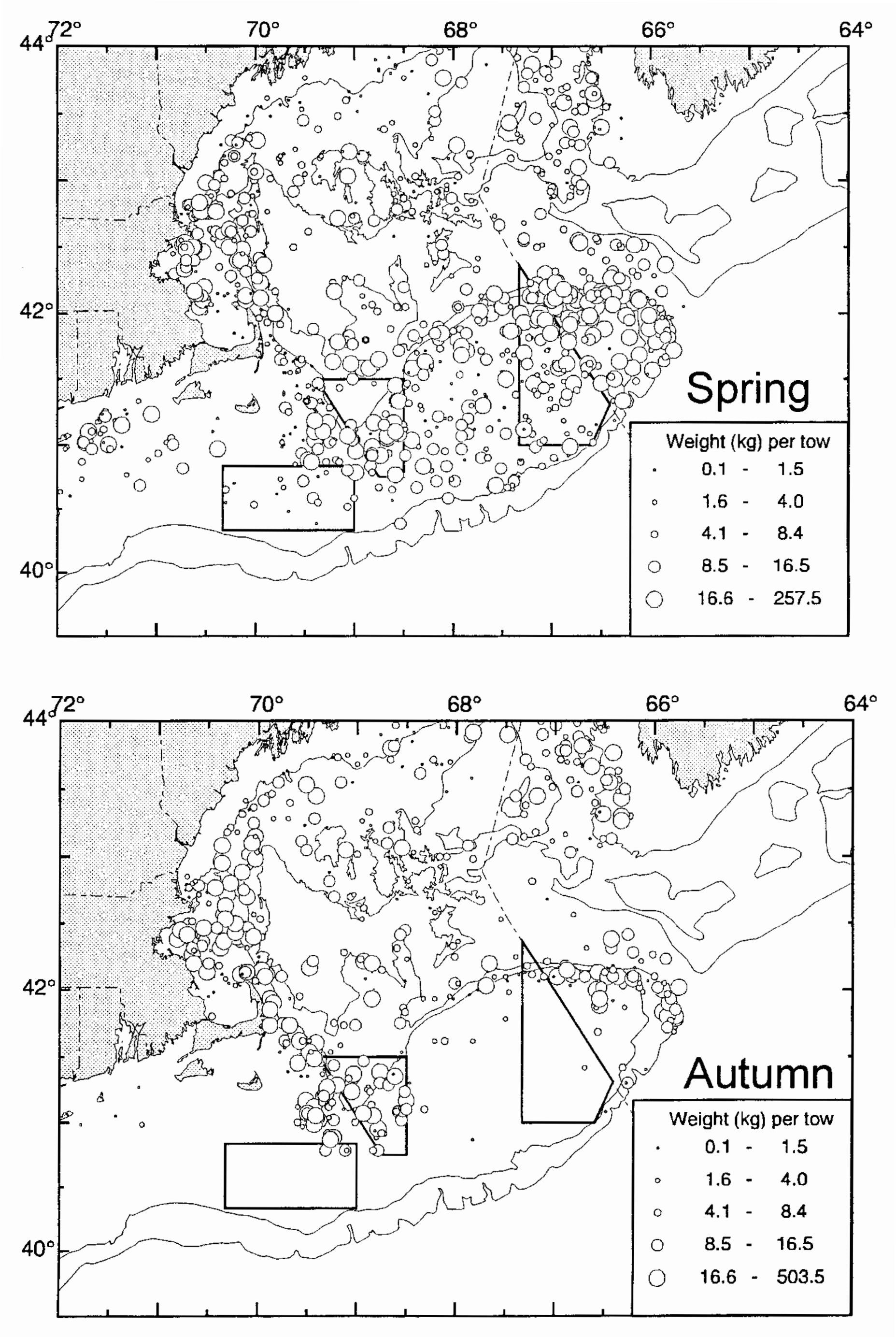

Figure 5. Distributions of Atlantic cod in National Marine Fisheries Service spring and autumn bottom trawl surveys, 1989–1998. Data are weights (kg) per standardized half-hour trawl haul.

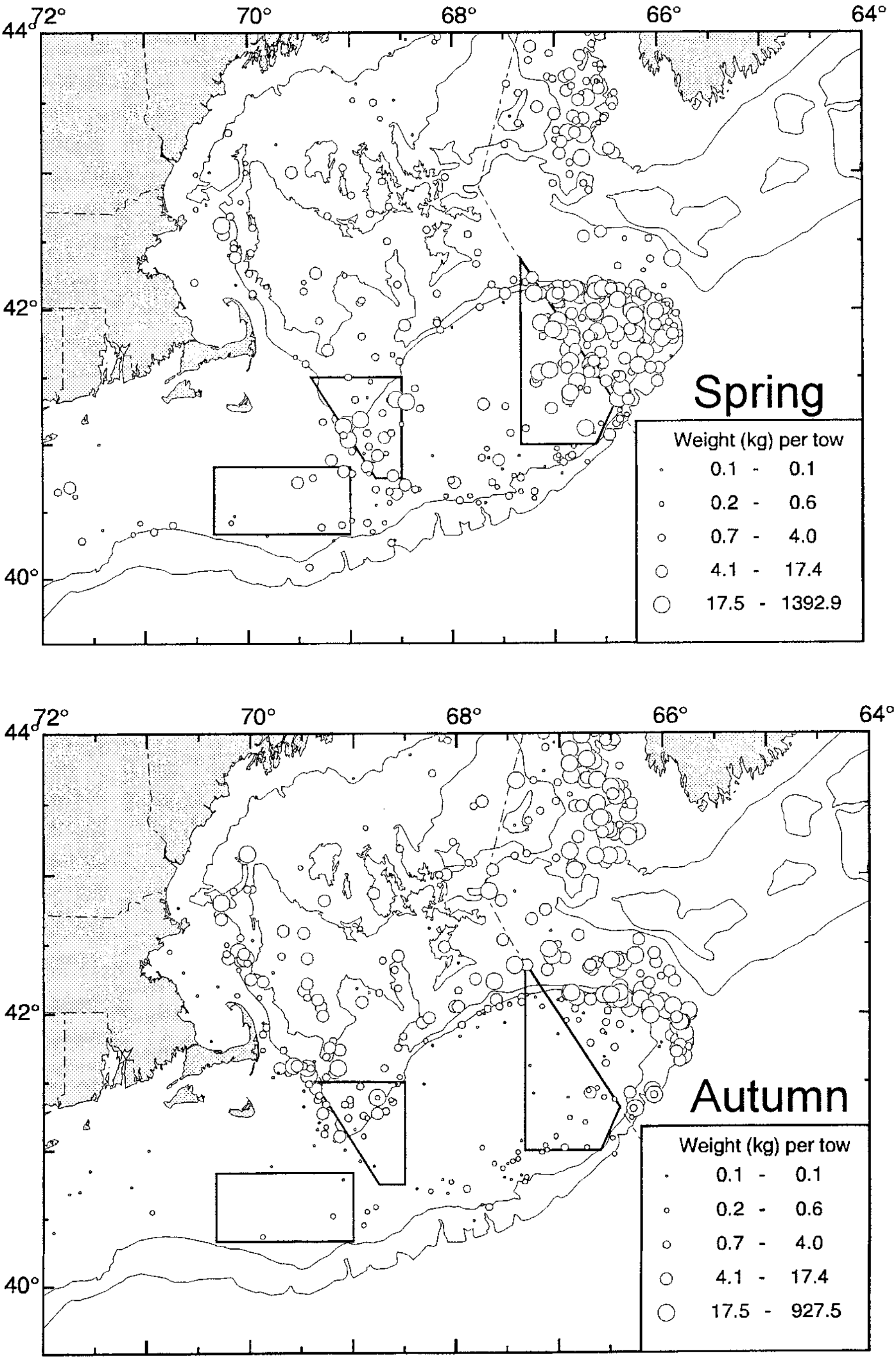

Figure 6. Distributions of haddock in National Marine Fisheries Service spring and autumn bottom trawl surveys, 1989–1998. Data are weights (kg) per standardized half-hour trawl haul.

eastern components of these two stocks have differentially declined, as cod and haddock cpue in areas adjacent to Closed Area II are relatively low, and fishing effort on eastern areas of the U.S. portion of Georges Bank has been reduced. Closure of the Canadian groundfish fishery from January through June effectively eliminates harvesting of pre- and postspawning aggregations during the first half of the year. In warmer months, eastern components of both resources are distributed mostly in Canadian waters, but complementary management regulations there have resulted in relatively low and declining harvest rates on these components throughout the year (NEFSC, 1999). Juvenile (age-0) haddock and cod in Area II are not subjected to harvest-related disturbance, but the significance of this protection to overall survival of prefishery recruits cannot be evaluated.

Closed Area I provides significant, year-round protection from fishing for the western spawning components of cod and especially haddock (Figs. 5,6; Brown et al., 1998). Before 1995, seasonal, intensive fishing of the western spawning components of haddock resulted in progressive declines in contribution to the overall resource (Brown et al., 1998; NEFSC, 1999). Retention of significant numbers of adult and juvenile haddock and cod within Area I throughout the year has resulted in maintenance of seasonal aggregations and has contributed to increased abundance of this component (Brown et al., 1998). Haddock are unlikely to recover to the biomass necessary to sustain maximum sustainable yield (MSY; B_{msy} = 105,000 mt) for the Bank-wide resource without recovery of the western spawning component protected by Closed Area I (Brown et al., 1998). The closure of Area I has thus been a significant factor in increasing the relative and absolute abundance of the western spawning component of haddock.

The Georges Bank (east of 69° W longitude) yellowtail flounder stock has increased in abundance since 1994 because of improved recruitment (and recruitment survival) in the mid-1990s, combined with very sharp reductions in exploitation rate (Figs. 3,4). Spawning-stock biomass is now near the time-series maximum (Fig. 3) but still below that necessary to support MSY (B_{msy} = 49,000 mt; MSY = 14,500 mt). Closed areas have clearly played an important role in reducing fishing mortality on the stock, as have the increase in regulated minimum mesh size, reductions in days at sea, and restrictive total allowable catches imposed by Canada. Because of the sedentary nature of yellowtail flounder, the closed areas (particularly Area II), where a relatively large fraction of the resource resides, have contributed to effective, year-round protection of a substantial portion of the resource (Fig. 7).

The southern New England yellowtail flounder stock has responded minimally to reduced fishing mortality since 1994, because of its extremely depleted spawning-stock biomass and relatively poor recruitment since 1987 (Fig. 3,4). Recruitment survival of the stock was relatively good in 1993 and 1994, but the resultant year classes have been insufficient to generate more than modest improvements in spawning-stock biomass. The exploitation rate declined from >80% in 1990 to <10% in 1994 and 1995. Low stock size, combined with protections afforded by the closed areas and mesh-size increase, have effectively eliminated much of the historic directed fishery for yellowtail in southern New England.

Atlantic Sea Scallop.—The fishery for Atlantic sea scallop is historically among the most valuable in New England, in recent years second only to that for American lobster. The sea-scallop fishery is pursued with heavy steel dredges, which account for virtually all the landings on Georges Bank and >80% of landings in the northeastern United States (the remainder are taken with otter trawls and by divers). Landings in both the Georges

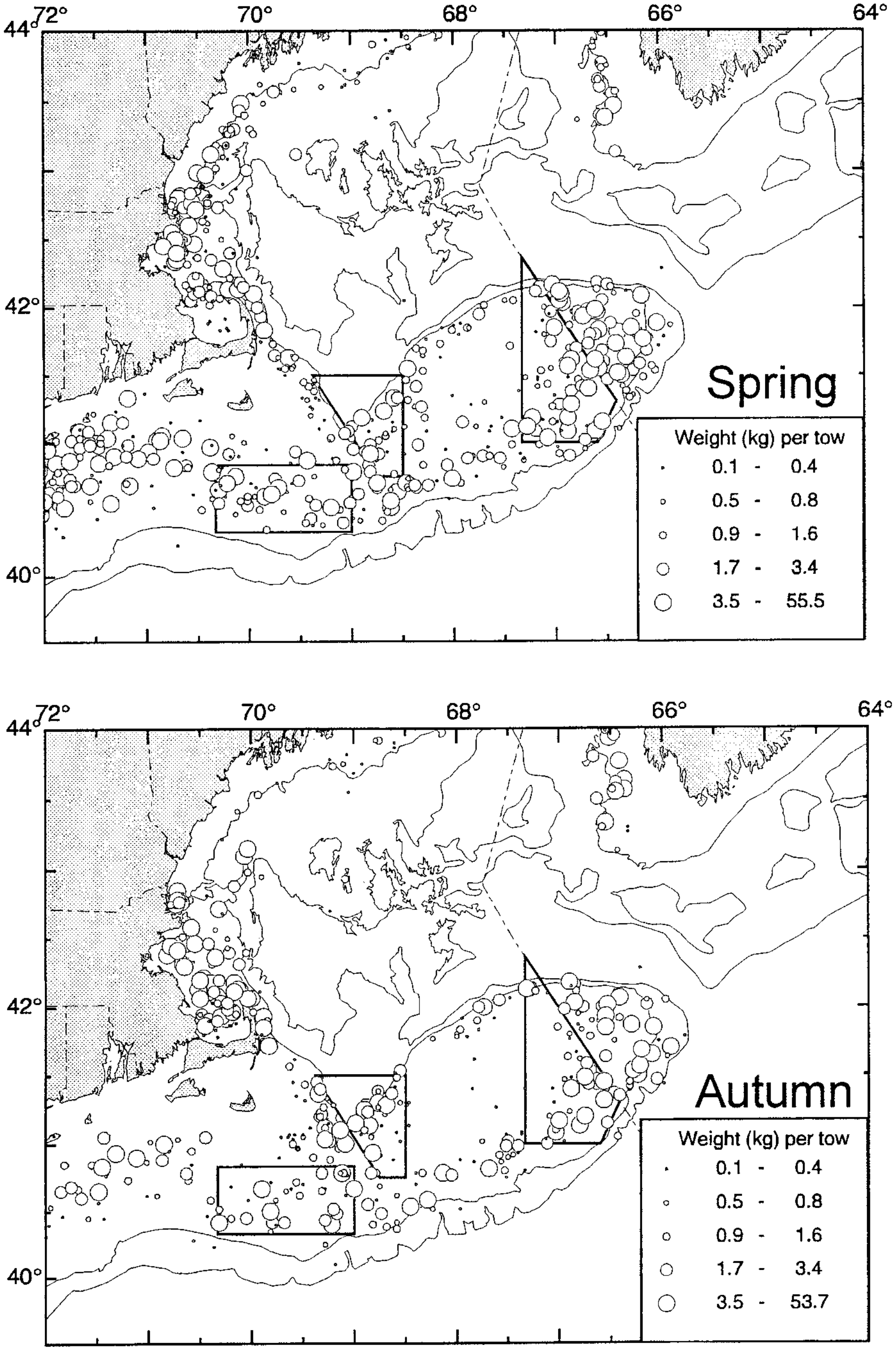

Figure 7. Distributions of yellowtail flounder in National Marine Fisheries Service spring and autumn bottom trawl surveys, 1989–1998. Data are weights (kg) per standardized half-hour trawl haul.

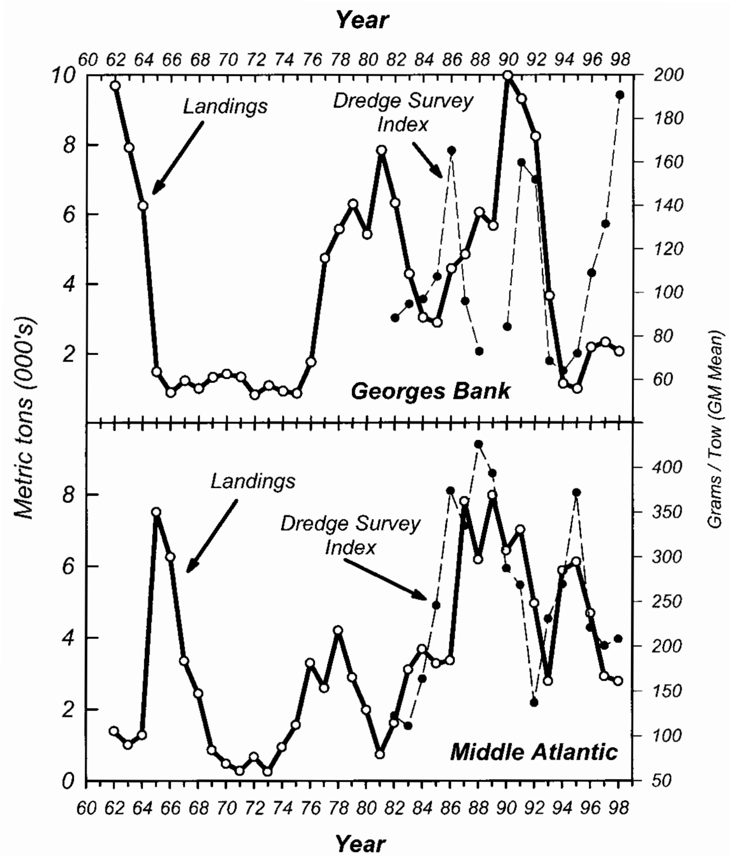

Figure 8. United States landings (metric tons, meats) and survey abundance indices for Atlantic sea scallop, *Placopecten magellanicus*, on Georges Bank and in the Middle Atlantic Bight, 1960–1998. Abundance indices are stratified mean meat weight (kg) per survey tow, standardized for dredge selectivity.

Bank and Middle-Atlantic areas have cycled in a typical 'boom and bust' pattern, dominated by infrequent large year classes (Fig. 8). The vessels have historically switched between the Georges Bank and Middle Atlantic Bight in response to the relative abundance of the resource (Fig. 8). Scallops have been heavily growth-overfished, and much higher yield per recruit could be obtained from the resource with lower fishing mortality rates and delayed size at entry into the fishery, given relatively rapid rates of growth and low instantaneous natural mortality (M = 0.1; NEFSC, 1997). Standardized dredge surveys conducted by the National Marine Fisheries Service generally track landings closely, indicating the high overall exploitation rate and level of dependence on incoming recruitment (Fig. 8).

Closed Areas I and II and the eastern portion of the Nantucket Lightship area are important historic areas for sea scallop fishing (NEFSC, 1997). Georges Bank sea scallop landings in 1994 were near the time-series minimum, reflecting low stock size and poor recruitment in the preceding few years (Fig. 8,9). Most U.S. sea scallop landings in 1994 were generated from the Middle-Atlantic component of the resource, so there was little opposition from the

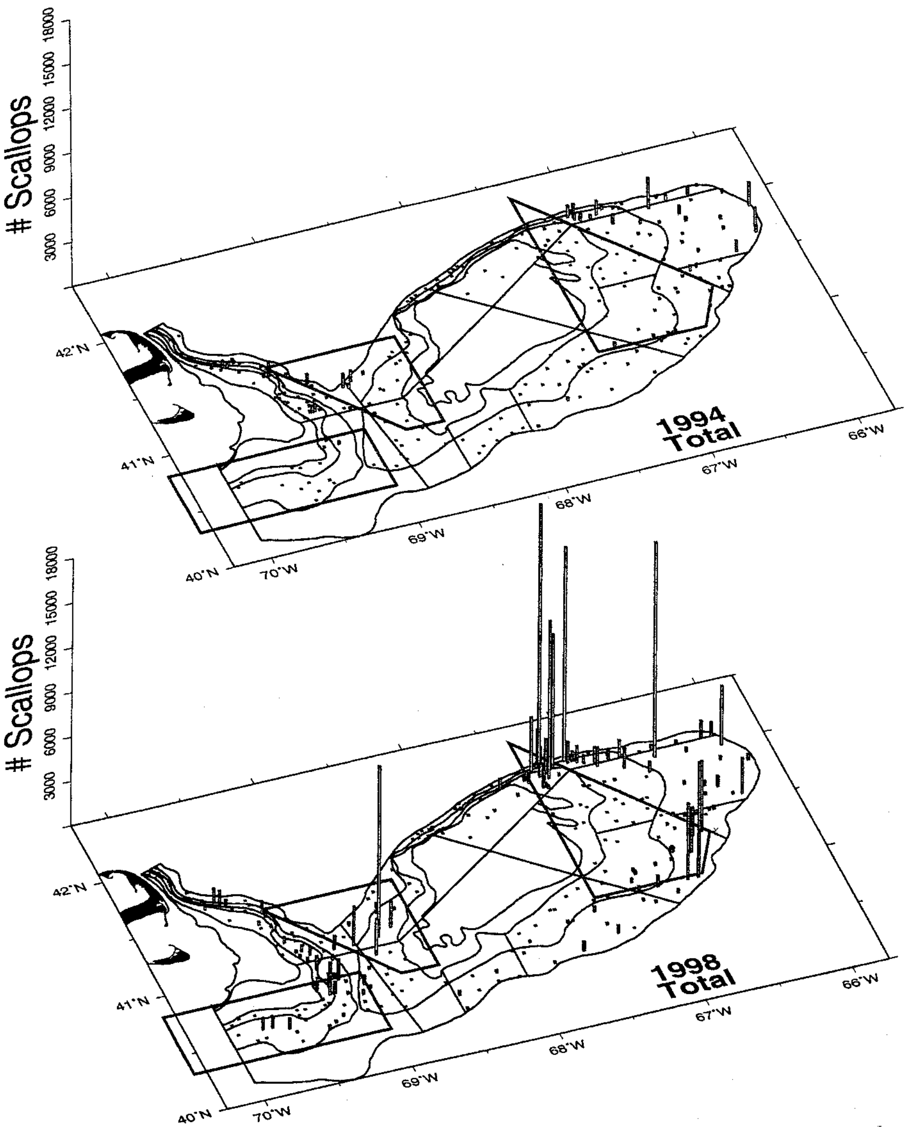

Figure 9. Geographic distribution and abundance of Atlantic sea scallop in the Georges Bank region, 1994 and 1998. Data are numbers of scallops taken in standardized dredge survey tows. Three Georges Bank and Southern New England closed areas (Fig. 1) are plotted, as are the boundaries of standard survey strata.

sea scallop fleet to the year-round closure of the Georges Bank and Nantucket Lightship areas in late 1994. Stock biomass increased rapidly on Georges Bank (Figs. 8,9; Table 3), to the time-series record for harvestable-sized animals (≥82 mm shell height) in 1998. Between 1994 and 1998 scallop surveys, total biomass in closed areas increased by a factor of 14, while harvestable biomass increased by a factor of 15 (Table 3).

Abundance of scallops in the U.S. portion of Georges Bank was low in 1994 and comprised mostly animals ≤82 mm (Fig. 10). Abundance in 1994 was moderately higher in

Table 3. Relative abundance and biomass of sea scallop within and outside closed areas on Georges Bank and Southern New England, 1994 and 1998. Data are from annual standardized dredge surveys conducted by the Northeast Fisheries Science Center. Results are stratified mean numbers and weights (kg, meats) per tow; data are poststratified to reflect the portions of survey strata located inside and outside the closed areas (Fig. 9). Data are given for all sizes (shell height, mm) and for harvested sizes (≥ 82 mm, shell height).

	Inside closed areas		Outside closed areas		Percent difference between inside and outside	
	All Sizes	≥ 82 mm	All Sizes	≥ 82 mm	All Sizes	≥ 82 mm
Abundance (#s)						
1994	59.35	30.21	35.41	16.44	+67.6	+83.8
1998	587.64	290.26	196.03	35.13	+199.8	+726.2
% Change	+890.1	+860.8	+453.6	+113.7		
Biomass (kg)						
1994	0.564	0.463	0.372	0.326	+51.6	+42.0
1998	7.950	7.138	0.878	0.513	+805.5	+1,291.4
% Change	+1,309.6	+1,441.7	+136.0	+57.4		

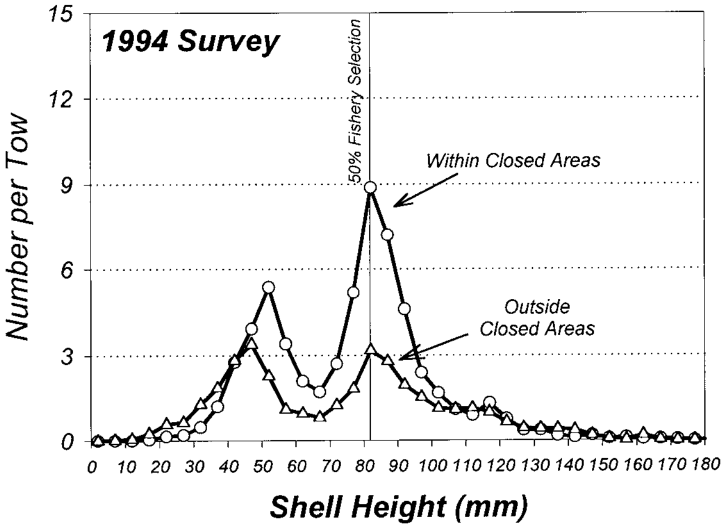

Figure 10. Standardized abundance of sea scallops (numbers per dredge tow), by shell height, taken in the July 1994 NMFS dredge survey on Georges Bank. Data are presented separately for open and closed areas. Length at 50% selection by the dredge fishery is plotted (82 mm shell height).

areas that were subsequently closed than in areas that remained open (Figs. 9,10). The relative abundance and biomass of scallops in open areas increased somewhat from 1994 to 1998 (although by a much smaller factor than in the closed areas; Table 3). Since 1994 several year classes have contributed to the stock rebuilding (Fig. 11), although none of the year classes that made up the resource in 1998 were substantially greater (and most less) than the median recruitment of the 1979–1998 time series. The scallop resource in 1998 was most dense in and around the HAPC (Figs. 2,9) and along the southern boundary of Closed Area II. Scallop recruitment in 1998 was abundant just south of the southern boundary of Area II and in the central portions of Area I and the Nantucket Lightship regions (Fig. 9). The difference in density of harvestable sizes between open and closed areas in 1998 is instructive because it indicates the potential for biomass production under conditions of moderate to below-average recruitment but low mortality on otherwise-fishable sizes. Events have demonstrated that closed areas have been far more effective than the tools used elsewhere and at other times to improve yield per recruit (i.e., maximum meat count regulations, minimum dredge-ring sizes, limited crew sizes). They also demonstrate the potential for damping year-to-year variation in annual yields by lowering exploitation rates and carrying over more harvestable-sized biomass from one year to the next (as opposed to the ‘recruitment fishery’ that now exists). Managers have extended the concept of using fishery closures as a tool to discourage fishing of small scallops by instituting two additional closed areas in the Middle Atlantic Bight, where recruitment has been identified or historic patterns indicate it is likely to occur.

One important element in the build-up of harvestable-sized scallop biomass in the closed areas is the level of enforcement. Because these areas are located offshore (in the case of Area II, over 150 km from land), enforcement has been primarily through traditional means such as Coast Guard cutters and aircraft. In addition, effective May 1998, all scallop vessels have been required to carry vessel monitoring systems consisting of a satellite-based receiver and transmitter. The location of each vessel is determined hourly. The

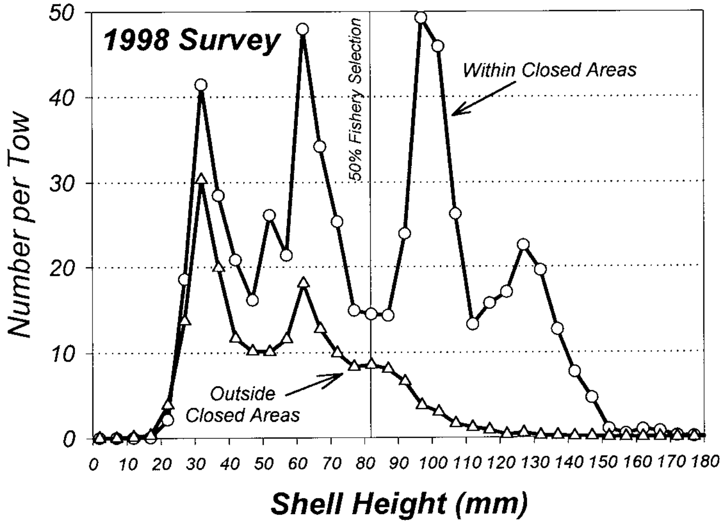

Figure 11. Standardized abundance of sea scallops (numbers per dredge tow), by shell height, taken in the July 1998 NMFS dredge survey on Georges Bank. Data are presented separately for open and closed areas. Length at 50% selection by the dredge fishery is plotted (82 mm shell height).

system was instituted to keep track of days at sea, but its mandatory use has been a substantial deterrent to egregious closed-area violations.

Discussion

The use of closed areas to meet various fishery management goals for temperate marine systems has had mixed results in the few situations where data are sufficient to permit evaluation (Halliday, 1988; Horwood, 2000; Piet and Rjinsdorp, 1998). Seasonal closed areas designed to protect spawning aggregations in the northeastern U.S. have had very limited effect, because of the level of effort outside closed areas and increased effort on postspawning aggregations after the closures ended (Halliday, 1988; Brown et al., 1998). Year-round closures of the North Sea 'plaice box' have been somewhat successful in limiting exploitation of juveniles and reducing by-catch mortality, but the overall level of exploitation of the stock remains very high, and fishing by some fleet sectors within the box continues (Horwood, 2000).

Several factors seem crucial to the efficacy of closed areas for reducing fishing mortality rates, protecting juvenile or undersized animals, and enhancing productivity: (1) the degree of fish movement across closed-area boundaries, (2) the spatial distribution and quantity of displaced fishing effort, (3) the relative catchability (cpue) of the target stock(s) outside the closures, and (4) the level of protection afforded to undersized animals taken by the fishery. In the case of severely overfished species that are widely distributed, or which make extensive movements, closed areas may not be effective as a primary management tool, unless extensive proportions of the range of the stock can be closed (Lauck et al., 1998)—much more than the 20% being advocated generally. In these cases, complementary management regulations controlling exploitation outside the closed area may be as important as the closed areas themselves in reducing fishing mortality. For animals with discrete juvenile distributions, closed areas may help to limit fishery selection on juveniles or other sizes whose exploitation contributes to growth overfishing.

The recently implemented closed areas on Georges Bank and in southern New England have been important but are not the only factor reducing exploitation rates (Fig. 3). The year-round closures have been most effective in reducing fishing mortality on the western spawning components of Georges Bank haddock and cod and on the Georges Bank yellowtail flounder stock. In all three cases, large fractions of these resources are located within the closed areas year-round, and diffusive or directed movement to open areas is limited. For eastern Georges Bank cod and haddock spawners, the closed areas provide effective protection while the stock is distributed on the U.S. portion of the Bank during the first half of the year. Complementary fishery regulations in U.S. waters outside the closed areas (including reduced effort, trip limits, and increased mesh size) and restrictive Canadian total allowable catches and other measures have resulted in an effective mix of management measures that have reduced fishing mortality despite significant flux across closed-area boundaries.

Closed areas have been most effective in the conservation of the shallow-water sedentary assemblage of fishes, including yellowtail flounder on Georges Bank and in southern New England. Other members of the assemblage, including several commercial flounders, skates, and miscellaneous other species, have likewise benefitted from reduced exploitation due to the closures. For southern New England yellowtail flounder, the closed areas circumscribe a substantial fraction of the resource, but the reduction in exploitation rate from about 80% in 1990 to <10% in 1997 was already underway before the Nantucket Lightship area was closed. Large fractions of the resource exist outside the closed areas. Reductions in exploitation rate are thus influenced greatly by the collapse of the fishery due to low stock sizes and other fishery-management measures applicable outside of the closures.

The HAPC established in Closed Area II was justified on the basis that gravel-pavement areas on the Bank are important nursery areas for juvenile cod and haddock (Lough et al., 1989; Collie et al., 1997). The northern portion of Area II and much of Area I contain extensive gravel-cobble sediments and recurrent juvenile distributions of these species (Figs. 2,5,6). Has the protection of these areas from trawl and dredge fishing since 1994 improved juvenile survival? One measure of recruit survival is the R/SSB (Fig. 4), an aggregate measure for the entire stock (both inside and outside closed areas). Improved recruitment survival for some groundfish stocks since the adoption of the year-round closed areas (Fig. 4) may be due to the protection of critical nursery habitats and ensuing increases in per capita survival rates therein. Alternatively, increases in R/SSB may be attributable to improved oceanographic conditions or demographic factors such as increased proportions of repeat spawners. Because recovery of these previously dredged bottom communities is expected to take nearly a decade (Collie et al., 1997), the full benefits of improved juvenile survival accruing from closures may not have yet been realized. Finally, although extensive gravel-cobble pavements are located within closed areas, large portions of this habitat east of the U.S.-Canada boundary (Fig. 2) remain open to trawl and dredge fishing, and the relative contributions of these areas to overall cod and haddock recruitment have not been assessed.

The rapid increase in sea-scallop abundance and survival of large animals within the closed areas demonstrates convincingly the extreme growth overfishing of the stock and the appropriateness of existing estimates of population parameters, including rates of growth and natural mortality (NEFSC, 1997; Figs. 10,11). Previous methods of addressing growth overfishing and improving yield per recruit, including maximum average meat counts, minimum dredge-ring diameter, and limits on the size of the crew available to shuck scallops, have not been effective because of the very high exploitation rates and the problem of compliance. The closed areas have proved much more effective in improving cohort yields by restricting exploitation during years of most rapid scallop growth (ages 0–5). Managers have closed additional areas in the Middle Atlantic area for this purpose.

There is considerable interest in allowing fishing on concentrations of large scallops, which have neared maximum cohort biomass, within the Georges Bank and Nantucket Lightship closed areas. A system of 'pulsed' closed areas appears to be a useful enhancement to management of the scallop resource for the purpose of optimizing yields, and the attributes of such an area rotation scheme are currently being implemented. Relatively dense concentrations of scallops within the closed areas prompted fishing groups to request access to them. Managers identified three biological issues relevant to the resumption of scallop fishing in the closed areas: (1) the rate and spatial/temporal variability of groundfish by-catch in scallop dredges; (2) potential for habitat destruction by sea-scallop dredges, in areas deemed essential for finfish and scallop recruitment; and (3) the overfished status of the sea-scallop resource and the need to reduce fishing mortality of the resource as a whole. Because of potential economic value of the sea-scallop biomass in the closed areas, increased research on the abundance and spatial distribution of scallops, by-catch rates and other factors related to groundfish rebuilding, and potential impacts on essential fish habitat was initiated through an industry-government partnership, in the summers of 1998 and 1999. This research (using intensive systematic dredging surveys) collected detailed scallop abundance and by-catch data using commercial scallop vessels fishing in a predefined grid pattern. Intervessel calibration and dredge efficiency experiments were conducted. When combined with the results of routine scallop and groundfish surveys conducted by the National Marine Fisheries Service and experiments and related monitoring of habitat recovery (Collie et al., 1997), the research was instrumental in defining the rates of groundfish by-catch associated with scallop harvesting in the three closed areas and the density and size composition of the scallop resource. On the basis of these data, a limited resumption of scallop harvesting was allowed in Closed Area II, south of 41°30' (Fig. 9). The fishery was constrained by scallop-catch trip limits and an overall limit on yellowtail flounder by-catch. The fishery was further monitored by means of daily reports of scallop catches through the vessel monitoring system, and observers sampled about 25% of the trips, from which by-catch data were updated daily. Dredging was not allowed in the HAPC, because of the lack of definitive information on the importance of the gravel habitats to groundfish recovery or the impacts of scallop dredging in these areas. Additional research comparing benthic habitat attributes within and adjacent to the closed areas was undertaken in 1999 by means of photographic transects, trawling, and dredging.

A long-term strategy to use closed areas to improve fishery yields could also incorporate critical source areas for larval production. Recent studies of scallop larval production in relation to hydrographic circulation on Georges Bank (Tremblay et al., 1994) have emphasized that some areas may be self-seeding, whereas others are net exporters of larvae widely across the Bank and to scallop grounds south and west. Permanent or long-term closures for spawning protection may increase overall recruitment to the stocks, and additional modeling work incorporating historical circulation patterns and distributions of scallop and adults and juveniles is needed to verify the predictive capabilities of these models (Tremblay et al., 1994). Identification of sources and sinks of larval production may be equally important in evaluating the effects of closed areas in relation to multiple spawning components of cod, haddock, and other species.

The closure of 17,000 km^2 in the Georges Bank and southern New England areas has not come without important costs in foregone fishing opportunities for the fleets. The closures have caused allocation changes among gear types and fleet sectors, because the most immediate impacts fell differentially on large trawlers and other mobile gear fleets that had been geared to fishing these offshore areas. Redeployment of these fleets to other areas and to other target species resulted in higher fishing mortality on some species than would otherwise have occurred. Likewise, displaced effort, particularly by large trawlers, came into more direct competition with more localized fisheries elsewhere. The direct impacts of this displaced effort cannot readily be evaluated because overall groundfish fishing effort, particularly in the large-vessel otter-trawl fleet, was also reduced by 50% about the time the areas were closed year-round. Closure of the Georges Bank areas in 1994 had little short-term effect on the sea scallop fishery but has prevented the more mobile vessels in the fleet from exploiting historical grounds on Georges Bank (with the exception of the limited reopening of a portion of Area II in 1999).

The year-round area closures discussed here are unique in several ways. They are among the largest attempted anywhere in temperate marine systems. The areas selected for closure, although originally designed to conserve particular stocks (haddock, yellowtail flounder), have had serendipitous beneficial impacts on a wide range of other species. Evaluation of their effectiveness in meeting conservation goals is complicated by the differing life histories of the important species and the degree of protection offered to each. None of the important fishery-resource species occurring in the closed areas complete their life cycle wholly within the closures, so effectiveness of the closures depends on fishery management in adjacent open areas. In general, year-round large closed areas have been easier to enforce than seasonal, small areas. Compliance has been relatively good because of high levels of dedicated ship and aircraft patrol, significant and increasing penalties for violators, and the introduction of innovative satellite-based vessel monitoring, which has acted as a deterrent to incursions.

Year-round closures have had important beneficial impacts on the stocks, but their absolute costs and their costs relative to those of other management measures have not been evaluated. Displacement of fishing effort to other areas or species may have increased fishing mortality elsewhere and might reduce the potential effectiveness of measures designed to rebuild other stocks. The extent to which these externalities have occurred reinforces the general premise that closed areas alone cannot compensate for grossly excess fleet capacity. What has been demonstrated is that, with significantly reduced effective fishing effort, stock status in the Georges Bank area improved substantially, despite only modest recruitment. For some stocks, improved recruitment survival combined with higher spawning-stock biomasses, is beginning to generate recruitment levels necessary to sustain fishing near maximum sustainable yields. Large year-round closed areas have been a major contributing factor to the improved conservation and partial rehabilitation of depleted groundfish stocks in the Georges Bank region. Future use of closed areas will undoubtedly be based, at least in part, on improving overall levels of recruitment by protecting areas of maximum larval export and critical juvenile nursery habitats.

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