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Management of the Nova Scotia Sea Urchin Fishery:

a Nearly Successful Habitat Based Management Regime

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Abstract

In the Nova Scotia green sea urchin fishery licensees fish either competitively, usually limited to the waters adjacent to one county, or fish restricted zones with only one license per area. There are no seasons and only a small area is regulated by quota.

Restricted zones are an important part of a habitat-based management regime. In exchange for the privilege of exclusive access to fishing grounds, fishers are obligated to fully use and enhance the habitat carrying capacity. Enhancement is accomplished by manipulating the urchin stock and its food. Advantages of the restricted zones over competitive fishing are: reduced costs of enforcement and assessment, lower cost of fishing, higher value of catch, reduced barriers to sharing information, and freedom to implement a harvest plan without interference from other fishers. Disadvantages are high start-up costs, unwillingness of some fishers to release area they are not fishing, and strong opposition from outside the fishery.

Stock assessments provide the number of licenses that can be supported rather than the more usual weight that can be harvested. Surveys measure the length of urchin feeding fronts at the deep edge of algal beds. Most harvesting occurs in these fronts and each licensee is able (or willing) to harvest only a finite length of front in a season. Resource audits to determined whether fishermen were managing their zones well measured the depths of the urchin feeding fronts. There is an optimum range between deep enough to leave adequate algal production and shallow enough to be accessible to divers. Catch per unit effort was not an index of stock abundance.

Diving is not perceived as a threat to the sustainability of the stock because urchins occur deeper than the harvest depth, sexual maturity is well below the minimum harvest size, and many legal sized urchins that spawn have mature gonads below market quality.

Disease caused by amoeboid pathogen is the biggest threat to the stock and to the fishery. From 1995 through 2000 disease killed 10-100 times the weight of urchins taken by the fishery. We have no method of preventing the spread of disease.

The fishery began in 1989 and has had annual landings up to 1300 t taken by as many as 36 active licenses.

Résumé

Dans la pêche de l'oursin vert de la Nouvelle-Écosse, les titulaires de permis pêchent soit de façon concurrentielle, habituellement dans les eaux adjacentes à un comté, soit dans des zones restreintes à un seul permis.

Il n'y a aucune saison de pêche, et des quotas ne s'appliquent que dans un petit secteur. Les zones à accès restreint constituent une partie importante d'un régime de gestion axé sur l'habitat. En échange du privilège que constitue l'accès exclusif à un lieu de pêche, les pêcheurs ont l'obligation d'utiliser pleinement et d'accroître la capacité de charge de l'habitat. L'accroissement de cette capacité se fait en modifiant le stock d'oursins et leur nourriture. Les avantages de ces zones à accès restreint par rapport à la pêche concurrentielle sont les suivants : coûts d'application des règlements et d'évaluation réduits, coûts de pêche moindres, valeur accrue de la prise, moins d'obstacles au partage d'information et liberté de mettre en œuvre un plan de pêche sans ingérence des autres pêcheurs. Les désavantages sont des coûts de démarrage élevés, la réticence de certains pêcheurs à céder un secteur où ils ne pêchent pas et une forte opposition de gens qui ne participent pas à cette pêche.

Les évaluations des stocks permettent de calculer le nombre de permis que le milieu peut soutenir plutôt que le poids total pouvant être capturé, la façon habituelle de procéder. Les relevés mesurent la longueur des fronts d'alimentation des oursins qui sont situées à la marge profonde d'herbiers d'algues. La pêche de l'oursin se pratique surtout le long de ces fronts; chaque titulaire de permis ne peut (ou n'est disposé à) pêcher qu'une longueur de front limitée pendant une saison. Dans le cadre de vérifications de la ressource visant à déterminer si les pêcheurs gèrent bien leur zone, on a mesuré la profondeur des fronts d'alimentation des oursins. Il existe une gamme optimale de profondeurs qui sont assez grandes pour laisser une production d'algues suffisante tout en étant assez faibles pour permettre aux plongeurs d'atteindre le fond. Les prises par unité d'effort ne constituent pas un indice de l'abondance du stock.

La pêche en plongée n'est pas considérée comme une menace pour la durabilité du stock parce que des oursins vivent à des profondeurs plus grandes que celles où on les récolte, qu'ils atteignent leur maturité sexuelle à une taille bien inférieure à la limite de taille minimale et que bon nombre d'oursins reproducteurs de taille légale ont des gonades matures qui ne sont pas de qualité marchande.

Une maladie causée par un organisme amiboïde constitue la plus grande menace qui pèse sur le stock et la pêche. De 1995 à 2000, la maladie aurait tué un poids d'oursins de 10 à 100 fois plus élevé que celui récolté par la pêche. Nous ne disposons d'aucun moyen d'empêcher la maladie de se propager.

Cette pêche a débuté en 1989; les débarquements annuels ont atteint 1300 tonnes, prises par jusqu'à 36 titulaires de permis.

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Introduction

The green sea urchin (*Strongylocentrotus droebachiensis*)is circumpolar in distribution (Mortensen 1943) supporting fisheries in Norway, eastern Russia, Korea, Alaska, British Columbia, and eastern North America (Newfoundland, Nova Scotia, New Brunswick, Quebec, Maine, New Hampshire, and Massachusetts) (Keesing and Hall 1998; Huston 1999). Although found to a depth of hundreds of meters, it is usually fished in less than 20 m. Its food is primarily macroalgae, but includes calcarious algae, benthic microalgae, detritus, and sessile animals such as mussels and barnacles (Himmleman and Steele 1971). Common predators are cancer crabs, starfish, sea birds, and several species of finfish (Himmleman and Steele 1971; Keats et al. 1987; Vadas and Steneck 1995).

It has separate sexes, maturing well below commercial size at about 7 g or 23 mm test diameter (Miller and Mann 1973; Fletcher et al. 1974; Wahle and Peckham 1999). In eastern Canada it spawns in March or April and gradually rebuilds the gonads in summer and fall (Miller and Mann 1973; Himmelman 1978; A. A. MacKay, unpublished rep. to New Brunswick Dept. Fisheries, Fredericton; Meidel and Scheibling 1998). A planktonic larval stage of several weeks (Strathmann 1978) gives ample opportunity for dispersion.

Although referred to as a roe fishery, both male and female gonads are marketed. Gonads are extracted in Nova Scotia, or the live urchins are shipped to Maine or Japan for extraction. The fishery operates from September when the roe first becomes large enough to market, to April, when the urchins spawn.

In most fisheries the unit of measurement for management is a ton of fish. The stock size is measured in tons, yield predictions are in tons, the total allowable catch is calculated in tons, and tons are allocated among fishing enterprises. Under that regime a great deal of money is spent by biologists monitoring and predicting recruitment to the fishery, by fishery managers and fishers allocating the potential yield among participants, and by police enforcing rules intended to maintain sustainable recruitment. Even with this expense, many fish stocks have been unstable or collapsed (Ludwig et al. 1993; Rosenberg et al. 1993). This system does not eliminate the tragedy of the commons. Individual fishers benefit from abusing the stock (e.g. by exceeding their quota or taking undersized fish), but the costs of the abuse is distributed among all users of the stock. Also, rarely is any individual fisher or fishery manger held accountable for management failure.

In the Nova Scotia sea urchin fishery the unit of management is a fishing license. Initially, an assessment is made of how many licenses a section of coast might support. Exclusive areas were given to many of the licensees. This allowed licensees to individually benefit from good resource husbandry and eliminated the need for most enforcement. However, it remained a public resource and users were obligated to use it well.

We call the above approach habitat-based management. Its position in a spectrum of fisheries management, classified by the level of control of the fish's life history, is as follows.

- Modern stock-based management intends to prevent growth overfishing, recruit overfishing, wasteful fishing such as discarding, overcapitalization, and destruction of fish habitat. Management controls the size and quantity of fish removed from the natural stock, the design of the fishing gear, and the amount of fishing effort.
- Releasing hatchery-reared early life history stages into the wild can enhance the natural stock by using more fully the carrying capacity of the habitat. This compensates for loss of natural reproductive capacity or destruction of juvenile habitat (Travis et al. 1998).
- Habitat-based management includes all the objectives of stock-based management, plus fuller use of habitat carrying capacity, plus increasing the habitat carrying capacity. The latter is achieved by manipulating the urchin stock and its food.
- Aquaculture is the final level of control. This ranges from muscle culture using wild spat reared in the ocean on artificial substrate, to talapia culture with food and habitat controlled in every life history stage.

Sea urchins are good candidates for habitat based management. As a dive fishery, the results of fishing and enhancement are visible to the fisher, unlike most fisheries where perceptions of the state of the stock are clouded by selectivity of the fishing gear. The food chain is simple, macroalgae to sea urchins, and both have low mobility (Garnick 1978; Scheibling et al. 1999; Duggan and Miller 2001).

The carrying capacity of the sea urchin habitat can be enhanced by manipulating the density of macroalgae and sea urchins. Examples of macroalgal recovery following experimental removal of several species of sea urchins were reviewed by Lawrence (1975). Keats (1991) reviewed the results of experimental removal of the green sea urchin in Newfoundland, Nova Scotia, Quebec, and New Hampshire. Leinaas and Christe (1996) observed rapid increase in kelp biomass following removal of the green urchin in Norway. Macrophytes (kelps, Irish moss, filamentous algae) increased greatly following sea urchin mass mortalities in Nova Scotia where it was estimated that kelp biomass alone increased 1.8 million tons (Miller 1985). There are few records of successful transfer of wild green sea urchins. However, when Johnson and Mann (1993) transferred them to a large enclosure on the sea bed they grazed all macrophytes in 3 months. Alan Baker (pers. comm.), a Nova Scotia sea urchin fisher, found he could successfully transfer the green sea urchin from areas of high to low density. Baker also increased gonad yields of wild green urchins by feeding them bundled kelp. Glantz (1992) increased the gonad yield of the purple urchin free on the sea bed by feeding them chopped kelp. Tegner (1989) provided a detailed review of enhancement techniques developed in Japan, including stocking urchins in areas with kelp culture. Hagen (1996) describes Japanese methods of nursery rearing of urchins for release on the sea bed.

In Nova Scotia the green sea urchin (Strongylocentrotus droebachiensis) and its principal food, Laminaria sp., are abundant (Wharton and Mann 1981; Miller 1985; Scheibling 1986), but not optimally distributed, providing ample opportunity for enhancement. Much of the sea urchin stock is of no commercial value because sea urchins are poorly fed and the gonads poorly developed (pers. comm., sea urchin fishers and buyers). Thus, a commercial sized sea urchin can be worthless or valuable depending on its nutritional state. Near the time of spring spawning Fletcher et al. (1974) found gonad indices six times higher at 6 m, near the lower edge of a kelp bed, than at 21 m. Keats et al (1984) reported peak gonad indices three-times greater in the kelp bed at 0-2 m depth than on barrens at 12-18 m. Wahle and Peckham (1999) found gonad indices at 5 m twice as large as at 15 m and Meidel and Scheibling (1998) found gonad indices twice as high in kelp beds as in adjacent barrens. In laboratory trials many authors have demonstrated differences in gonad size in response to food quantity and quality (e.g. Vadas 1977; Himmelman 1984; Lemire and Himmelman 1996; Hooper et al. 1997).

In the early 1980s, 270,000 t of sea urchins died along the outer coast of Nova Scotia (Moore et al. 1986). The cause was a waterborne pathogen (Miller and Colodey 1983; Scheibling and Stephenson 1984; Miller 1985) later identified as an amoeba (Jones 1985). Older lobster fishers interviewed in the 1980s recalled previous sea urchin mass mortalities west of Halifax in the 1930s and possibly the 1950s, but not east of Halifax (Miller 1985). Fishers in Cape Breton recalled no disappearance of sea urchins before 1982 (based on interviews in eight ports in 1986). After release from sea urchin grazing, macrophytes rapidly recolonized the rocky habitat (Miller 1985; Scheibling 1986; Johnson and Mann 1993). Because most of the suitable habitat was previously barren of macrophytes (Wharton and Mann 1981; Miller 1985), the disease probably benefited the sea urchin fishery that began a few years later. However, its return in the mid-1990s has nearly eliminated a prosperous fishery.

The history of landings from several North American sea urchin fisheries indicate stocks can be depleted. Landings in the red sea urchin fisheries in northern California, Oregon, and Washington fell >75% within 5 years (Kelvass and Hendrix 1997). Landings of green urchins declined 85% from 1992-95 in British Columbia (Perry and Waddell 1999) and 55% in 4 years in Maine (T. Creaser, Maine Dept. Marine Resources, West Boothbay Harbor, Maine, pers. comm). The red urchin fishery in British Columbia (Harbo 1998) and the fishery for green urchins in New Brunswick (Robinson 1994) have been more sustained.

Here we describe the recurrence of disease, development and implementation of a management regime, with emphasis on individual fishing zones, results of fishery-dependent and fishery-independent monitoring, and recommendations for further management actions.

Methods

Fishery Independent Surveys

Fishery independent surveys of most commercial fish stocks support stock based management regimes, i.e. where a ton of fish is the unit of management. Samples are taken to estimate the density of harvestable sized animals and these densities are expanded to the area of distribution to obtain total stock size.

We did not use biomass surveys because the harvestable portion is difficult to measure and the cost was prohibitive. Harvestable biomass depends on urchin size, gonad quality, water depth shallow enough for divers, and an urchin density that can be profitably harvested by divers. There is no external indicator of gonad quality; urchins of identical size and appearance may be worth $6 per kg or worthless to the fisher. Even if gonad quality was sampled during a survey (at considerable expense), most urchins have small gonads in the summer, the season most favorable for surveying. Furthermore, urchins form a slow moving belt from deep water to the feeding front. Log records report repeat harvesting of the same area over successive years. Therefore, how wide an area from the front should be included in estimating the future harvest is unknown. Measuring biomass would be expensive because it is carried out by divers hand collecting urchins from quadrats. Guysborough County alone has over 500 km of feeding front. A sparse sampling rate representing 4 km of front per day would be three summer's work for a dive crew.

We also did not obtain size frequencies. The cost of collection was high, most commercial sized urchins are within a narrow range of 15 mm (Wharton and Mann 1981; Moore et al. 1986) and size is not a useful indicator of age (Robinson and MacIntyre 1997).

Surveying was carried out when the potential for new licenses was being assessed, when sizes of restricted zones were being negotiated, to audit the degree of utilization of the restricted zones, to measure length of feeding fronts used to calculate harvest per meter, and to observe the extent of urchin mortalities from disease. The amount of habitat that could be surveyed per day is given in Table 1. The length of shore listed is the rocky-bottom subtidal including the circumference of islands and shallow shoals

Table 1. Types of urchin resource surveys and survey rate per day.

Purpose	Methods	Survey rate/day
Potential for new licenses	100-500 m of front viewed at intervals of ~5 km, presence of macroalgae and legal sized urchins noted	~12 intervals along 40-70 km of shoreline and shoals
Old method for negotiating size of restricted zone	Same as above with more and longer front checks, better records on location of harvestable urchins	~20 intervals ~40 km of shoreline and shoals
New method for negotiating size or restricted zone	Measure length of all feeding fronts less than 40 ft. depth; note depth, location, presence of macroalgae and legal sized urchins	10-20 km of front
Audit of utilization of restricted zones	Measure length of all fronts <20 ft. depth, record exact locations	10-20 km of front
Exact length of front to calculate mean wt. yield/m of harvested front	Diver measures front with metered string laid out by swimming	2 km of front
Occurrence of urchin mortalities from disease	"Spot" dives of about 10 min. near the deep edge of macrophyte beds	10 locations along 40 km of coast
Potential for new licenses	100-500 m of front viewed at intervals of ~5 km, presence of macroalgae and legal sized urchins noted	~12 intervals along 40-70 km of shoreline and shoals

With some qualifications, surveys were one-dimensional, the length of sea urchin feeding fronts. The qualifications were whether urchins were large enough to harvest and whether urchins were present below the front to repopulate it once it was harvested?

Surveys were conducted from an outboard-powered skiff with several advantages. The skiff could be trailered to the survey locations, it could be operated by the science staff rather than a professional crew, and the skiff could travel as fast as 30 knots between locations to be surveyed. It was maneuverable enough to operate on wave-exposed rocky shores in as little as 1 m depth. Its low freeboard did not impede visibility and maneuverability made it well suited for diver support.

We used four methods to observe a feeding front. For the first three the front was located from the boat by looking for a line of sharp contrast between the dark macrophytes and light rock bottom. If water clarity permitted, the boat driver simply steered along the front observing from the surface. If the water surface was rough or the sun angle unsuitable, surface glare could be eliminated by looking through a glass-bottomed bucket submerged just below the surface. The third method was towing a diver holding onto a tow-board at the end of a 20 m length of rope. This method was most suitable where fronts were too convoluted for the skiff to follow. The towed diver could steer the tow-board from side to side on the surface or descend as deep as 3 m.

The fourth method required a diver to swim along the front near-bottom and was used only if the front was not visible from the surface or we needed a precise measure of its length. Before the diver entered the water the front was located using a color sounder. A macrophyte bed was usually distinguishable from the macrophyte-free bottom, but this distinction could not always be made if the macrophytes were short-statured *Fucus* rather than the larger kelps. If the macrophytes extended to the depth where rocky bottom turned to soft bottom, an urchin feeding front was not present and this was not always apparent from the sounder image. Because of the time to deploy and retrieve a diver and his slow pace compared to the skiff, this method was employed only as a last resort.

Surveys to estimate the number of new licenses that might be supported were carried out on an ad hoc basis very summer from 1994-2000. Surveys used as a basis for negotiating sizes of restricted zones were mostly carried out in the summers of 1995 and 1996. Under short deadlines using the above methods, the authors made observations at about 900 locations and formed subjective assessments on the amount of area that could be managed and harvested by a license holder. Most effort was spent in the areas of greatest interest to fishers, Guysborough, Halifax, and Shelburne Counties. These surveys were also used for dispute settlement where requested areas overlapped.

Methods were more quantitative for the audits of exclusive fishing zones following a 4-year trial period. We measured the km of feeding front found at depths less than 20 feet below low tide. One end of a front, or the location where it receded to greater than 20 feet deep, was located. That position was taken from a differential GPS. The boat then steamed along the front to the other end or to where it became >20 feet deep, and a position was again taken. The steaming distance between the two points provided the length of the front, and the end points its location. When the fronts were too convoluted for the boatman to follow, a conservative multiplication factor was applied, usually between 1.5 and 3. Before beginning the survey the boat operator and diver conducting the survey calibrated their ability to estimate these factors by comparing the steaming distance to the measured length of the front.

A variation of the above methods can provide a measured length of nearly all harvestable front. This was intended for use in future negotiations of the sizes of exclusive zones. Instead of the length of front to 20 feet deep, the length of all fronts down to 40 feet were included. The presence of macroalgae and whether most urchins were greater than the legal minimum size were also noted.

Mean yields per meter of front for 9 beds in Shelburne and Guysborough Counties were used in calculating the approximate length of front fished by a license. A diver laid a metered string along a front to measure its length. Yields were the kg harvest per year averaged over 2 or 3 years (from 96-97 to 98-99) as reported in science logs for individual beds. All beds had been harvested for at least one year before the record was used, so none were harvests of virgin beds.

The distribution of sea urchin mortalities was surveyed during late October and early November, 1995 by diving at 59 locations in Halifax, Lunenburg, and Queens Counties. Groups of diseased urchins are easily identified because they become detached from the substratum and their spines droop. September-November is the season when mortalities occur (Miller and Calodey 1983; Jones 1985). Commercial sea urchin harvesters provided documented survey results for another 41 sites in Lunenburg and Queens Counties. Each year from 1996-2000 commercial urchin divers provided observations from dozens of sites during September-November.

Fishery Monitoring

Fishery monitoring has been entirely by catch records and personal communication with fishers and buyers. Volunteer logs, including fishing location, diver hours, and percentage gonad yield, were introduced in the 1994-95 season and collected by Science Branch through 1999. These records provided most of the monitoring data used for management advice. In addition, mandatory catch records were supplied from the beginning of the fishery as copies of buyers purchase slips. These included weights and prices. The sales slips were replaced by mandatory catch monitoring (DMP) in the 1997-98 season. Under the DMP system fishers are required to hire a commercial monitoring company to enter on a DFO data base daily catch records submitted by fishermen. For about one-fifth of the trips a company representative met the boat when it landed to verify that the catch was reported correctly.

Although the fishery began in 1989, the mandatory landings records were probably unreliable until the 1995-96 season. Many sales slips were never submitted. Also, neither fishing effort nor percentage gonad yield was recorded. Fishing location was either not entered or was on too large a scale. Because a separate DMP document is filed for each fishing day, more than 1000 pages of records have been generated annually and these are difficult to retrieve. Errors and omissions in entry are common. For example, 1999-2000 landings for Cape Breton were listed as 16 t, whereas about 60 days of records for two licenses totaling 64 t were omitted. Fundamental problems with the system are that fishers are required to buy a service they don't want, private firms enter data into a DFO data base controlled by a group with minimal use for the data, and the primary user of the data, Science Branch, has no authority over its collection, entry, or filing.

Results

Sea Urchin Disease

Although the disease in the 1980s may have enhanced the fishery by allowing regrowth of macroalgae, its return in the 1990s was detrimental to a prosperous fishery. Diseased urchins were seen in small patches from 1990-1994 (sea urchin divers, pers com., 1991 unpublished contract report from P.M. Smith to P. Budreski). Then in 1995 it was wide-spread, completely eliminating the fishable stock along 120 km of shore (Scheibling and Hennigar 1997; Fig. 1). In the Autumn of 1995 four license holders were allowed to relocate to areas not depopulated by disease. This practice was discontinued because it deprived local residents the opportunity to enter the fishery. More ad-hoc surveys and reports from urchin fishers indicated disease eliminated the fishery along a further 80 km of coast in 1996-97, 80 km more in 1999, and 140 km more in 2000, reaching the same extent observed in the early 1980s. Since 1995, the stock supporting 32 licenses has been completely lost, and it has reduced the stock for another 6 licenses. Occurrence of disease since 1981 is shown in Fig. 1.

Although we did not survey sea urchin biomass or density, Sable Offshore Energy Inc. did measure density and biomass for three years at a location in Guysborough County when disease was present. Using divers and video they sampled 160 randomly located quadrats in the same 0.6 km^2 area each year. Numerical abundance decreased about 80% from 1998-2000 (Table 2). Biomass of commercial sized urchins (>50 mm test diameter) decreased more than 95% from 1998-2000.

Table 2. Number of urchins per m^2 at <20 m depth in near Country Harbour, Guysborough County, based on quadrat sampling (Sable Offshore Energy Inc. unpub. rep.).

	Year		
Urchin test diameter	1998	1999	2000
>10 mm	19.7	6.0	2.6
>50 mm	9.9	2.1	1.3

The infrequent, but devastating occurrence of the amoeboid pathogen begs the question of its origin. Four hypothesis are considered.

Ho. 1. Sea urchins become weak and lose their resistance to disease after becoming dense enough to remove most of the macrophyte biomass. In areas where disease was first noted in 1995, Pennant Bay and Mahone Bay, sea urchins occupied no more than 20 % of the area they occupied during the early 1980s and kelp cover was several times greater than in the early 1980s (Moore and Miller 1983; 1995 survey), yet urchin mortality was complete in the autumn of 1995. During this time the disease was rare or nonexistant in Shelburne Co. and eastern Guysborough Co. where urchins dominated the shallow subtidal and kelp was scarce (1995 summer survey). Thus, the weak urchin hypothesis is not a sufficient explanation.

Ho. 2. Unusually high summer-autumn temperatures favor the outbreak of disease. Clearly, the pathogen is active only near the seasonal high temperatures. Significant mortalities occurred only in late summer and autumn (Miller and Colodey 1983; Scheibling and Stephenson 1984; Miller 1985) and reproduced most rapidly in laboratory cultures at 15^o and 20^{o}C, slowly at 10^{o}C, and not at all at 5^{o}C (Jellett and Scheibling 1988). Scheibling and Hennigar (1997) obtained interannual correlation of disease outbreaks with positive deviations of temperature from long term means taken from a monitoring station in Halifax Harbour, but a less convincing relationship with satellite imagery of sea surface temperatures. Miller (1985) also used satellite based sea surface temperatures and found that warm years were uniformly warm over areas with and without disease outbreaks. Therefore, high temperature may be necessary but not sufficient condition for disease outbreaks.

Ho. 3. The pathogen is introduced from offshore every summer. Wave-like expansion of sea urchin mortalities from year-to-year suggests retention of the pathogen in the habitat. Sizeable urchin mortalities were seen in the field every year from 1980-85 (Miller 1985; fishers, pers. comm.); they spread east and west from a focal area west of Halifax. In 1992-94 urchin mortality was again noted in localized areas (Scheibling and Hennigar 1997; urchin fishers pers. comm.), spread aggressively in 1995 (Scheibling and Hennigar 1997; pers. obs.; fishers, pers. comm.), moderately in 1996-98, and again aggressively in 1999 and 2000 (fishers, pers. comm.). The progress east of Halifax has been in a wave. The progress west of Halifax also progressed linearly from 1995 to 96 when areas experienced total morality, but was less tidy before and after those years. It is difficult to conceive of an offshore introduction that would result in the pattern observed.

Ho. 4. The pathogen is introduced from a point source, such as land runoff or ship ballast water. Although this possibility is not contradicted by our observations, the pattern of spread suggests retention in the urchin habitat.

Ho. 5. Observations are consistent with the pathogen being introduced in the early 1980s and possibly again in the early 1990s, retained in the urchin habitat, and spread furthest in years with the most favorable environmental conditions.

Unfortunately, there are no documented cases of disease in a wild marine finfish or shellfish stock having been eliminated or even curtailed (pers. comm. DFO pathologists S. McGladdery and G. Olivier (Moncton, N.B.), J.E. Stewart (Dartmouth, N.S.)).

Possibilities suggested for disease control are as follows. i) Sea urchins could be moved below the seasonal thermocline where temperatures are too low for the disease to become active. This would be practical on only a small scale. Urchins would have to be caged because the depths are beyond the practical working depths of divers. ii) Disease resistant animals might be bred, released, and survive to harvest, however; hatchery costs would be considerable and the remaining natural population from deep water would dilute the hatchery reared gene pool. iii) If the annual outbreak of disease could be predicted, the annual harvest might be accelerated. However, most urchin gonads are not sufficiently developed for harvest before the onset of disease in early Autumn and the disease progresses rapidly. iv) Perhaps the urchin density could be reduced below that where the disease will spread. We do not now know the critical density and most of the stock is too small or undernourished to be of commercial value. Thus, large quantities of urchins that should be the recruits for future harvests would have to be moved or destroyed.

We expect the spread of disease to continue. The only encouragement we can offer is that following the near complete mortality in the early 1980s, urchins returned to most of 400 km of shore by the early 1990s.

Potential for new licenses

From 1995-2000 about 15 weeks in total was spent surveying to estimate the potential for accepting new licenses. However, because of advancing disease the stock as continually shrinking. Based on these surveys, audits of restricted zones, disease surveys (see Table 1), and reports from fishers of disease advance, the number and location of licenses we believe the stock could support in December, 2000 is presented in Fig. 2. We found no feeding fronts in southern Yarmouth County. G.J. Sharp (DFO Science Branch, Dartmouth, Nova Scotia, pers. com.) has conducted diving projects within Lobster Bay and near the Tusket Islands over 20 years and has never seen a feeding front of urchins. In 1997 Shelburne County was under-exploited by the 7 active licenses, but disease has since reduced its potential to one or two licenses. During 1995-99 disease eliminated all the harvest potential in Queens, Lunenburg, and Halifax Counties. Guysborough County was impacted by disease in 1999 and 2000, but sufficient stock remains in the eastern portion for about four licenses. A cursory look in 2000 revealed much of the stock on the south shore of Chedabucto Bay (west of Canso) had been eliminated by disease. Our most recent information for the western shores of Chedabucto Bay is based on a 1996 survey. Then, urchins were confined to scattered patches of hard bottom among sand and gravel. Subtidal macrophytes were mostly Fucus and Ascophyllum, low in urchin feeding preference (Himmelman 1980) and producing small gonads (Larson et al. 1980). This area might support one license.

We have not seen nor heard about disease induced mortalities on the shores of Cape Breton Island. In 1998 off the southern coast urchins were found nearly everywhere on wave-exposed shores. The best balance of urchins and kelp was on offshore shoals near the line separating Richmond and Cape Breton Counties. However, there was scarcely a 10 km length of exposed shore that did not contain harvestable quantities. This area should support at least 6 licenses, but enhancement would be required before some areas became lucrative. Southeast Cape Breton Island, including Scatterie Island and shores 15 km to the north and west, is a diverse area ranging from expansive kelp beds and few urchins to abundant urchins with sparse macrophytes. Two active licenses are adequately supported. The remainder of the eastern end of Cape Breton Island was surveyed in 1996 and 2000. Urchin feeding fronts were rare. The area has little harvest potential and now supports two licenses poorly.

A more quantitative estimate of the area needed to support a license could now be made using the average annual yield in kg/m of feeding front. Nine harvested beds had a measured total length of 12,900 m. Logbook records of annual harvests divided by the length of feeding front in each bed ranged from 2.2-10.7 kg/m and averaged 5.4 kg/m. Annual harvests of active fishers have ranged from 23,000 to 90,000 kg. At these harvest levels, and a potential of 5.4 kg/m, a license would need 4300 to 16,700 m of front. The length of front to a depth of 40 feet depth could be measured as described in the methods.

We have not surveyed Digby County although it now supports six licenses. This fishery demonstrated the importance of leading by example. None of 10 license holders since the early 1990s had significant landings before 1998-99. They complained of poor quality urchins bringing insufficient revenue, strong currents and depths too great for diving, and frequent winter storms. However, two licenses were transferred to new fishers before the 1998-99 fishery and at least one of these fishers found how to fish successfully. In 1998-99 four active fishers landed 245 t, whereas the previous maximum was 20 t.

Fishery Monitoring

Although catches were underestimated early in the fishery, they probably never exceeded 100 tons until the 1994-5 season (Table 2). The big increase in 1994-95 was in response to a near doubling in price in the previous season (J.A. Nelson, Policy Branch, DFO, Dartmouth, N.S., unpub. rep.).

It was possible to maintain acceptable roe yields for several months (Table 3), by selectively fishing beds in September and October with early ripening gonads. Gonads typically start increasing in size in July, reach 40% of maximum size by September, and peak in February-March before spawning (Himmelman 1978; Meidel and Scheibling 1998). After the season restriction was removed for most of the fishery in 1998, landings were approximately evenly distributed over the months of September through March (Table 4). These changes were possible because fishers became familiar with the stock where they fished.

Table 2. Number of active licenses and catch (t) for each of four areas. Disease constrained the western Nova Scotia catch beginning in the autumn of 1995. It appeared in eastern N.S. the same year but didn't have a major impact until the autumn of 1999. Most of Cape Breton remains unfished in spite of 20 licenses in force.

Fishing	Western N.S.		Digby		Eastern N.S.		Cape Breton		Total
Season	Licenses	Catch	Licenses	Catch	Licenses	Catch	Licenses	Catch	Catch
91-2	7	37			2	10	1	7	54
92-3	6	34			2	2	1	1	37
93-4[a]									
94-5	10	466			11	790	3	34	1290
95-6	10	312	2	5	21	658	3	46	1021
96-7	8	317	1	33	22	915	2	60	1325
97-8	7	263			16	700	4	61	1024
98-9	8	351	4	245	18	605	3	98	1299
99-00	7	136	6	362	9	324	3	80	902

[a]data unreliable

Table 3. Percentage roe yield by month for two seasons and three fishing areas.

Month	95-96 Eastern N.S	95-96 Western N.S.	98-99 Cape Breton	98-99 Eastern N.S.	98-99 Western N.S.
Sept.	a	a	a	9.3	8.3
Oct.	8.6	7.7	9.1	9.7	10.9
Nov.	8.1	7.9	8.7	11.3	9.8
Dec.	10.7	8.6	a	10.4	10.5
Jan.	10.7	8.7	8.6	10.6	11.2
Feb.	11.1	8.9	8.4	10.9	10.8
Mar.	9.8	8.7	9.4	10.2	10.3
Apr.	9.0	6.9	12.0	11.4	9.5
May	10.8	7.5	a	a	7.0

[a] No data.

Table 4. Percentage of the annual catch by month for 1995-6 when fishing was prohibited before October 1, and 1998-99 when there was no season restriction.

Month	1995-6 season	1998-9 season
Aug.	0	1.2
Sept.	0	11.5
Oct.	15.6	12.3
Nov.	12.7	12.9
Dec.	13.5	12.8
Jan.	12.9	15.6
Feb.	14.0	15.7
Mar.	22.6	11.6
Apr.	7.3	6.2
May	1.3	0.3

There is no apparent trend in harvest per diver hour over six fishing seasons (Table 5). Considering that throughout this period much of the fleet was learning to fish urchins, virgin stocks were being fished-up, and disease was reducing stock size, the catch rates are surprisingly uniform.

Table 5. Kilograms of urchins harvested per diver hour.

Season	Cape Breton	Eastern N.S.	Western N.S.
1994-5	79	98	68
1995-6	a	83	73
1996-7	80	70	77
1997-8	75	80	81
1998-9	107	81	96
1999-0	a	73	88

[a]insufficient data

Management Plan

After a year of consultations with licensees and other interested parties a new management plan was implemented in 1995 and evolved in detail over the next few years (Table 6).

Table 6. Principal regulations for the Nova Scotia sea urchin fishery in force in 2000.

- Recreational fishing is prohibited.
- Harvesting is by diving only.
- Exploratory licenses holders are chosen by public draw from qualified applicants, either to replace inactive licensees or to expand the fleet.

- Exploratory license holders must have proof of sale of 2 tons the first year and 4 tons in subsequent years to maintain their license.
- A holder of an exploratory license is usually restricted to fishing the water adjacent to one county.
- An exploratory licensee can apply for permanent status after being active for about 3 years.
- A permanent license has no landing requirement and only a permanent license is transferable to another fisher.
- A license holder that has proven to be a successful harvester (harvesting more than about 25 tons in a year) may apply for a restricted zone.
- Only one license holder may fish within a restricted zone, and with minor exceptions he cannot fish outside the zone.
- Although licenses to fish competitively can be permanent, a restricted zone is renewed annually by license condition.
- For catch monitoring, a licensee must submit daily records to a private company who enters records into the management agency's data base. On about 20% of fishing days a company employee meets the fisher at dockside to confirm that the catch is reported correctly.
- No more that four divers may fish from one license in one day.
- There are no fishing seasons unless fishers fishing competitively in one area request one.
- Minimum urchin size is 50 mm test diameter.
- Urchins culled from the catch must be discarded on the fishing ground.
- Sea cucumber is the only species that can be retained as a bycatch.

Restricted Zones

Development and Implementation

In 1995 the new management plan, including exclusive fishing areas, was approved after a year of discussions. The exclusive areas were soon renamed “restricted zones” after it was pointed out that "restricted" might be easier to defend. The conditions for receiving a zone were: only one licensee could fish in a zone and he could not fish outside it, the zone applied to no fishery other than sea urchins, the licensee must enhance the productivity of the stock in the zone, and he could have the zone for a trial period of 4-years if enhancement was carried out. Fishers were asked to request an area no larger than they could manage and to attempt to resolve any competing interests for the area. Methods of enhancement were discussed and individuals were asked to report on their successes and failures.

The legal authority for zones was found in the Canada Fisheries Act. This act provides for many types of management areas used to regulate total catch and fishing locations. Urchin zones were an extension of this provision, limiting a fishing area to one licensee.

The proposal to introduce zones created bedlam for several months, both in and out of the urchin fishery. In Guysborough county, the most lucrative fishing area, a group of eight license holders wrote the provincial and federal ministers' of fisheries, the provincial and federal politicians representing their area, and senior DFO officials stating the county was just big enough for them to divide among themselves. Licensees from adjoining counties attempted to establish eligibility by claiming fishing history in Guysborough County. There were many overlapping requests for areas, with the same fishers submitting proposals as part of a group as well as individually. It became necessary to quickly survey most of the sea urchin habitat in the county in order negotiate zone sizes. By October nine zones had been negotiated and by 1998 the county contained 14 zones with room for several more.

Two groups strongly objected to the zone concept. Chiefs of 13 Nova Scotia native bands, including several bands with licenses, objected on the grounds that private ownership of fishery resources was contrary to their traditions. They suggested another type of property right, individual transferable quotas. Fishers who did not hold an urchin license objected to zones for many reasons, including that they were nontraditional and they would permanently exclude new applicants from the fishery.

By late 1997 boundaries of 26 zones had been negotiated and a few others denied. In Cape Breton two fishers requested zones in 1995, but agreement on size was not reached until 1997. In eastern Halifax County in 1995 six fishers choose zones without overlapping borders, sizes were reduced moderately by negotiation. In Shelburne County none applied for a restricted zone in 1995. But, in the absence of zones, six fishers negotiated a gentlemen's agreement on separate fishing areas. This agreement immediately failed when four of the six chose to fish in the same harbour. After another year of conflict over fishing areas, the Shelburne County fishers asked for zones. All but one of the borders were settled amicably. Although only a few hundred meters of shore were in dispute, two weeks of discussion failed to settle the remaining border until the two parties agreed to binding arbitration.

Fishers were often allowed a zone larger than they could manage to help overcome their apprehensions about confinement to an area. However, this created the need for later realignment.

In spite of seemingly good intentions, only a few zone holders experimented with enhancement methods in 1995-96. Therefore, before they were permitted to fish in the 1996-97 season they were required to choose an enhancement measure, such as transplanting urchins to food or clearing an area of urchins to allow algae to regenerate, and the area where it was to be applied. They were also required to hire an independent diver to inspect and provide a written description of the area before and after enhancement. This was intended to demonstrate to fishers that enhancement could work, but was only a qualified success as many did not continue enhancement activities.

A second requirement before the 1996-97 season was more successful. They were asked to submit a detailed map of algal and sea urchin distribution in their zone. This was to ensure that they knew their zone well enough to plan harvests before the season. Nearly all admitted to finding new urchin beds and most maps were well done.

In the summer of 1997 a grant was obtained from the National Research Council of Canada (IRAP) to aid fishers in developing enhancement methods. One license holder in particular, Alan Baker of Jeddore Hbr., Halifax Co., was diligent and successful in developing methods for moving kelp to underfed urchins and moving underfed urchins to kelp. He shared his methods with other licensees and an employee of the project conducted demonstrations in other zones. Because fishers with zones were not competing for catch, the usual barriers to sharing information was removed.

Zone Audits

In the early 1999 industry representatives and DFO met several times to develop criteria for auditing the quality of management. All agreed the audit was a condition of the zone, although some argued that previous attempts at enhancement, with or without success, should be sufficient.

Audit criteria were based on the length of the sea urchin feeding front and its depth. Nearly all harvesting occurs at the feeding front. With a maximum of four divers one license could harvest only a finite length of front in a winter season. Harvesting is necessary maintain fronts at a minimum depth and to prevent the urchins from grazing nearly all the macroalgae. All surveyed fronts included urchins of commercial size and densities. Some required manipulation to increase urchin gonad size. The important audit criteria for measuring successful management of a zone were as follows:

1. Up to 1000 m of sea urchin feeding front could be unmanaged without penalty. The shortest contiguous front that would contribute to the 1000 m was 100 m (with minor exceptions).
2. Unmanaged front was described as locations where dense macroalgae extended to less than 20 feet depth below low tide, in areas where suitable algal habitat existed to that depth. Sea urchin density on the algae-free bottom should be sufficient ($\geq$0.5 kg/m^2) to keep it clear of algae, i.e. the urchins were the agent preventing the algae from growing deeper. Urchin densities of <0.5 kg/m^2 can maintain the bottom free of macrophytes (Bernstein et al. 1981; Chapman 1981; Moore et al 1986**).**
3. If greater than 1250 m of unmanaged front was found in a zone, DFO and the licensee would immediately negotiate new borders to bring it to under 1000 m. Between 1000-1250 m the licensee was given time to reduce the total to 1000 m.

The audit survey for 14 zones was conducted by DFO in the summer of 1999 with industry paying for a significant portion. Zone-holders were invited to accompany the survey team.

Only one of the 14 zones audited met the criteria for a well managed zone, i.e. less than 1000 m of front in less than 20 feet depth (Table 7). All but one zone also had more than 1000 m of front less than 12 feet deep.

If we compare mean depths fished (from Science logs) to mean depths of front occurring at less than 20 feet (from the audit), it is clear that most of the front <20 feet was not fished. Depths were corrected to low tide during the audit survey and mean depths from logs were reduced by 2.5 feet to account for the mean tidal height. In all zones the mean depth fished was greater than the mean depth of front <20 feet, and in 11 of the zones the depth difference was $\geq$12 feet.

Comparing the length of front fished with the length of front in <20 feet indicates that fishers had far more front in their zones than they were willing or able to fish. The last column in Table 7 gives the estimated length of front fished during the 1998-99 season. This was obtained by dividing each fisher's landed weight by 5.4 kg/m, the average annual harvest per meter from 9 beds representing 12.9 km of front. Fisher L is the worst case. He fished 1900 m at an average depth of 22 feet, but had 66,4000 m of front at an average depth of 7 feet. In total, these 14 licenses fished an estimated 89 km of front in the 98-99 season. Based on records of fishing locations and recorded depths, we estimate that these zones contained about 224 km of shallow front that was fished little or not at all. No doubt additional front deeper than 20 feet was also unfished, but this was not surveyed.

The degree of underutilization of zones was disappointing. It indicates area highgrading, i.e. the fishing areas most accessible or with the best gonad yield and ignoring the remainder.

Table 7. Results of the 1999 audit survey and mean depth fished in the 1998-99 season as reported on Science logs.

	Feeding front < 20 ft. deep		Length of front	Mean depth fished in 98-9	Estimated front
Fisher	Length (m)	Mean depth	<12 ft. deep	season (ft)	fished (m) 98-9
A	300	17.0	0	40	6400
B	5900	15.1	1700	31	9800
C	6000	14.2	1400	29	8000
D	16,400	10.7	8300	34[a]	5800
E	22,000	11.9	11,800	25[a]	2900
F	13,400	11.4	6100	23[a]	0
G	19,000	12.2	6800	35[a]	3200
H	3300	16.2	0	18	1100
I	13,000	13.9	3100	26	11,900
J	29,700	9.6	22,600	17	16,800
K	32,700	11.8	18,500	21	13,400
L	66,400	7.0	66,300	22	1900
M	1900	2.5	1900	30	3300
N	50,700	3.5	43,900	17	4900
Totals	280,700		192,400		89,400

[a]Depths for 97-98, no depths provided for 98-99.

With this audit our zone management system broke down. Although the terms of the audit were negotiated between DFO and zone holders during the previous winter, and the management plan called for a review of zones at this time (after 4-years), soon before the audit was to begin some zone holders realized they would loose a large portion of their zone if the negotiated criteria were applied. They threatened to withdraw their funding for the audit unless they were allowed more time to work on their zones. Given the 4-year duration of zones and the large area that remained unfished, significant change was very unlikely. Nevertheless fishery managers acceded to the fishers demand not to apply the terms of the audit. The audit was completed and results presented to fishers and fishery managers in September, 1999. Eighteen months later no action was taken and no plans formulated.

Next, fisheries managers requested a public assessment meeting with external reviewers. The meeting concluded that the resource had been underused in Shelburne, Guysborough, Richmond, and Cape Breton counties; that the disease had killed 10-100 times the weight taken by the fishery since 1995; that large quantities of unused resource was being lost to disease and should be made available to other fishers. Ten months after this meeting thousands more tons of urchins had died of disease, the zones had not been resized, and no additional fishers have been given access.

Measures of Success

The benefits of zones are not easy to quantify because of little data from areas without zones and because zones were not fully exploited. However, zone holders are adamant that zones are beneficial and they have not asked to give up their zones and re-enter the competitive fishery.

Price per kg to the fisher is higher for Eastern Nova Scotia than other areas (Table 8). Much of the year-to-year change in price simply reflects market demand. Although still uneven in application, the zone advantages have been better applied in eastern than western Nova Scotia, the only areas with zones.

Table 8. Price per kg (round to fishers) in five locations (unpublished reports by J.A Nelson, Policy Branch, DFO, Dartmouth, Nova Scotia).

Location	1995	1996	1997	1998
Eastern Nova Scotia	3.30	3.30	2.80	2.37
Western Nova Scotia	3.20	2.67	1.95	1.95
Southern N. B.	2.11	2.31	2.18	2.22
Newfoundland	1.20	1.38	1.38	1.56
Quebec	1.91	1.47	1.53	

We expected the percentage roe yield to increase over time within a zone. For the 13 zones for which we have 4 or 5 years of records, eight showed no trend, four increased yields by 2% or more, and one showed a decrease (Table 9). However, the fisher with the best audit results (fisher 10) also had the largest increase in gonad yields, 4%.

We also expected the annual mean depth of fishing to be deeper with time. Fishing depths for seven licenses showed no trend and six licenses fished ≥5 ft. deeper. However, five of the six that fished deeper did so in the year they reported major disease impact (Table 9). When there is partial mortality from disease, the mortality is greatest in shallow water (Miller 1985; Scheibling and Hennigar 1997; pers comm. Nova Scotia sea urchin fishers). Most fishers must not have fished their zones hard enough to produce the expected results.

Table 9. For 4 or 5 seasons in 13 zones: mean percentage of gonad yield, mean catch in kg per diver hour, mean catch in kg per boat day, and mean depth fished.

Fisher	Season	Mean % gonad	Mean kg/hr	Mean kg/day	Mean depth (ft)
1	95/96	10.5	68	1097	15
	96/97	7.9	39	590	18
	97/98	9	46	565	17
	99/00	8.1	73	1094	32

2	95/96	9.5	70	1138	18
	96/97	9.3	57	907	20
	97/98	9.7	42	585	22
	99/00	7.4	83	1288	27
3	95/96	7.6	52	781	29
	96/97	8.1	57	704	24
	97/98	11.6	59	974	25
	98/99	10.1	56	448	24
4	95/96	8.5	56	887	27
	96/97	8.5	49	857	25
	97/98	10	76	1075	27
	98/99	10.5	78	986	26
	99/00			633	
5	95/96	7.8	84	1075	17
	96/97	7.2	87	1127	17
	97/98	9.6	125	1409	18
	98/99	12.1	97	1049	23
	99/00	10.3	79	992	29
6	95/96	11.1	79	1126	23
	96/97	13.4	85	1244	19
	97/98	11.4	88	1389	21
	98/99	11.6	118	1335	19
	99/00	10.5	78	1211	27
7	95/96	9.1	63	965	24
	96/97	9.1	59	948	24
	97/98	9	61	936	25
	98/99	10	62	884	28
	99/00	10	57	795	28
8	95/96	9.3	158	1554	24
	96/97	9.4	81	1502	33
	97/98	10.2	142	1029	33
	98/99	9.9	81	1182	34
9	95/96	10.7	127	1231	30
	96/97	9.9	70	1331	26
	97/98	11.3	70	1430	31
	98/99	10.8	108	1522	33
10	95/96	11.5	69	1121	35
	96/97	11.8	71	928	32
	97/98	14.1	85	1043	36
	98/99	15.5	93	693	42
11	95/96	11.4	70	998	24

	96/97	10.6	70	823	21
	97/98	11.5	69	686	24
	98/99	13.4	77	998	25
	99/00*	11.6	87	1251	34
12	95/96	7.9	76	1122	15
	96/97	8.1	67	1265	17
	97/98	7.8	87	1464	12
	98/99	7.7	103	1670	15
	99/00			1842	
13	96/97	9.9	92	1160	21
	97/98	9.9	93	1167	30
	98/99	10.7	99	1062	30
	99/00	11.3	85	781	30

We also expected the catch per unit of effort, measured as kg/diver hour and kg/boat day to decrease as virgin stocks were fished up. This did not occur even in the best managed zones (Fig. 8). Scatter plots for 13 fishers in eastern and western Nova are shown in Fig. 4. There is clearly no trend with time. When we looked at fishers individually there were still no time trends (Table 9). Fishers F, G, and K lost a large portion of their urchins to disease early in the 1999-00 season and their season landings dropped by about one-half. However, their catch per day and per diver hour scarcely changed (Table 10).

Table 10. Catch rates of three fishers before and after loss of urchin stock to disease.

		Landings (kg)		
Fisher	Season	Season	Day	Diver hr.
F	98/99	91,000	1340	118
	99/00	46,000	1210	78
G	98/99	65,000	880	62
	99/00	38,000	800	57
K	98/99	58,000	1000	77
	99/00	21,000	1250	87

If catch per unit effort is an index of stock abundance as usually assumed in fisheries assessments, then catch per day and catch per diver hour should correlate with annual landings. Plots for each of 12 fishers in Fig. 5 show few correlations. These results suggest two conclusions: CPUE is not an index of abundance in this fishery and fishers are able to plan their day's harvest to obtain more-or-less uniform catch rates.

Freedom to schedule harvest of their urchin beds gives zone holders advantages they would not have if they competed for a common resource pool. For example, as they become familiar with the beds in their zone they can choose to harvest exposed areas on calm days and save sheltered areas for inclement days. If the price for urchins is low they can choose to delay their harvest without fear of loosing the urchins to another fisher. They can learn which beds develop marketable gonads early in the season and how many times per season each bed can be harvested with acceptable yield. They were able to maintain acceptable roe yields throughout the season (Table 3) in spite of marked seasonal change in average yields and they were able to distribute their catch over a long season (Table 4).

In a competitive fishery a fisher should harvest any urchins of commercial value when they are first found, without regard to optimum yield, location, or price. Finding new beds is a significant portion of fishing costs and if a bed is not fished when located the fisher risks loosing his investment to a competitor.

Individual fishers can benefit from their own enhancement activities. Because fishers do not share grounds or the urchin stock, there is no requirement for group agreement or participation, or no need for altruism if some fishers do not contribute their share of the work. They can also survey beds during the summer off-season and depend on the stock still being there whenever they choose to harvest it. The tragedy of the commons is avoided.

Enforcement costs are reduced. Fishers police their own borders. There has been only one charge in 6 years for fishing illegally in a zone. Seasons were eliminated to free each fisher to exploit his zone to his best advantage. Fishers usually see the benefit of not wasting their resource and cull undersized urchins on the fishing grounds rather than in port. There is less incentive to misreport landings than under quota management. Although there is a minimum legal size, the size landed is now controlled by market demand. Illegal bycatch of lobster does involve enforcement, but the penalty is high and infractions are probably rare. The 4-diver limit initially required occasional enforcement, but with greater concern for diver safety, boat captains became content with 2-4 divers.

Ongoing fishery assessment costs should be lower than for a competitive fishery. Once zones are assigned it becomes the responsibility of each fisher to manage the stock within. Because the unit of management is the license rather than a ton of fish, there is no need to determine stock size for a catch quota or for allocating the stock among competing interests. Except for infrequent audits to verify that zones are being adequately used, the management agency has no stock management responsibilities. This is a difficult concept for many science managers and fishery managers who are accustomed to asking for estimates of stock size. They are unprepared for the answer that "stock size doesn't matter because we don't allocate stock. We allocate habitat and fishers develop the stock."

Stock reproductive capacity is probably adequately maintained. Algal beds are increased providing more food. Because of exclusive control, fishers can afford to harvest the best quality urchins leaving lower quality, but still reproductive urchins. Some areas can be zoned as refuges and left unfished. The minimum sized animal harvested leaves many reproductively mature urchins; size at first maturity is about 7-10 g (Miller and Mann 1973; Wahle and Peckham 1999), whereas the minimum harvest size is about 60 g.

Disadvantages

A disadvantage of zone management is the high start-up cost. Zone holders like having protection from competition and freedom to schedule harvesting. However, most asked for a larger zone than they could manage, in part because they were unsure how much they could manage, and because avarice is not uncommon in the fishing industry. If there are competing claims for the same area, these must be negotiated. A zone needs to be large enough to support up to four divers, but not so big that beds in need of developing or in inconvenient locations can be ignored. Of course, some fishers fish harder than others and zone sizes require adjustment over time to reflect this.

We now have better methods for determining zone size. We can obtain good quantitative measures of the length of feeding front, as described under survey methods. This, multiplied by 5.4 kg/m (5.4 t/km) gives the approximate annual yield potential if all fronts are managed. For new zones, a policy decision is needed as to how much potential harvest should be allocated to one license.

Industry self-policing of zone size and allowing new entrants has been a difficult responsibility for fishers to assume. The privilege of holding a zone and the increased responsibility for managing the urchin habitat naturally leads to a club mentality. The club members resist expanding the membership, especially if this means reducing the size of their zones.

In hindsight, DFO should have developed the specific audit criteria years rather than months before the 4-year deadline for the audit and obtained a signed contract with the zone holders. The 1995 management plan was clear that full utilization and enhancement of a zone was required and was the responsibility of each zone holder. This was reinforced in numerous meetings and news letters over the following 4 years. The requirements for mapping the zones and carrying out enhancements were intended to aid in this adjustment. However, it developed that most fishers had not accepted this responsibility and fisheries managers were unwilling to enforce the terms of the agreement.

A further difficulty with individual zone management is the constant need to defend the approach against outside interests. There were many examples of "willful ignorance", selectively choosing information to support a case for access. Because it was a lucrative fishery, applicants who were unsuccessful in obtaining a license tried to circumvent the rules for access, even at the cost of destroying the management regime that made it a lucrative fishery. Moving urchins even short distances from high density to low density areas was an anathema to lobster fishers who dislike having to pick urchins from their traps. Explaining that fewer urchins will be left on the fishing grounds if fishers are allowed to move them and enhance their commercial value did not ease the resistance. Politicians and DFO employees come under strong pressure to eliminate individual zones simply because they are non-traditional.

Quota Management in Digby County

Two passages between islands in the southern part of Digby county proved a good place to fish because of high densities of good quality urchins and shelter from waves. At the end of the 1998-99 season all four active fishers asked for restricted access to these areas. Instead, fisheries management allocated equal ITQ shares to these four plus two inactive licenses. Science provided an arbitrary total allowable catch of 136 t, 70% of the 1998-98 catch from the passages. Fishers were required to increase dock side monitoring from 20% to 100% of days fished to prevent quota overruns. Fishers could also fish outside the passages unrestricted by quotas.

Table 11. Catch, CPUE and TAC for two years for the passages on Digby Neck.

	Total catch (t)	Catch/boat day (t)	TAC (t)
1998-99	195	1.0	none
1999-00	236	0.7	136

In spite of the quotas and expensive dockside monitoring of the catch, the (reported) overrun was 100 t or 74% and the catch per day dropped 30% (Table 11). This overrun apparently occurred because fishers reported fishing outside when they were fishing inside the passages and data entry by the dockside monitoring company was incomplete. No fishing location was recorded for 102 of 296 fishing trips. Since there is no biological basis for the TAC and apparent lack of will to observe it, there was no recommendation for another TAC. For the 2000-01 season fishers again wanted ITQs. They were allowed to set their own quotas as a test to see if they were able to enforce limits of their own choosing.

This fishery demonstrated the importance of leading by example. None of 10 license holders since the early 1990s had significant landings before 1998-99. They complained of poor quality urchins bringing insufficient revenue, strong currents and depths too great for diving, and frequent winter storms. Two licenses were transferred to new fishers before the 1998-99 fishery and at least one of these fishers found how to fish successfully. In 1998-99 four active fishers landed 245 t, whereas the previous maximum was 20 t.

Discussion

Kelp-Urchin Cycle

Sea urchins and algal abundance vary through a natural cycle, but only a small portion of the cycle is optimum for sea urchin harvest. Therefore, it is to the harvester's advantage to maintain the cycle in the optimum range.

Scheibling (1984), Miller (1985), and Johnson and Mann (1988) published cycles of Nova Scotia sea urchins and macroalgae with documented examples. Fig. 5 is another version with new elements. Mature sea urchins move up from deep water to the deep edge of algal beds and are not limited to recruiting from the plankton as previously supposed. Fishing logs showed that the same kelp edges were harvested up to six times in 3-years. Sea urchin mortality from disease can occur on a scale of tens of meters as well as over large areas (Miller 1985; Scheibling and Hennigar 1997; Nova Scotia sea urchin fishers, pers. comm.) and mortalities have followed all levels of urchin abundance (stages two, three, and four).

Stages one and four can last many years whereas two and three are typically more ephemeral. Lush kelp beds have dominated western Nova Scotia continually since at least the 1940s (MacFarlane 1952) whereas urchin dominated barrens predominated on the outer coast of Nova Scotia in Queens and Shelburne Counties from at least the 1950s until disease struck in the early 1980s (Miller 1985). By the mid-1980s, released from urchin grazing, kelp dominated Queens and Shelburne Counties (Miller 1985). This was soon followed by the reestablishment of urchin barrens and an active urchin fishery in shallow water by 1993 (personal obs.). The cycle was shorter in St. Margarets Bay, western Halifax County. From 1968-74 urchins removed most of the macroalgal biomass and maintained the habitat as an urchin dominated barren until disease occurred in the early 1980s. This was immediately followed by the return to macroalgal domination (Mann 1977; Miller 1985).

The optimum level for urchin harvesting is stage three. The urchins are abundant and the feeding front is shallow enough to be accessible by divers. Yet, ample algae remains to feed the urchins at the feeding front and to prevent their decimating the algal beds between fishing seasons. This is not a stable state (Mann 1977). Fishers must harvest feeding fronts to maintain the balance of algal growth and urchin grazing. The threshold urchin density for grazing the front into more shallow water is about 2 kg/m^2 (Breen and Mann 1976; Scheibling et al. 1999), but varies with wave exposure and season (Himmelman 1984; Scheibling et al. 1999). If succession progresses to stage four where urchins lack sufficient food to grow marketable gonads, fishers should reverse the cycle to stage three. They can keep the bottom free of urchin grazing long enough for algae to reestablish, either by removing the urchins or importing algae. There are many published examples of kelp self-seeding, as discussed in the introduction. Managing the urchin food supply is a necessary part of managing an urchin stock.

Fishery Management Options

Pinkerton (1994) proposed a fisheries co-management approach in which government relinquishes part of the management control to stakeholders. The management units have clear spatial boundaries, clear membership, and few enough members that they can monitor one another.

The approach to managing the Nova Scotia sea urchin fishery had common elements.

1.The fishers and management agency jointly develop a management plan. This included the spatial scale of management and requirements to enhance stock productivity.
2. Small groups or individual fishers are given day-to-day responsibility for managing the resource in accordance with the management plan.
3. Every few years the management agency audits compliance with the management plan, and applies penalties for non-compliance.

The above model was implemented over a few years in order to gain acceptance by the participants. Zones for individuals and small areas for competitive fishing (counties) were successfully negotiated. Stock enhancement technology was developed and was applied by a few fishers. Regulations were largely self-enforced. Information on enhancement and harvest methods was freely shared. Planned harvest schedules allowed fishers to obtain a higher price for their landings and reduced the cost of fishing. Because government cannot afford to develop and police resource management on a small spatial scale, a simple and repeatable audit criterion was developed for measuring whether urchins beds throughout a zone were being well managed.

Problems in implementing the management plan were: mass sea urchin mortalities changed the resource availability and distribution, several fishers were unwilling to relinquish fishing area they were not using, stock enhancement was too infrequent, and the management agency was unwilling to enforce requirements for full utilization of zones. If the specific rules of the audit had been written into the management plan sooner and strong penalties for noncompliance specified, perhaps adherence to this part of the plan would have been better.

Catch quotas are not recommended as a conservation measure. Stock size would be expensive to measure. With a few exceptions, harvesting occurs on the feeding front which is replenished by urchins crawling up from deeper water. The distance below the front that should be included in the biomass estimate is not known. Also, survey results would change yearly with harvest and disease.

Three methods of sizing zones are i) allocating to a zone the total length of feeding front, managed plus managed, that could yield a predetermined annual landing (e.g. 60 t) if all front was well managed; ii) allocate to a zone the length of feeding front sufficient to maintain the recent landings of a licensee, and iii) reduce the size of under-used zones according to the rules developed for the 1999 audit.

If there is a lack of will to match the zone size with its use, then areas should be fished competitively by an increased number of licenses.

A chronology of important events in the short history of this fishery are listed in Appendix 1.

CPUE as an Index of Abundance

Even after loosing a large fraction their stock to disease, Nova Scotia urchin fishers maintained the catch per diver hour and boat day. CPUE is best as an index of stock abundance when fishers are fishing "blind" and there is a large random element to encountering fish. The better fishers are at "seeing" the fish or the fish habitat, as is the case in dive fisheries, the more focused their effort on commercial densities. They may fish progressively deeper or farther from port while maintaining a similar CPUE. CPUE was found not to be a useful index of abundance in dive fisheries for abalone (Keesing and Baker 1998; Prince and Hilborn 1998; Prince et al. 1998).

In the Maine fishery, Creaser and Hunter (2000, unpub. report on commercial port sampling) found over 5 years when total landings decreased 60%, catch per unit effort for divers decreased only 6% and for draggers decreased only 8%.

Sustainability of the Resource

We feel the dive fishery is not a threat to the sustainability of the resource. Urchins with gonad yields below market acceptability (minimum market acceptability varies from 5-10%), urchins too deep for divers to harvest, and urchins at sub-commercial densities are reproductive refuges. Urchins also have a refuge in size because they become sexually mature far below the minimum commercial size. Recent studies have suggested that sea urchins require a minimum density for successful egg fertilization (Pennington 1985; Levitan et al. 1992; Levitan and Sewell 1998; Wahle and Peckham 1999). We do not know what that density is for <u>S. droebachiensis</u>. However, after near 100% mortality in the nearshore zone in early 1980s, the stock recovered by the mid-90s along most of the 400 km of affected coastline.

Dive fisheries can risk serial depletion of stocklets (Prince et al. 1998; Prince and Hilborn 1998). This occurs in abalone fisheries when divers fish out each bed, perhaps below sustainable levels, as they are discovered. McShane (1995) suggests each bed needs its own management plan. However, devising and updating plans for hundreds of beds would be a prohibitive cost for a management agency. Because most urchins in any one location are not harvested, the risk of serial depletion would be less. Zones would reduce the risk further because the zone holder can afford to fish at a lower exploitation rate, taking only the best quality urchins, without risk of another fisher taking the urchins left for another day.

Urchin disease has proven to be the major threat to sustainability. It killed more than 270,000 t of urchins in Nova Scotia in the early 1980s (Moore et al. 1986) and from 1995-2000 killed 10-100 times the biomass taken by the fishery. Incidence of disease appears unrelated to fishing effort.

A considerable increase in effort is warranted in Cape Breton where we have not seen mass mortalities from disease and a large stock remains nearly unexploited. Licenses apparently need to be cycled through many fishers until several are found who can fish successfully. Much of the biomass is low quality because of poor nutrition. In order to fish down the stock to establish a better balance between the urchins and their food supply, the fishery could be fished competitively by a high number of licenses for a short time, then revert to a core group of licenses. In Guysborough Co. the 1999 zone audits revealed substantial underutilization of resource. We know from previous surveys that areas outside zones also contain harvestable resource, and this was fished very little by the three competitive licenses in the county. In the fall of 1999 substantial mortality from disease occurred, but surveys in 2000 identified substantial remaining resource. In Halifax, Lunenburg and Queens Counties large disease induced mortalities occurred in 1995, 1996, and 1999. Fishers report that there are now no harvestable concentrations of urchins remaining. In Shelburne County landings in 1999-00 decreased 60% from 1998-99 due to disease, and mortalities expanded further in 2000. In 1999 and 2000 there was not enough resource to support the existing fishers; however, the large zones and uneven distribution of mortalities, restricted access. Disease appears not to be a problem in Digby County. Because of high currents, low visibility, and depths at high tide, this a difficult area to survey. Fishers in Digby have only recently learned to overcome these problems to harvest successfully.

Because of continuing loss of resource to disease, because most zones were too large and underused, and because resource recovery post-disease will likely have a different biomass distribution, we recommend immediate elimination of all zone boundaries bordering mainland Nova Scotia.

Research and Data Needs

We need to know the width of zone supplying the feeding front and the rate of movement through this zone in order to identify the habitat area supplying the harvest. Using newly developed tags (Duggan and Miller 2001) such a study is now possible.

Data from the fishing fleet are inadequate. Since DMP was instituted, participation in the Science log program has decreased. DMP logs do not satisfy the minimum requirements. Additional data are needed on latitude and longitude to 0.1 min., percentage roe yield, and depth fished. Even the data recorded are of poor quality with missing and inaccurate information common. A change from daily to monthly documents would reduce the paper flow and make working with the hard copies easier.

After sea urchin disease has run its course, a survey of the remaining stock in areas of partial mortality would help with future decisions on allocation.

Management of Other North American Sea Urchin Fisheries

The green sea urchin is taken commercially in seven jurisdictions on the Atlantic coast and three on the Pacific coast; the red urchin (*Strongylocentrotus franciscanus*) is taken in five jurisdictions on the Pacific coast (Table 12). Most fisheries are dive only, but four Atlantic jurisdictions allow dragging in addition to diving. Nearly all have minimum sizes. Washington has a maximum size because juvenile red urchins are thought to shelter among the spines or large adults to avoid predators. Some Pacific jurisdictions have rotating area closures to allow stocks to recover. Washington and British Columbia rotate seasons over many management areas as quotas assigned to each area are fished up (Perry and Waddell 1999; DFO 1999). Each licensee has a season quota, but this can be accumulated from more than one management area. These quotas are set conservatively based on <u><</u>5% of standing stock shallower than a prescribed depth (usually 10 m). Washington previously rotated open and closed areas (Botsford et al. 1993).

Table 12. Summary of North American sea urchin fishery regulations (summarized from Huston 1999).

Location	Season	Dive only	Dive + drag	Min. size (mm)	Max. size (mm)	Temporary area closures	Perm. area closures	Catch quotas
Maine	Y	N	Y	51	N	N	N	N
N.H.	Y	N	Y	51	N	N	N	N
Mass.	Y	N	Y	51	N	N	N	N
N.B.	Y	N	Y	50	N	N	Y	42 or 75 t/license
Nova Scotia	N	Y	N	50	N	N	N	N
Newfoundland.	Y	Y	N	48	N	N	N	100 t / license
Quebec	N	Y[a]	N	50	N	N	N	N
California	Y	Y	N	83/89	N	N	Y	N
Oregon	N	Y	N	89	N	Y	Y	N
Washington-red	Y	Y	N	102	133	N	Y	~3%B
B.C. – red	N	Y	N	89	N	Y	Y	~2%B
B.C. – green	Y	Y	N	55	N	Y	Y	~5%B
Alaska – red	N	Y	N	N	N	N	Y	~6%B
Alaska-green	Y	Y	N	N	N	N	N	N

N – no, Y – yes [a]trapping permitted in one area

There are many other examples of area based management with claims of at least partial success. Community zones for harvesting loco (a large gastropod) resulted in higher CPUE, larger animal size, and higher prices (Castilla et al. 1998). Mottet (1980) identified local control over allocating sea leases an important ingredient in Japanese fisheries management. The southern New Brunswick rockweed harvest is allocated to one enterprise who is limited to an annual harvest of 7% of the biomass spread over several harvest areas (Ugarte and Sharp 2001). They are accountable to an oversight committee and must employ an independent party to audit compliance. Pinkerton and Weinstein (1995) and Johannes et al. (2000) discuss several examples of area based management of fishery resources.

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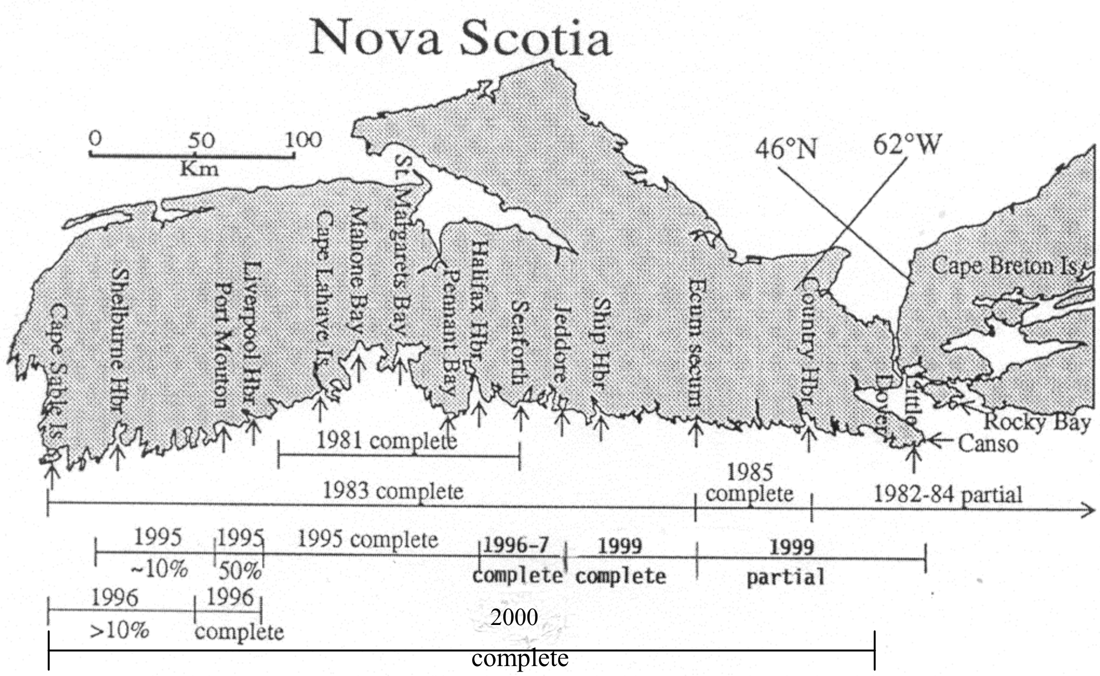

Fig. 1. Occurrence of sea urchin mass mortalities from 1981-2000

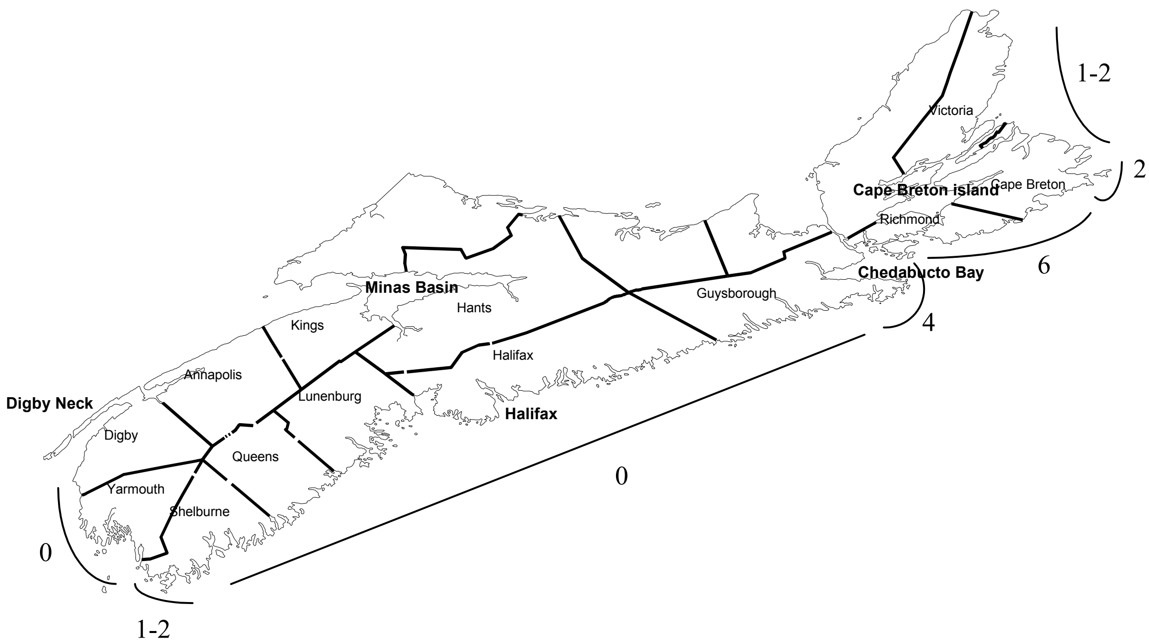

Fig. 2. Nova Scotia counties referred to in text and approximate number of licenses that could be supported in each area in December 2000.

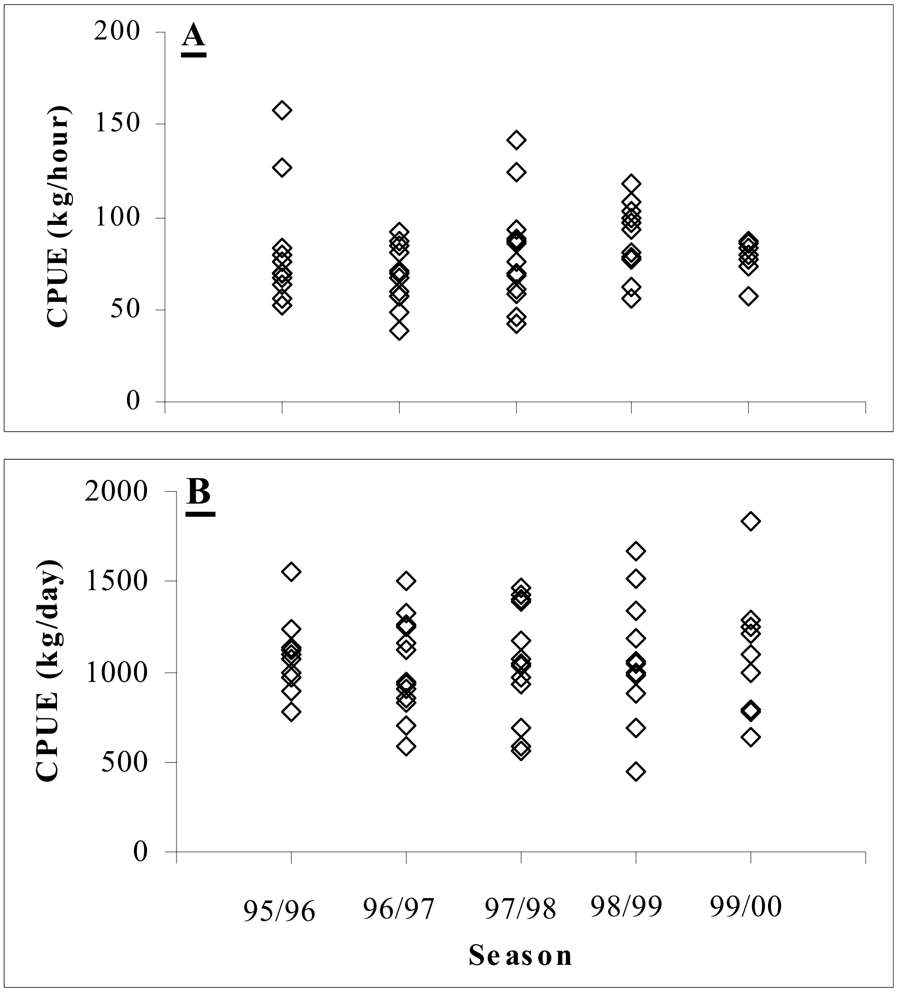

Fig. 3. Mean annual catch per diver hour (A) and per per boat day (B) for 14 licenses with zones.

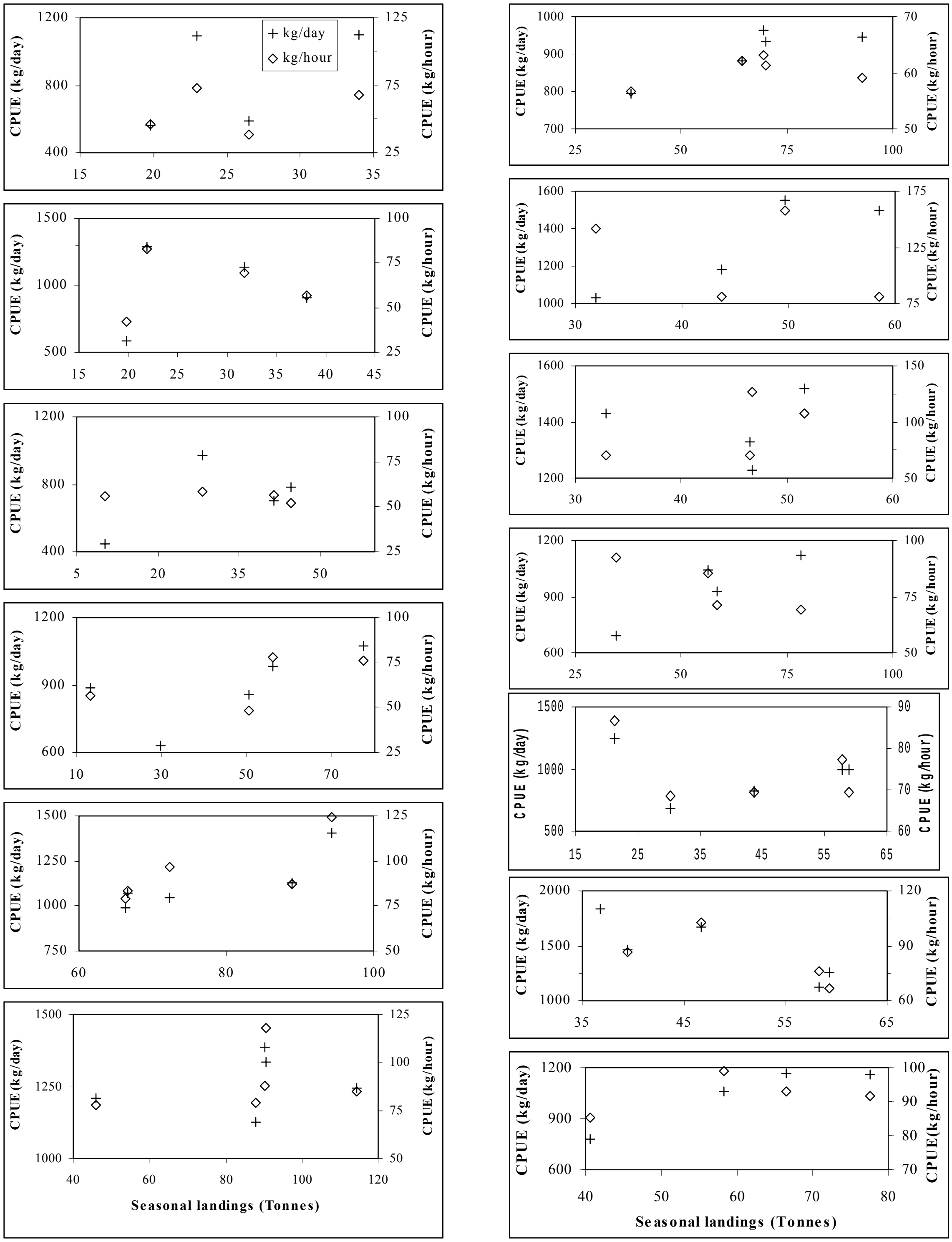

Fig. 4. Annual catch per diver hour and per boat day versus annual landings for each of 13 licenses.

4. Algal beds are reduced to refuges inaccessible to urchins.

1. Macroalgae dominates stable rock surfaces to ~20 m depth.

Disease kills nearly all urchins to 30 m depth.

or

Disease kills urchins in patches to <10 m depth.

3. Urchin beds grow smaller as urchin grazing clears the bottom and keeps it clear.

2. Urchins migrating from deep water form dense feeding fronts on the deep edge of algal beds. Urchins settling into algal beds from the plankton grow and eat holes in the algal beds.

Fig. 5. Sea urchin-macroalgal cycle in Nova Scotia. Urchin mortality from disease can follow any of successional stage 2, 3, or 4, reversing the cycle, and mortality can be either complete or partial.

Appendix 1. Significant events in development of the Nova Scotia sea urchin fishery 1989-2000.

Year	Event
1989	-New exploratory licenses were issued on request to any holder of a commercial fishing license. -Harvesting was permitted by diving only with no bycatch of other species.
1991	-New exploratory licenses were issued to holders of commercial fishing license by public draw. -The license holder must fish the license him/herself (owner-operator rule). -Recreational fishing is prohibited. -No more than four divers can operate from one license in one day. -A use-it-or loose-it clause was instituted (inconsistent enforcement). -A daily record of landings must be submitted monthly (inconsistent enforcement).
1993	-New licenses are permitted to fish only waters adjacent to their county of residence. -Seventeen new licenses issued to 10 aboriginal bands.
1994	-Licensees issued before 1993 were required to choose fishing areas among groups of counties. -Fishing season set at Oct.1 to Apr. 30 or May 31, depending on area. -Volunteer daily science logs containing precise fishing locations, catch, and percent roe yield were initiated.
1995	-A new conservation harvesting plan was adopted. -Eligibility for new licenses: 5-years full time fishing experience, holder of a license for a major fishery, and meet a minimum earnings requirement from fishing. -License holders must have proof of sale of 2000 kg of urchins in their first year and 4000 kg in subsequent years to retain a license. (inconsistent enforcement) -Minimum urchin size 50 mm test diameter. -Under-sized urchins must be culled from the catch at sea. -Licensees must choose to fish in only one county in which they have a fishing history, (or in one part of two large counties, or in groups of small counties). -Bycatch of sea cucumbers permitted. -License holders can apply for a restricted zone within their county as an annual condition of license. They alone can fish within the zone, but they can not fish outside the zone. Zones are instituted for a 4-year trial period with agreement to enhance the productivity of the zone. -The borders of 16 zones were negotiated between fishermen and DFO. -Licensees adopted safety guidelines for divers and fishing vessels. -Within 1-month of adopting a new management plan disease eliminated the urchin stock fished by nine licensees and reduced the stock of 6 others. Four of these licensees were given permission to relocate to new areas.
1996	-All holders of restricted zones were required to submit a detailed map of kelp and urchin distribution in their zone. They were also required to conduct trial enhancement, with inspections by an independent diver before and after the trial.

-Guidelines were set for zone applications: a history of landing at least 25,000 kg in one season, a demonstrated attempt to settle any boundary disputes with other fishers, a promise to keep records and enhance the productivity of the zone.
-Seven new restricted zones were established in Shelburne County.
-A grant was obtained to develop enhancement methods.
-Eighteen permits were issued by the Nova Scotia Dept. Fisheries for cage culture of urchins; none remained active by 1998.
-Two sea urchin dragging permits were granted for deep water in the Bay of Fundy. One remained in 2000, but no significant landings were been taken.

1997 -Most licenses active for 3 years or more were converted from exploratory to permanent, making them eligible for transfer (sale).
-Participation (catch) requirements were eliminated for the permanent licenses.
-Licensees issued zones in 1996 completed maps of urchin and kelp distribution.
-Two new restricted zones were negotiated.
-Five shore-based aquaculture permits were issued by the province of Nova Scotia, none remained active in 2000.

1998 -Fishing seasons were eliminated.
-Reporting of landings to private enterprises (dockside monitoring companies) was introduced.
-Landings in Digby County increased to 250 t from 20 t the previous year.

1999 -10 new licenses were issued in Cape Breton by public draw.
-Terms for auditing zones for compliance with zone management criteria were negotiated between licensees and DFO.
-Audits were carried out in 14 zones. Most zones did not meet the criteria for being well managed and biologists recommended reduction in sizes of these zones. Fishers objected and zone sizes were not adjusted.
-Individual transferable quotas were established for 6 licenses fishing two prime fishing areas in Digby County.
-Disease expanded further. Since 1995 it has eliminated the entire stock fished by 19 licenses.

2000 -At the request of fisheries managers, the rationale for fishery management, an assessment of the stock, and options for future management were presented at a sea urchin regional assessment. Because several zones were greatly under-exploited and because the stock was being quickly lost to disease, it was recommended that the zones be collapsed or reduced in size and new entrants be allowed to exploit the remaining stock (DFO 2000).
-By December, 2000 the areas fished by 13 more licenses experienced complete or near complete loss of stock from disease.