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Stock Assessment and Quota Options for the Green Sea Urchin, *Strongylocentrotus droebachiensis*, Fishery in British Columbia, 2010-2013

Évaluation des stocks et options en matière de quotas pour la pêche aux oursins verts, *Strongylocentrotus droebachiensis*, en Colombie-Britannique, 2010-2013

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ABSTRACT

The green sea urchin (*Strongylocentrotus droebachiensis*) fishery is a small but important component of British Columbia's dive fisheries. Integrated Fishery Management Plans (IFMP) for this fishery are prepared for three year periods. There are two major fishing regions for green urchin populations (Northeast and Southeast Vancouver Island) and they both appear to be under low fishing pressure. The catch per unit of effort has been increasing since 1993-94 and is currently at its highest level since the start of the fishery in 1987. However total landings and landed values have been at their lowest levels during the past five fishing seasons as a result of poor market prices in Japan.

This paper provides quota options for both Northeast Vancouver Island and Southeast Vancouver Island using a Bayesian biomass dynamic model. The model uses data from both the commercial fishery and from fishery-independent surveys. It is recommended that fishery-independent surveys be continued and expanded to include other Pacific Fishery Management Areas (PFMAs).

A new three year IFMP (2010-2013) will be developed following advice from this paper.

RÉSUMÉ

La pêche aux oursins verts (*Strongylocentrotus droebachiensis*) est de petite envergure, mais représente un élément important de la pêche en plongée en Colombie-Britannique. Pour cette pêche, on élabore des plans de gestion intégrée de la pêche (PGIP) de trois ans. Il existe deux grandes régions de pêche pour les populations d'oursins verts (au nord-est et au sud-est de l'île de Vancouver). La pression de la pêche semble faible dans ces deux régions. La capture par unité d'effort est en hausse depuis 1993-1994 et est actuellement à son taux le plus élevé depuis le début de cette pêche en 1987. Cependant, les débarquements totaux et les valeurs des prises sont à leur taux le plus faible depuis les cinq dernières saisons de pêche en raison des bas prix sur le marché japonais.

Ce document présente les options en matière de quotas pour le nord-est de l'île de Vancouver et le sud-est de l'île à l'aide d'un modèle bayésien dynamique de biomasse. Ce modèle utilise les données tirées de relevés de la pêche commerciale et de relevés indépendants. Il est recommandé de poursuivre les relevés indépendants et de les élargir afin d'inclure d'autres secteurs d'exploitation des pêcheries du Pacifique (SEPP).

Un nouveau PGIP de trois ans (2010-2013) sera mis au point en fonction des recommandations de ce document.

1.0 INTRODUCTION

1.1 DESCRIPTION OF THE ISSUE

Commercial harvesting for green sea urchins, *Strongylocentrotus droebachiensis* (Fig. 1), in British Columbia began in 1987. This fishery remains a small, but important, component of British Columbia's dive fisheries. The green sea urchin fishery was managed with few restrictions until 1991, when licence limitation was introduced to control record high effort and catches, followed by quota limitations in 1994 and an individual quota system with dockside validation in 1995. Currently, Integrated Fishery Management Plans (IFMP) for this fishery are prepared for three year periods. Stock assessments which analyse fishery-dependent and fishery-independent data are required to provide the scientific advice for these management plans.

*Figure 1. Juvenile to adult stages of the green sea urchin (*Strongylocentrotus droebachiensis*) from British Columbia. Wolf Carolsfeld, photo.*

Previous stock assessments were conducted by Harbo and Hobbs (1996), Perry *et al*. (1998, 2001, 2003, 2006), and Perry and Waddell (1998, 1999). Overview and methodological papers in the primary literature were published in 2002 (Perry *et al*. 2002) and 2005 (Zhang and Perry 2005). These publications document the rationale and methods for this assessment (see in particular Perry et al. 2002, 2003; and Zhang and Perry 2005). Consequently, the background and methods of this assessment will not be described in detail in this present report.

Fisheries and Oceans Canada (DFO) Fisheries Management has requested advice on: (1) the ranges of sustainable harvest quotas for the major commercial harvest areas on the coast [Pacific Fisheries Management Areas (PFMAs) 12-13, and 18-19]; (2) the risks or uncertainties associated with the range of quota options; (3) the recent trends in the local populations of green urchins in areas where data exist; (4) the trends in population structure; (5) whether the current annual surveys at the index locations need to be continued to provide reliable data on a longer time series, and whether additional sites should be initiated; and (6) recommendations for additional research needed in the program. Note that since the previous green sea urchin assessment (Perry et al. 2006), PFMAs 11 and 20 have been closed, and this assessment is for PFMAs 12, 13, 18 and 19 only.

The purpose of the present paper is to update the previous results, including the most recently available information from harvest logbook data and fishery-independent surveys over the last four fishing seasons (2005-06 to 2008-09), to provide scientific advice to fisheries managers on the status of the green sea urchin stocks in British

Columbia, and to provide quota options for the new three year IFMP (2010-2013). It is an update of a paper presented in November 2005 (Perry et al. 2006).

1.2 BIOLOGY

Green sea urchins (*Strongylocentrotus droebachiensis*; Fig. 1) occur in cool temperate waters in both the Pacific and Atlantic Oceans. They are circumpolar in the Pacific, occurring from northern Washington State through the Aleutian Islands and west to Hokkaido (Japan) and Korea. Green urchins occur inter-tidally and to depths of >140 m, generally on rocky, gravel or shell substrates. Sexes are separate, with sizes at maturity of about 25 mm in southern B.C. (Waddell and Perry 2005). In B.C., the spawning period generally occurs during February and March. Larvae are pelagic for 9 - 10 weeks depending on temperature. In Alaska it takes about 4 years (Munk 1992) for a green urchin to reach a test diameter of 55 mm (the minimum legal size in B.C.).

1.3 THE FISHERY

1.3.1 Management

The green sea urchin fishery in B.C. developed rapidly in the late 1980s, with few management restrictions until 1991 when licence limits were introduced. Landings reaching a peak of 1042 t and a landed value of Cdn$4.4 million dollars in 1992, followed by a sharp decline, in part induced by management regulations and quota limits set in 1994. The fishery is conducted by hand-picking by SCUBA divers using small vessels due to the patchy distribution of the resource. It is principally a roe fishery whose product is shipped live to the Japanese market, with the highest market prices usually occurring around Christmas.

The “licence year” is defined from 1 June to 31 May of the next year. The “fishing season” currently opens in the late summer and runs through to the early spring of the next year (September to March), and is denoted by the year started and year finished (e.g., 2009-10). Accordingly the analyses presented in this report are conducted on a “fishing season” basis. The fishery is managed with a 55 mm test diameter size limit, licence limitations, PFMA quotas, individual quotas and area closures. The PFMAs now open to harvesting green sea urchins are Northeast Vancouver Island (NEVI; PFMA 12 and 13) and Southeast Vancouver Island (SEVI; PFMA 18 and19) (Fig. 2). Since the last assessment in 2005-06, PFMA 11 and 20 have been closed due to low fishing activity. Therefore, note that the data presented for the NEVI and SEVI regions will look slightly different than in the last assessment (Perry et al. 2006), as they now represent data for fewer PFMAs. Management actions since the inception of the fishery are summarized in Table 1.

Figure 2: Map of south coastal British Columbia showing areas open to fishing in 2009-2010 for the green sea urchin, Strongylocentrotus droebachiensis*. PFMAs 12-13 are Northeast Vancouver Island; PFMAs 18-19 are Southeast Vancouver Island.*

Table 1. Summary of management actions in the green sea urchin fishery, 1987 to 2008/2009.

Year	Management Actions
1987	Scientific permits were issued, July 22 to December 31, to fishing vessels for harvest by diving. Logbooks were issued with permits to collect data on stock abundance and distribution. Permits were limited to the inside waters of Vancouver Island, PFMAs 12 to 19, 28 and 29. Some minor area closures for parks or study areas were in effect as for most dive fisheries. A precautionary minimum size limit of 40 mm was set as a condition of the permit. Sales slip data did not have a separate species code, so green and red sea urchin landings are mixed. As a result, landings have been estimated from logbook returns and hails from processors. Effort was restricted by limiting the season to the months of traditional peak market demand for sea urchins, Oct.-Dec. and Jan.-Feb. Nineteen vessels reported landings.
1988	Permits were issued for the period Jan. 16 to Feb. 28. Sales data for green sea urchins was recorded with a separate species code. A conservative closure was set, Jan. 16 to Feb. 28 in subareas 13-1 to 13-3 due to the intensive fishery in a small area. A Z category (Z-A) licence for green sea urchins was introduced for the fall fishery which opened Oct. 1. The minimum size limit was increased to 55 mm test diameter and set as a condition of licence. The season was limited again, Jan. 1-Feb. 28 and Oct. 1-Dec. 31. Sixty-eight vessels reported landings.
1989	The Z-licence, minimum size limit and seasonal restrictions continued. A conservation closure was set for subareas 12-1 and 13-29 to 13-40, north of Campbell River, Jan. 31-Feb. 28/89 due to heavy fishing pressure and a high incidence of undersized urchins landed. One hundred thirteen vessels reported landings.
1990	The Z-licence, minimum size limit and seasonal restrictions continued. There were 91 vessels reporting landings. Licence limitation for 1991 was announced with the eligibility criteria of landings of 9,072 kg (20,000 lb.) over the two year period 1988 and 1989. At least 33 vessels were expected to qualify before appeals were held.
1991	Licence limitation – 47 vessels qualified and 47 vessels reported landings.
1992	A conservation closure was set in the Kelsey Bay area, subareas 12-1, 13-32, 13-33 and 13-35, Feb. 25-Feb. 28. These subareas did not reopen for fall fishing until Dec. 7.
1993	Licences increased to 49. Notification of fishing required. No suction devices. Additional permanently closed areas for parks and reserves, IFF. South Coast: Reduced fishing times; Inside waters: season Jan. 4 to Jan. 28, 7 days/wk; Feb. 1 to Feb. 25, 4 days/wk, Mon.-Thurs. Fall fishery Nov. 1 to Dec. 16, 4 days/wk, Mon.-Thurs.; Dec. 6 to Dec. 30, 7 days/wk. Kelsey Bay limited to 7 days, Jan. 4 to 10. W.C.V.I.: season reduced to Oct. 4 to 28, 1992, 7 days/wk. North Coast: 7 days/wk, season reduced to Jan. 1 to Feb. 28 and Oct. 1 to Dec. 31.

Table 1. Continued.

1994	South Coast: A ceiling catch of 990,000 lb (449 t) was set along with PFMA quotas. Fishers requested to harvest 25% in Jan.-Feb. and the balance in Nov.-Dec. The days fishing were limited to 4 days/week (M-R) for some periods and others at 7 days/week. North Coast: No quota set; season reduced to periods Jan. 1 to Feb. 28 and Nov. 1 to Dec. 31. Consideration will be given for spring/summer fisheries depending on roe quality and landings.
1995/1996	Fishing licences changed to expire on May 31, 1996. No fishing occurred prior to Nov. this year. South Coast: South Coast: Pilot individual licence quota (IQ) system implemented with port validation. PFMA quotas also established, with total of 382,276 lb (173.4 t). Only PFMAs 12, 13, 17 to 20, and 28 open; other PFMAs available under an exploratory protocol. Fishing season was Nov. 20, 1995 to May 31, 1996. North Coast: No individual quotas. PFMAs 3 and 4 only open from Nov. 20, 1995 to Jan. 31, 1996, with quota of 200,000 lb (90.72 t). Other PFMAs open to fishing only under an exploratory protocol.
1996/1997	Harvest logs and validation forms combined onto one sheet. Biosamples (sample test measurements) were collected by validators. South Coast: South Coast: IQ system still in effect (quota divided among 49 licence holders), with port validation. PFMA quotas established, with a total of 359,435 lb (163.0 t). Only PFMAs 12, 13, 17 to 20 and 28 open; other PFMAs available under an exploratory protocol. Fishing season was Nov. 12, 1996 to Jan. 31, 1997, with an extension to Feb. 15, 1997. North Coast: North Coast closed, except under an exploratory protocol.
1997/1998	Two year Management Plan (October 15, 1997 to May 31, 1999). Second season of the extended pilot program (validation process). Biological sampling of commercial catch. South Coast: PFMAs 11, 12, 13, 17 to 20 and 28 open from Nov. 10, 1997 to Mar. 15, 1998; other PFMAs available under an exploratory protocol. PFMA quotas, with total of 366,079 lb (166.1 t) (IQ 7,471 lb or 3,389 kg). North Coast: North Coast closed, except under an exploratory protocol. Survey undertaken in PFMA 4.
1998/1999	Third season of the extended pilot program (validation process). Biological sampling of commercial catch. South Coast: PFMAs 11, 12, 13, 17, 18, 19, 20, and 28 open from Nov. 10, 1998 to Mar. 15, 1999; other PFMAs available under an exploratory protocol. PFMA quotas, with total of 366,079lb (166.1 t) (individual quotas 7,471 lb or 3,389 kg). North Coast: Total quota of ~12,725 lb (~5,772 kg) allotted to PFMA 4 from Feb. 12 to Mar. 15, 1999.
1999/2000	Validation program continued. Biological sampling of commercial catch. South Coast: PFMAs 11, 12, 13, 18, 19, and 20 open from Nov. 10, 1999 to Mar. 15, 2000; other PFMAs available under an exploratory protocol. Note PFMAs 17 and 28 are closed due to conservation concerns. PFMA quotas, with total of 414,393 lb (188.0 t) (individual quotas 8,457 lb or 3,836 kg). North Coast: Total quota of 13,000 lb (5,897 kg) allotted to PFMA 4. Season open from Jan. 21 to Mar. 15, 2000.
2000/2001	Validation program continued. Biological sampling of commercial catch. South Coast: PFMAs 11, 12, 13, 18, 19, and 20 open from Nov. 10, 2000 to Mar. 15, 2001; other PFMAs available under an exploratory protocol. Conditional surveys for PFMAs 18 and 20 were performed which allowed those areas to stay open with the same quotas as the previous year. PFMA quotas, with total of 414,393 lb (188.0 t) (individual quotas 8,457 lb or 3,836 kg). North Coast: Total quota of 13,000 lb (5,897 kg) allotted to PFMA 4. Season open from Nov. 10, 2000 to Mar. 15, 2001. First Nations had conservation concerns about the resource. Commercial fishers agreed not to fish the area this season.
2001/2002	Validation program continued. Biological sampling of commercial catch. A two-year Management Plan was established for the 2001/02 and 2002/03 fishing seasons. South Coast: Quota PFMA 13 was split into two: 13A (subareas 1 to 27) and 13B (subareas 28 to 43). PFMAs 11, 12, 13A, 13B, 18, 19, and 20 open from Nov. 20, 2001 to Mar. 15, 2002, with an extension of the opening to Apr. 19, 2002; other PFMAs available under an exploratory protocol. PFMA 20 required a survey prior to fishing, which was not undertaken, so it was not fished. PFMA quotas, with total of 394,646 lb (179.0 t) (individual quotas 8,054 lb or 3,653 kg). Only 68% of allowable catch landed due to oversupply of product by other countries, mainly Russia. North Coast: Only PFMA 4 was considered for opening, but it required a survey prior to quota allocation. However, the survey was not undertaken. First Nations had conservation concerns about the resource. Commercial fishers agreed not to fish the area this season.
2002/2003	Validation program continued. Biological sampling of commercial catch. Continuation of the two-year Management Plan established the previous year. South Coast: PFMAs 11, 13A, 13B, 18, 19 and 20 open from Oct. 15, 2002 to Mar. 15, 2003; PFMA 12 was open from Nov. 4, 2002 to Mar. 15, 2002; other PFMAs available under an exploratory protocol. PFMA 20 required a survey prior to fishing, which was not undertaken, so it was not fished. PFMA quotas, with total of 394,646 lb (179.0 t) (individual quotas 8,054 lb or 3,653 kg). Strong competition from Russia kept the price down again, and resulted in only 80% of the TAC being landed. North Coast: Only PFMA 4 was considered for opening, but it required a survey prior to quota allocation. However, the survey was not undertaken. First Nations had conservation concerns about the resource. Commercial fishers agreed not to fish the area this season.

Table 1. Continued.

2003/2004	Validation program continued. Biological sampling of commercial catch. New three-year Management Plan established (Nov. 2003-Oct. 2006). South Coast: PFMA 13 was re-divided to create new PFMA 13C (PFMA 13A = subareas 1 to 22; PFMA 13B = subareas 27 to 35; and PFMA 13C = 23 to 26 and 36 to 43). Earlier season start (Nov. 1) and closure (Mar. 1) established. PFMAs 11, 12, 13A, 13B, 18, 19 and 20 open from Nov. 1, 2003 to Mar. 1, 2004; other PFMAs available under an exploratory protocol. PFMA 13C opened Dec. 30, 2003 with quota of 25,000 lbs that were deducted from PFMA 13A. PFMA quotas increased to total of 410,055 lb (186.0 t) (individual quotas were 8,368 lb). Only 90% of allowable catch landed due to oversupply of product by other countries, mainly Russia. Research closure of Neill Ledge in PFMA 12 revoked. North Coast: First Nations still have conservation concerns about the resource and commercial fishers still agreed not to fish the area this season.
2004/2005	Validation program continued. Biological sampling of commercial catch. Continuation of the three-year Management Plan (Nov. 2003-Oct. 2006). South Coast: PFMAs 11, 12, 13A, 13B, 18, 19 and 20 open from Nov. 1, 2004 to Mar. 1, 2005; PFMA 13C needed a biomass survey before opening, but this did not occur; other PFMAs available under an exploratory protocol. PFMA quotas, with total of 410,055 lb (186.0 t) (individual quotas 8,368 lb). Only 44% of allowable catch landed due to lower price per pound caused by oversupply of product by other countries, mainly Russia. North Coast: First Nations still have conservation concerns about the resource and commercial fishers still agreed not to fish the area this season.
2005/2006	Validation program continued. Biological sampling of commercial catch. Continuation of the three-year Management Plan (Nov. 2003-Oct. 2006). South Coast: PFMAs 11, 12, 13A, 13B, 18, 19 and 20 open from Nov. 1, 2005 to Mar. 1, 2006; plus extra fishing in Oct. 2006 in PFMAs 12 and 13; PFMA 13C needed a biomass survey before opening, but this did not occur; other PFMAs available under an exploratory protocol. PFMA quotas, with total of 410,055 lb (186.0 t) (individual quotas 8,368 lb). Only 20.5% of allowable catch landed due to lower price per pound caused by oversupply of product by other countries, mainly Russia. North Coast: First Nations still have conservation concerns about the resource and commercial fishers still agreed not to fish the area this season.
2006/2007	Validation program continued. Biological sampling of commercial catch was suspended. New two-year Management Plan (Nov. 2006-Oct. 2008). South Coast: PFMAs 12, 13A, 13B, 18 and 19 open from Nov. 1, 2006 to Mar. 1, 2007, with two extensions (Mar. 3 to 21 and Mar. 22 to 31, 2007). PFMAs 11, 13C and 20 were closed due to low activity in previous years; other PFMAs available under an exploratory protocol. PFMA quotas, with total of 447,174 lb (202.8 t) (individual quotas 9,126 lb). Only 10.9% of allowable catch landed due to lower price per pound caused by oversupply of product by other countries, mainly Russia. Only 11 active licences and 8 vessels fished. North Coast: First Nations still have conservation concerns about the resource and commercial fishers still agreed not to fish the area this season.
2007/2008	Validation program continued. Biological sampling of commercial catch was suspended. Continuation of the two-year Management Plan (Nov. 2006-Oct. 2008). South Coast: PFMAs 12, 13A, 13B, 13C (re-opened), 18 and 19 opened earlier, from Sept. 21, 2007 to Mar. 1, 2008, with an extension to Mar. 21, 2008. Other PFMAs available under an exploratory protocol. PFMA quotas, with total of 447,174 lb (202.8 t) (individual quotas 9,126 lb). Only 31.9% of allowable catch landed due to lower price per pound caused by oversupply of product by other countries, mainly Russia. There were 19 active licences and 7 vessels fished (compared to 49 active licences on 27 vessels in 1999/2000). North Coast: First Nations still have conservation concerns about the resource and commercial fishers still agreed not to fish the area this season.
2008/2009	Validation program continued. Biological sampling of commercial catch was suspended. A one year Management Plan (IFMP) was implemented (Sept. 1, 2008 to August, 2009). South Coast: PFMAs 12, 13A, 13B, 13C, 18 and 19 open. PFMAs 18 and 19 opened earlier on Sept. 3, 2008, while remaining PFMAs opened Oct. 1, 2008. Openings of all PFMAs extended to Mar. 31, 2009, except PFMA 19, which reached its quota by Sept 29. Quota Area 18 now includes subarea 19-6 and that portion of subarea 19-5 north of a line running due east from Cormorant Point, while Quota Area 19 now excludes these subareas. Other areas available under an exploratory protocol. PFMA quotas, with total of 447,174 lb (202.8 t) (individual quotas 9,126 lb). Only 36.2% of allowable catch landed due to lower price per pound caused by oversupply of product by other countries, mainly Russia. There were 22 active licences and 12 vessels fished (compared to 49 active licences on 27 vessels in 1999/2000). North Coast: First Nations still have conservation concerns about the resource and commercial fishers still agreed not to fish the area this season.

1.3.2 Impacts of the Russian Fishery

Over the last several years, British Columbia's green and red sea urchin fisheries have been drastically affected by the Russian sea urchin fishery in the Kurile Islands off the east coast of Hokkaido, Japan (which is largely illegal, unregulated, and unreported: IUU). This fishery has been flooding the Japanese market with low cost product, and therefore lowering the demand (and value) for urchins from B.C. The annual landings from the Russian IUU fishery (red and green urchins combined) increased from 1,000 t in 1998 (Krause 2006), to approximately 15,000 t in 2006 (G. Krause, Explorations Unlimited Inc., Brentwood Bay, B.C., pers. comm., June 18, 2009), B.C.'s poorest year for the green sea urchin harvest. B.C. dive fishers have been experiencing great difficulties in trying to compete over the past five years, to the extent that only 11% of the quota was landed in the 2006-07 fishing season. Landings by the IUU fishery in 2008 are estimated to have decreased to 11,750 t (G. Krause, pers. comm., June 18, 2009), but this is still considered massive compared to the annual quota of 203 t for green sea urchins in B.C. There has been speculation that the sequential exploitation by these "roving bandits" will result in the depletion of sea urchins (Berkes et al. 2006), causing prices to rise again, and B.C. may once again be competitive in the Japanese market. However, this has taken longer to happen than originally thought (G. Krause, pers. comm.) and there has been concern by the Industry about the economic sustainability of this B.C. fishery. Other confounding factors for the green urchin fishery are the rise of the Canadian dollar, which is putting the B.C. "uni" (urchin roe) in a higher price bracket, and weakness in the Japanese economy, which is reducing the consumption of mid-range luxury goods (Krause 2008).

1.3.3 Green Sea Urchin Fisheries in Other Areas

Although there were very small amounts of green sea urchins harvested decades ago in Alaska, with a peak of 87 t harvested in 1988, there is currently no green sea urchin commercial fishery in Alaska. Due to logistical difficulties with the market in terms of quality and survival during shipment, and low abundance of commercially desirable urchins in this region, it never became a developed fishery (Sagalkin (2008); Kyle Hebert, Alaska Department of Fish and Game (ADFG), Juneau, Alaska, pers. comm. Feb. 11, 2010, and Sagalkin, ADFG, Kodiak, Alaska, pers. comm. Mar. 10, 2010).

In Washington State, the green urchin commercial fishery occurs in all inner waters (excluding the Neah Bay area), but mainly in the San Juan Island area. The "…non-Indian sea urchin quota shares…" for 2009-10 were set at 113.4 t (WDFW 2010).

Green sea urchins (*S. droebachiensis*) are an important fishery in Atlantic Canada. Fig. 3 provides an overview of landings since 1999. Landings in New Brunswick (875 t in 2007) and Newfoundland (157 t in 2007) have been declining recently (see also DFO 2008a), whereas landings in Nova Scotia (410 t in 2007) and Quebec (761 t in 2007) have been increasing. Quebec in particular has seen landings increase dramatically in recent years, as new beds were discovered at the mouth of the Saguenay River (DFO 2008b). This compares with harvests of less than 100 t in B.C. in 2008-09.

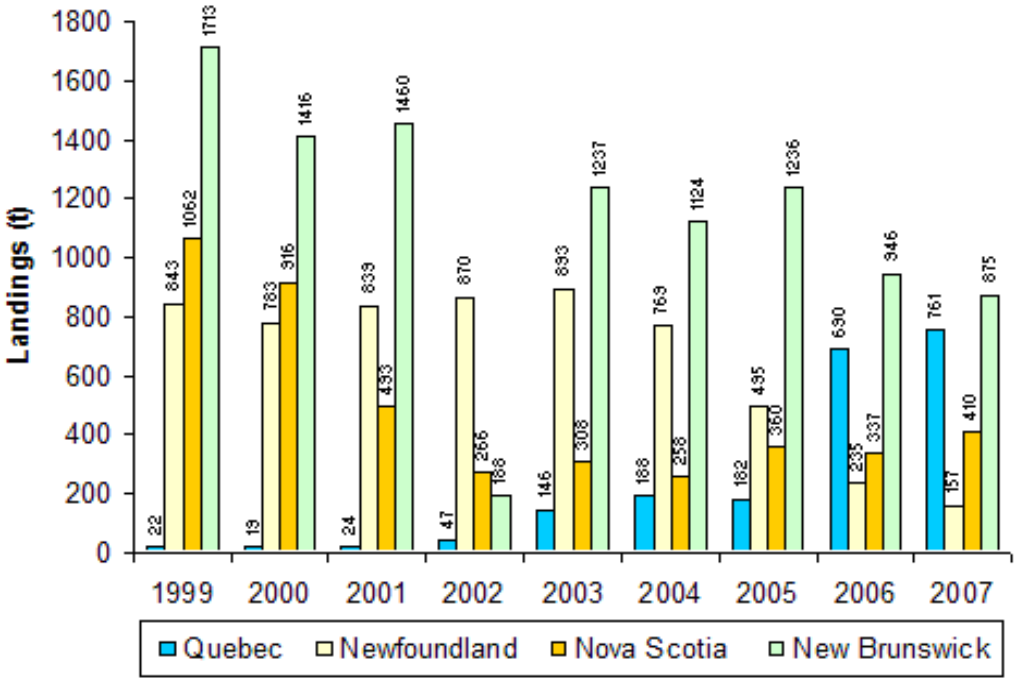

Figure 3. Green sea urchin landings in Atlantic Canada and Québec, 1999-2007 (from DFO, 2009).

The green sea urchin fishery in Maine (by diving and dragging) is still operating but at low levels compared to the boom years of the mid-1990's. Reported urchin landings have dropped from a peak of 41.6 million lbs (18,900 t) in 1993 to less than 2.2 million lbs (998 t) in 2007 (Clark 2008). However, this lower catch was still valued at US$3.2 million (Ganong 2009), which is higher than the annual harvest value of B.C. green urchins. Stocks have plummeted in Maine, and despite efforts to curtail the season and reduce the number of harvesters, the urchin population remains stagnant, neither increasing nor decreasing (Ganong 2009).

2.0 METHODS

For complete details and rationale for procedures used, please refer to previous assessments (Perry et al. (1998, 2001, 2003, 2006), and Perry and Waddell (1998, 1999)), and overview and methodological papers in the primary literature (Perry et al. 2002, and Zhang and Perry 2005).

2.1 COMMERCIAL DATA ANALYSIS

As a condition of licence, the harvesters must submit commercial logbooks at each landing, through the green sea urchin Validation Program. An observer from the Service Bureau, contracted by the West Coast Green Urchin Association (WCGUA), validates the weight and records it on a Validation and Harvest Logbook, and provides it to the Shellfish Data Unit at the Pacific Biological Station. This system has proven to be invaluable in obtaining high quality catch information since 1995.

Commercial landing and effort data from the harvesters' Validation and Harvest Logbooks were used to calculate catch per unit of effort (CPUE) for each fishing season, for each of the two main areas where green sea urchins are harvested in British Columbia: Northeast Vancouver Island (NEVI; PFMAs 12 and 13) and Southeast Vancouver Island (SEVI; PFMAs 18 and 19). This information was used to run the Bayesian Biomass Dynamic Model. Logbook data collected prior to the Validation Program (before 1995) have greater uncertainties. In these cases, if harvesters entered a zero value for dive time or total landings, these entries were excluded from the calculation of CPUE.

Note that median CPUE's were used in the Bayesian analysis, not mean CPUE's (as discussed in Perry and Waddell 1998), and the standard error of the median CPUE was calculated as 1.2533 * standard error of the mean CPUE (Sokal and Rohlf 1981).

2.2 FISHERY-INDEPENDENT SURVEYS

In order to obtain fishery-independent data, green sea urchin surveys were undertaken jointly between DFO and industry (WCGUA), beginning in October, 1995 (Waddell *et al.* 1997, 2002, 2003; Waddell and Perry 2005, 2006, 2007, in prep.(a)). A survey protocol was developed to study interannual variability in green sea urchin populations, and the impacts of commercial fishing on the green sea urchin populations. The first and longest series of surveys has been conducted in PFMA 12 (NEVI region), in eastern Queen Charlotte Strait, specifically the Stephenson Islets, Stubbs Island, and the NW sector of the Plumper Islands Group (Fig. 4). The Stephenson Islets were identified by the fishing industry as a key, first-choice location for commercially harvesting of green urchins, while scientific research closures were established for the other two nearby sites (controls). For the first three years, the surveys in PFMA 12 were conducted twice a year, just prior to the opening and immediately following the closing of the commercial green sea urchin fishing season. Then these surveys were continued annually (prior to commercial opening only), and more recently are conducted every two years at this location. Another series of joint DFO-industry surveys were initiated in PFMA 19 (SEVI region), at Fulford Reef and in the Chain Islets in March, 2008, and have been conducted semi-annually thereafter (Fig. 5; Waddell and Perry in prep.(b)).

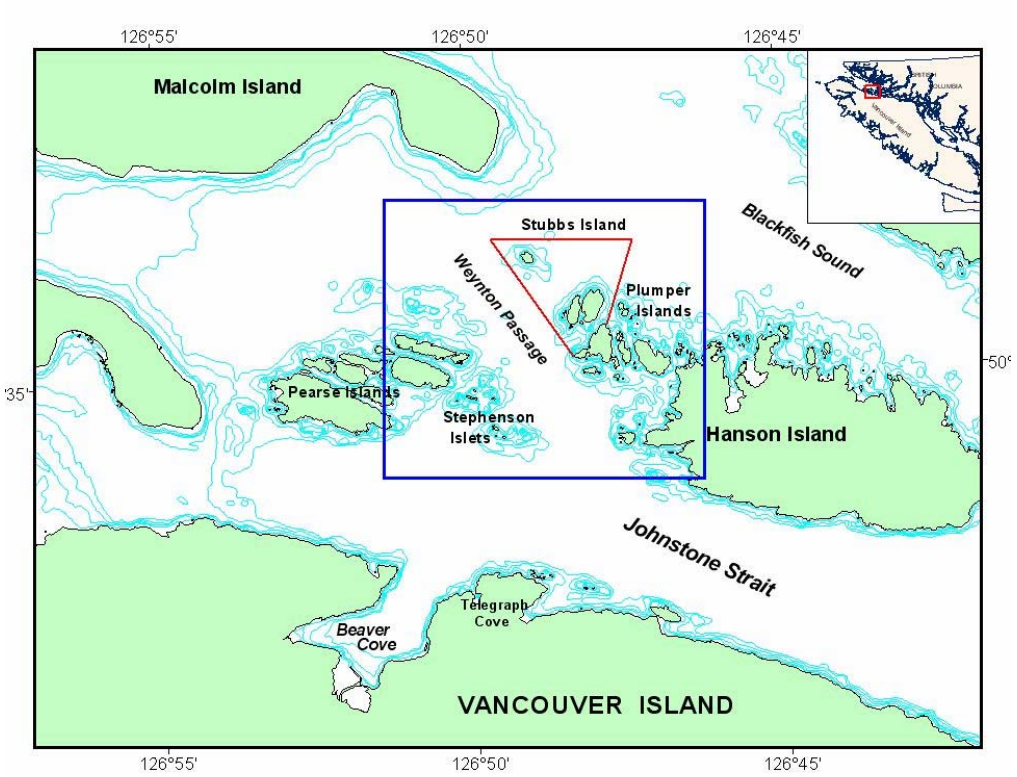

Figure 4. Site locations of the PFMA 12 green urchin surveys (Stephenson Islets, Stubbs Island and the Plumper Islands). The red border represents the boundaries of the research closure area. No commercial fishing may occur within these boundaries.

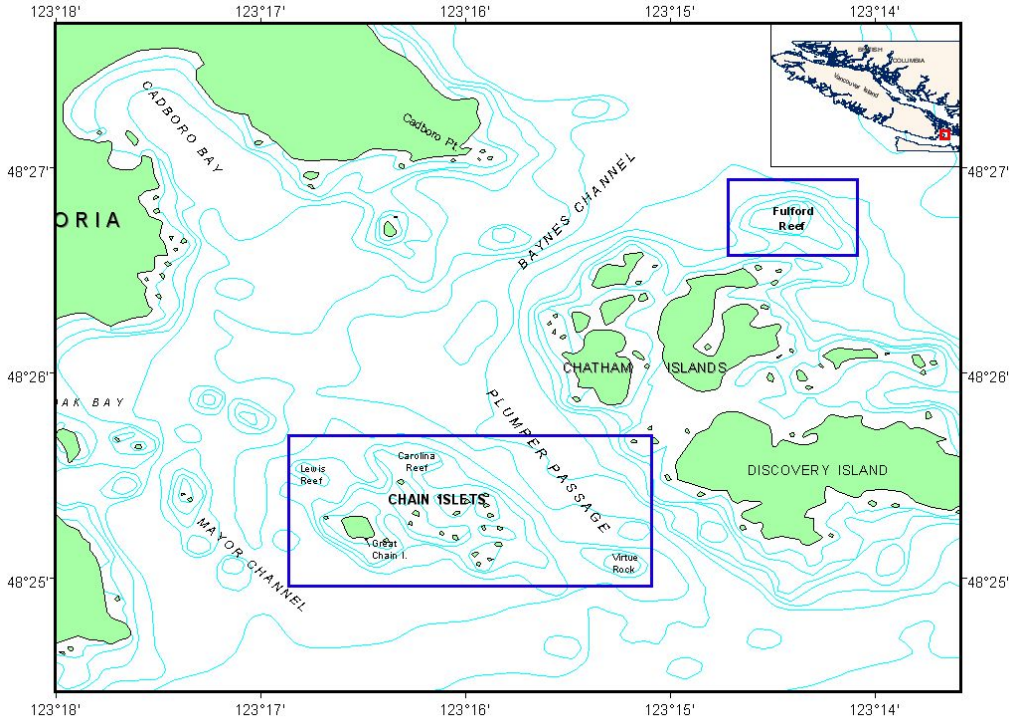

Figure 5. Site locations of the PFMA 19 green urchin surveys (Fulford Reef and the Chain Islets).

2.2.1 Field Methodology

Every survey was conducted by SCUBA divers, using the transect-quadrat method. The transect positions were randomly selected during the first survey and marked on a chart prior to arriving at the survey area (Waddell *et al*. 1997, 2002). The transects ran perpendicular to the shoreline and/or depth, starting at 10.0 m (32.8 ft) below Chart Datum (CD) and continuing up to zero CD. A weighted (lead) line was laid from shallow to deep to mark the transect, with a surface marker buoy indicating the deep end of the line. Starting at the deep end, the divers placed a 1 m^2 aluminum quadrat on the substrate beside the lead line and measured the test diameter (TD) (using calipers) of all green sea urchins within the quadrat. The depth, substrate and type of vegetation were also recorded for each quadrat, and then the quadrat frame was rolled over in the direction of the lead line (or the compass bearing when lead line could not be used), and the procedure was repeated along the full length of the transect. In addition, three green sea urchins of each of three size classes (small, medium and large) were randomly collected along the transect lines during the surveys for later laboratory analyses of size and weight and dissected to obtain roe quality information. The results of these surveys were also incorporated in the model for the Bayesian analysis.

For more details of the dive survey procedures, refer to Waddell et al. (1997, 2002, 2003) and Waddell and Perry (2005, 2006, 2007, in prep. (a) and (b)).

2.2.2 Survey Data Analyses

The green sea urchin survey data were separated into 3 size classes: legal-sized (≥55 mm TD); sublegal-mature (25 mm ≤ TD < 55 mm); and sublegal-immature (<25 mm) urchins. Green urchin TD– weight relationships were calculated using regression analysis, using lab measurements taken of urchins collected from the surveys. These TD-weight relationships were applied to every TD measured in the field to determine individual urchin weights. Further, the mean individual urchin weight ($\overline{W}_j$) was calculated for each size class (j). The standard error about the mean weight for each size class (SE($\overline{W}_j$)) was determined by calculating the standard deviation of the mean weight and dividing by the square root of the sample size.

Mean densities of green urchins were calculated as described by Jamieson and Schwarz (1998). The appropriate calculation for the mean density (of a particular size class of urchins) is:

(1) $$\overline{D} = \frac{\sum_{i=1}^{n} U_i}{\sum_{i=1}^{n} L_i}$$

and the standard error of density is:

(2) $$SE(\overline{D}) = \sqrt{\frac{1}{\overline{L}^2}\frac{1}{n}\frac{\sum (U_i - L_i\overline{D})^2}{n-1}}$$

with n = the number of transects sampled in a particular site;

U_i = the total number of urchins of the appropriate size class in transect i, $i = 1,2,...,n$;

L_i = the total number of quadrats in transect i; and

$\overline{L}$ = $\frac{1}{n}\sum_{i=1}^{n} L_i$, the average area of the transects in the site.

Since the area of a quadrat was 1 m^2, L_i is also equal to the area of the transect.

The total number (or abundance) of green urchins was calculated by multiplying the mean density ($\overline{D}$) for each size category, in each location, by the total area (A) of the location (from 0 to 10 m below Chart Datum). Although green sea urchins are commonly observed well below this depth range, the majority of the urchins are located in this depth range, and the abundances are considered minimal values.

The total biomass for a particular site was then calculated as

(3) $$B = \sum_{j=1}^{3} \overline{D}_j (\overline{W}_j)(A)$$

where j subscripts the three size classes.

The standard error of the total biomass for a particular site, which includes the uncertainties in the mean density and mean weight by size category, was calculated as:

(4) $$SE(B) = \left[\sum_{j=1}^{3} \left[\left(\left(\frac{SE(D)_j}{\overline{D}_j} \right)^2 + \left(\frac{SE(W)_j}{\overline{W}_j} \right)^2 \right)^{\frac{1}{2}} (B_j) \right]^2 \right]^{\frac{1}{2}},$$

with symbols as previously defined, and assuming that the area (A) (used within the calculation for B_j) is known without error. A further assumption is that the errors in mean density and mean weight, and among size classes, are independent and random.

2.3 BAYESIAN ANALYSES

The Bayesian model, which is described in Perry et al. (2003) and Zhang and Perry (2005), is now implemented in WinBUGS, an interactive Windows software program for Bayesian analysis of complex statistical models (Spiegelhalter et al. 2003). The data used for the analysis include the median catch per unit of effort (CPUE: kilograms per diver hour) for each season of the commercial fishery from 1987-88 to 2008-09 (including standard errors), and the biomass estimates and standard errors of legal-sized and sublegal-sized green urchins from twelve fall surveys at the index site in PFMA 12 (Stephenson Islets, Stubbs Island and Plumper Islands). The risks associated with various quota options were calculated in the statistical package R. As in the last assessment, the model was run separately for the Northeast Vancouver Island (NEVI) region and Southeast Vancouver Island (SEVI) region.

2.3.1 Biomass Dynamic Model

The expected biomass in year *y*, $\hat{B}_y$, is related to the biomass, B_{y-1}, and the commercial catch, C_{y-1}, in the previous year:

$$\hat{B}_y = B_{y-1} + r \times B_{y-1}\left(1 - \frac{B_{y-1}}{K}\right) - C_{y-1}$$

where *r* is an intrinsic rate of population growth, and *K* is the average maximum biomass the system can support (carrying capacity). Re-parameterization was carried out for B_y in order to increase the Markov chain mixing speed and to reduce parameter correlations (Miller and Meyer, 2000):

$$P_y = B_y / K$$

where P_y represents the ratio of the biomass in year *y* to the carrying capacity. The biomass dynamic model becomes:

$$\begin{cases} \hat{P}_y = 1 & (if \quad y = 1) \\ \hat{P}_y = P_{y-1} + r \times P_{y-1} \times (1 - P_{y-1}) - \dfrac{C_y}{K} & (if \quad y > 1) \end{cases}$$

where $\hat{P}_y$ represents the expected ratio of the biomass in year *y* to the carrying capacity. The expected catch per unit effort in year *y*, $\hat{U}_y$, is assumed to be proportional to the biomass in year *y*:

$$\hat{U}_y = q \times K \times P_y$$

where *q* is known as the catchability coefficient.

We use the state-space modeling approach, which allows us to incorporate both the observation and process errors into the model fitting. Both errors are assumed to follow the log-normal distribution:

$$U_y \sim LN\left(\log(\hat{U}), \sigma_u^2\right)$$

$$P_y \sim LN\left(\log(\hat{P}), \sigma_P^2\right)$$

where U_y is the CPUE for year *y* based on the catch data, and σ_U^2 and σ_P^2 are the corresponding variances on the log scale.

2.3.2 Incorporation of Uncertainties About Catch Data in the Early Years

There are 22 years of commercial catch and effort data (1987-2008). In the model, the years are sequentially referred as year 1 for 1987 and year 22 for 2008.

Catch and effort data from the early years of the fishery (years 1-9; 1987 – 1995) are very uncertain, because of the boom nature of the fishery, variable recording diligence, and different strategies of fishing. Uncertainties about the catch information in the early years are modeled and incorporated into the biomass dynamic model. The catch in each of the early years is modeled using a normal distribution:

$$C_y \sim N\left(\hat{C}_y, \sigma_{c,y}^2\right)$$

where C_y and $\hat{C}_y$ are the actual and reported catches in year *y*, respectively, and $\sigma_{c,y}^2$ is the variance of the normal distribution. We assume a coefficient of variation of 30% for the uncertainty about the catch ($\sigma_{c,y} = 30\%\hat{C}_y$).

Similarly, the true CPUE in each of the early years is modeled using a normal distribution:

$$U_y \sim N\left(\hat{U}_y, \sigma_{u,y}^2\right)$$

where U_y and $\hat{U}_y$ are the actual and estimated CPUE in year *y*, respectively, and $\sigma_{u,y}^2$ is the variance of the normal distribution. We assume a coefficient of variation of 50% for the uncertainty about CPUE ($\sigma_{u,y} = 50\%\hat{U}_y$).

In later years (years 10-22; 1996-2008) the reported catches and estimated CPUEs are assumed to represent the true catches and CPUEs, because of careful monitoring and dockside validation. Therefore, for these later years, $C_y = \hat{C}_y$ and $U_y = \hat{U}_y$.

2.3.3 Incorporation of Fisheries Independent Survey Data

Surveys were conducted in the Stephenson Islets, Stubbs Island, and the Plumper Islands in the fall of years 10-18, 20, and 22. The estimated abundance of green sea urchins in the surveyed area (Stephenson Islets, Stubbs Island, and Plumper Islands), serves as another index for the abundance of green sea urchin in the entire region. The actual biomass in the surveyed area is modeled by a normal distribution:

$$\hat{S}_y \sim N\left(S_y, \sigma_{s,y}^2\right)$$

where $\hat{S}_y$ and S_y are the survey derived and actual biomass for the surveyed area in year *y*, respectively, and $\sigma_{s,y}^2$ is the variance estimated based on the survey data in year *y*. We incorporate survey information into the biomass dynamics model by associating

the biomass in the surveyed area with the biomass in the entire region in a direct proportional manner:

$$S_y = \rho \times B_y$$

where B_y is the biomass for the entire region in year *y*, and ρ is an unknown proportional coefficient.

Surveys were also conducted in Southeast Vancouver Island, but the time series is short (< 3 years) for any given location. Thus, survey data were not used in the modeling of green urchin populations in Southeast Vancouver Island.

2.3.4 Prior Probability Distributions

Either vague informative or uninformative priors were applied to the model parameters. Based on preliminary information (Zhang and Perry, 2005), K, σ_U^2 and σ_P^2 were assigned vague priors, and the other parameters were assigned uninformative priors. For the stock in Northeast Vancouver Island, K has a lognormal distribution, $K \sim LN(7.56, 0.73^2)$, with a median of 1928 tons and a 75th percentile of 3158 tons. The inverses of σ_U^2 and σ_P^2 are assigned gamma distributions: $1/\sigma_U^2 \sim gamma(1.0, 0.0144)$ and $1/\sigma_P^2 \sim gamma(1.0, 0.0729)$, so that the means are 0.12 for σ_U and 0.27 for σ_P. The two gamma distributions both have a coefficient of variation of 100%. For the stock in the Southeast Vancouver Island, $K \sim LN(6.53, 1.17^2)$, with a median of 685 tons and a 75th percentile of 1508 tons. The inverses of σ_U^2 and σ_P^2 are assigned gamma distributions: $1/\sigma_U^2 \sim gamma(1.0, 0.0169)$ and $1/\sigma_P^2 \sim gamma(1.0, 0.0784)$, so that the means are 0.13 for σ_U and 0.28 for σ_P. The two gamma distributions both have a coefficient of variation of 100%. The prior distributions for the remaining parameters were taken to be uninformative. The catchability coefficient, *q*, has a uniform distribution on the log-scale. In practice, the inverse of *q* was assigned a gamma distribution: $iq \sim gamma(0.005, 0.001)$, $q = 1/(3000 \times iq)$. The intrinsic population growth rate, r, has a normal distribution with a very large variance: $r \sim norm(0.5, 100^2)$, and ρ has a beta distribution, $\rho \sim beta(1, 1)$, namely the probability between 0 and 1 is equally likely.

2.3.5 Model Execution

The WinBUGS software program (Spiegelhalter et al. 2003) was used for the Bayesian analyses. After likelihood distributions and priors are specified, WinBUGS automates the calculations, for each of the model parameters, of the full conditional posterior distribution or of the joint posterior probability distribution. In the former case, samples are taken from each of the full conditional posterior distributions for the corresponding model parameter, using the Gibbs sampler, a Markov Chain Monte Carlo (MCMC) method. In the latter case, samples for the model parameters are taken from the joint posterior probability distribution, using the Metropolis–Hastings algorithm, another MCMC method. The samples are then used to represent the posterior

probability distribution for the parameter value. Each model parameter is, therefore, cohesively estimated based on all the information provided on data, likelihood functions, model structures, and priors.

It requires several samples, partly depending on the initial values, before the posterior probability distribution is reached. This period is known as the burn-in period. In this study, the first 100,000 samples are treated as a burn-in period, and are therefore discarded. To reduce autocorrelation, every 10th sample from the posterior distribution was selected after the burn-in period. Altogether, 10,000 samples were saved. Two chains were used with different initial values for the convergence test by the Gelman-Rubin diagnostics (Gelman and Rubin, 1992). Evidence of convergence was warranted by this test, as the two independent chains virtually overlapped with each other after the burn-in period.

3.0 RESULTS AND DISCUSSION

3.1 THE FISHERY

This analysis updates information from the green sea urchin fishery and fishery-independent surveys in the 2005-06 to 2008-09 fishing seasons. It should be noted that PFMA 11 and 20 have been closed since the 2006-07 fishing season. As a result, the calculations performed in this assessment include only PFMAs 12, 13, 18 and 19. Landings from PFMA 11 represented less than 1% of the total landings from NEVI from 1987-88 to 2008-09, and landings from PFMA 20 represented less than 10% of the total landings from SEVI during the same time period. Since 2007-08, the fishery opened as early as September in some PFMAs, as compared to November in the earlier years of the fishery.

Landings since the 1994 fishing season have been limited by quotas. From the 2004-05 fishing season and onward, the total landings, the total effort, and the total landed value of green sea urchins have all been among their lowest levels since the inception of the fishery (Fig. 6a-b, Table 2). The 2006-2007 fishing season represented the lowest point for all of these parameters, when the total landed value was Cdn$0.073 million. This has all been due to the market conditions in Japan, and is not indicative of low stock abundance in B.C (see later section on Additional Stakeholder Perspectives). However, there has been some improvement in the B.C. fishery since the 2006-07 fishing season, and the overall CPUE has increased each year since 2004-05 to reach its highest value in 2008-09 (Fig. 6a).

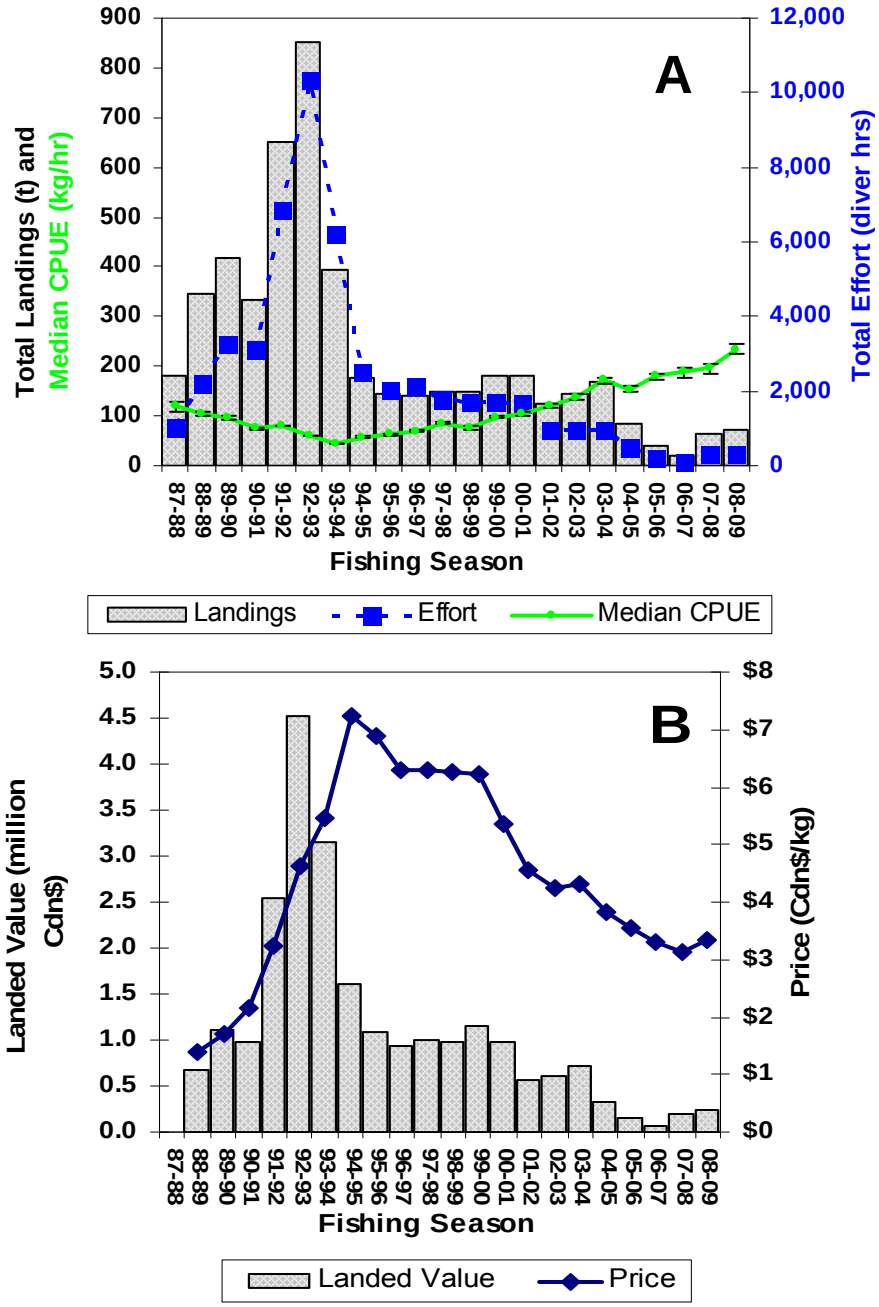

Figure 6. a) Landings (from sales slip data up to 1995, then from harvest and validation logs), effort, and catch per unit of effort (CPUE) for PFMAs 12, 13, 18, and 19 (combined); and (b) landed value and unit price for the green sea urchin fishery in B.C.(for all open PFMAs combined). Data are presented on the basis of a fishing season (Fall of year i to Spring of year i+1).

Table 2. Green sea urchin landings (tonnes) and effort for British Columbia by fishing season (Fall to Spring), 1986-87 to 2008-09, as reported on sales slips, harvest logbooks, and validation logs for all open PFMAs combined.

Season	Number of Active Licences[6]	Vessels with Landings	Fishing Days[2]	Total Landings (t)	Total Allowable Catch (t)	Total Landed Value (million $)[4]	Average Landed Value ($/t)[1]	Total Diver Hours[2]	Total Number of Divers[2]
1986/87[2]		2	4	2	-			14[5]	1[+]
1987/88[2]		29	290	207	-			1,216[5]	48[+]
1988/89[1]		77	688*	480	-	0.669	1395	2,418[5]	118[++]
1989/90[1]		115	1,095*	642	-	1.104	1719	3,691[5]	169[++]
1990/91[1]		71	923*	455	-	0.981	2155	3,310[5]	106[+]
1991/92[1]		49	1,510*	783	-	2.534	3235	7,523[5]	152[+]
1992/93[1]		56	1,987*	978	-	4.530	4632	11,835[5]	199[++]
1993/94[1]		53	1,267*	577	-	3.145	5453	7,667[5]	183[++]
1994/95[1]		43		223	Year 1994[7]	1.614	7251		
1994/95[2]		42	673*	221	449.0	1.604		3,161[5]	101[++]
1995/96[2]	46[1]	39	500	157	173.4	1.085	6896	2,201[5]	85[++]
1996/97[3]	48[1]	32	458	150	163.0	0.942	6289	2,300[5]	72[+]
1997/98[3]	49[1]	27	423	160	166.1	1.004	6283	1,958	59
1998/99[3]	49[1]	26	376	156	166.1	0.982	6269	1,861[5]	60[+]
1999/00[3]	49[1]	27	357	187	188.0	1.160	6215	1,810	65
2000/01[3]	48[1]	28	315	181	188.0	0.973	5366	1,701	56
2001/02[3]	39	15	185	123	179.0	0.557	4545	977	32
2002/03[3]	42	17	206	144	179.0	0.611	4247	973	30
2003/04[3]	46	17	213	168	186.0	0.725	4310	985	34
2004/05[3]	30	16	113	83	186.0	0.316	3828	506	24
2005/06[3]	14	12	62	42	186.0	0.151	3550	232	22
2006/07[3]	6	8	28	22	202.8	0.073	3315	116	13
2007/08[3]	19	7	70	65	202.8	0.203	3146	323	18
2008/09[3]	22	12		73	202.8	0.245	3339	308	18

Footnotes:

* incomplete data (missing landing or effort data in the harvest logbooks).

[1] from sales slip data

[2] from harvest logbooks

[3] from combined harvest/validation logbooks

[4] Landed values for harvest log data calculated as the average landed value ($/t) from sales slip data, multiplied by total landings (t) from harvest logbook data. Landed values for sales slip data calculated as the summation of landed weight multiplied by the unit price for every landing.

[5] incomplete records of fishing hours (effort)

[6] from D&D Year-End Reports

[7] South Coast quota only. There was no quota set for the North Coast until 1995/96 (90.72 t), but landings were minimall (4.3 t). There have been no significant landings in the North Coast since then.

[+] possibly one or two more (due to sales slips with no CFV #, or missing diver codes)

[++] probably several more (due to missing diver codes)

The median catch per unit of effort declined each fishing season from the start of the fishery until 1992-93 in the SEVI region (PFMA 18 and 19) and until 1993-94 in the NEVI region (PFMA 12 and 13)(Fig.7). Since then the median CPUE has increased, so that by 2008-09 it reached the highest values over the history of the fishery in both regions (Fig. 7). The standard errors about the medians are small, but have become wider since 2002. Trajectories of median CPUE versus effort indicate that the median CPUE's had

returned to the high levels seen during the early days of the fishery for the NEVI (PFMA 12 and 13; Fig. 8a) region by approximately 2003-04, and for the SEVI (PFMA 18 and 19; Fig. 8b) region by approximately 2000-01.

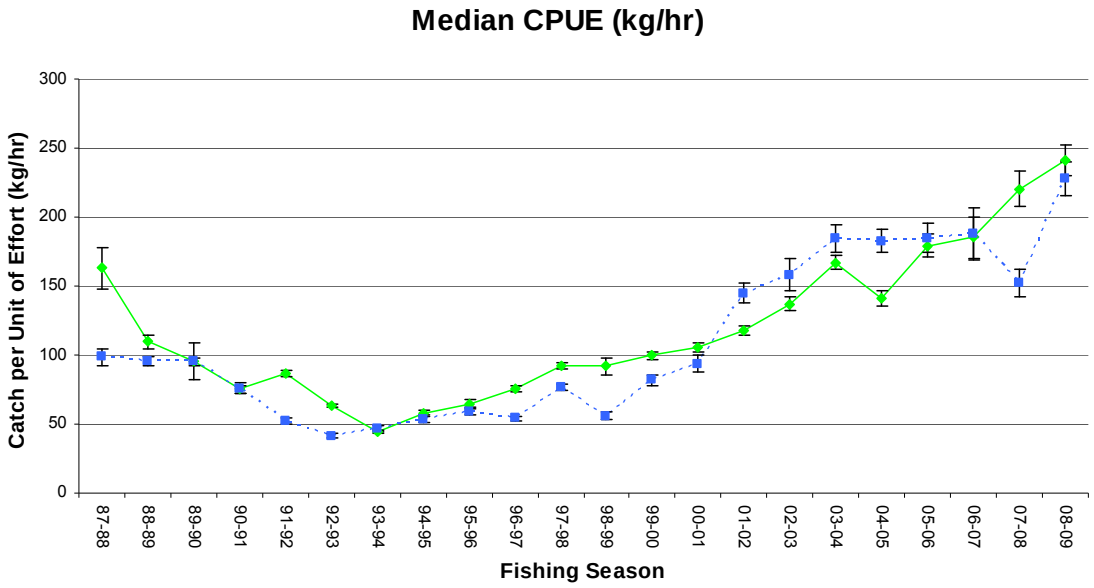

Figure 7. Median catch per unit of effort ± 1 standard error (kg/diver hour) on a fishing season basis for the green urchin fishery in B.C.. Solid line: Northeast Vancouver Island region (PFMA 12 and 13); dashed line: Southeast Vancouver Island region (PFMA 18 and 19).

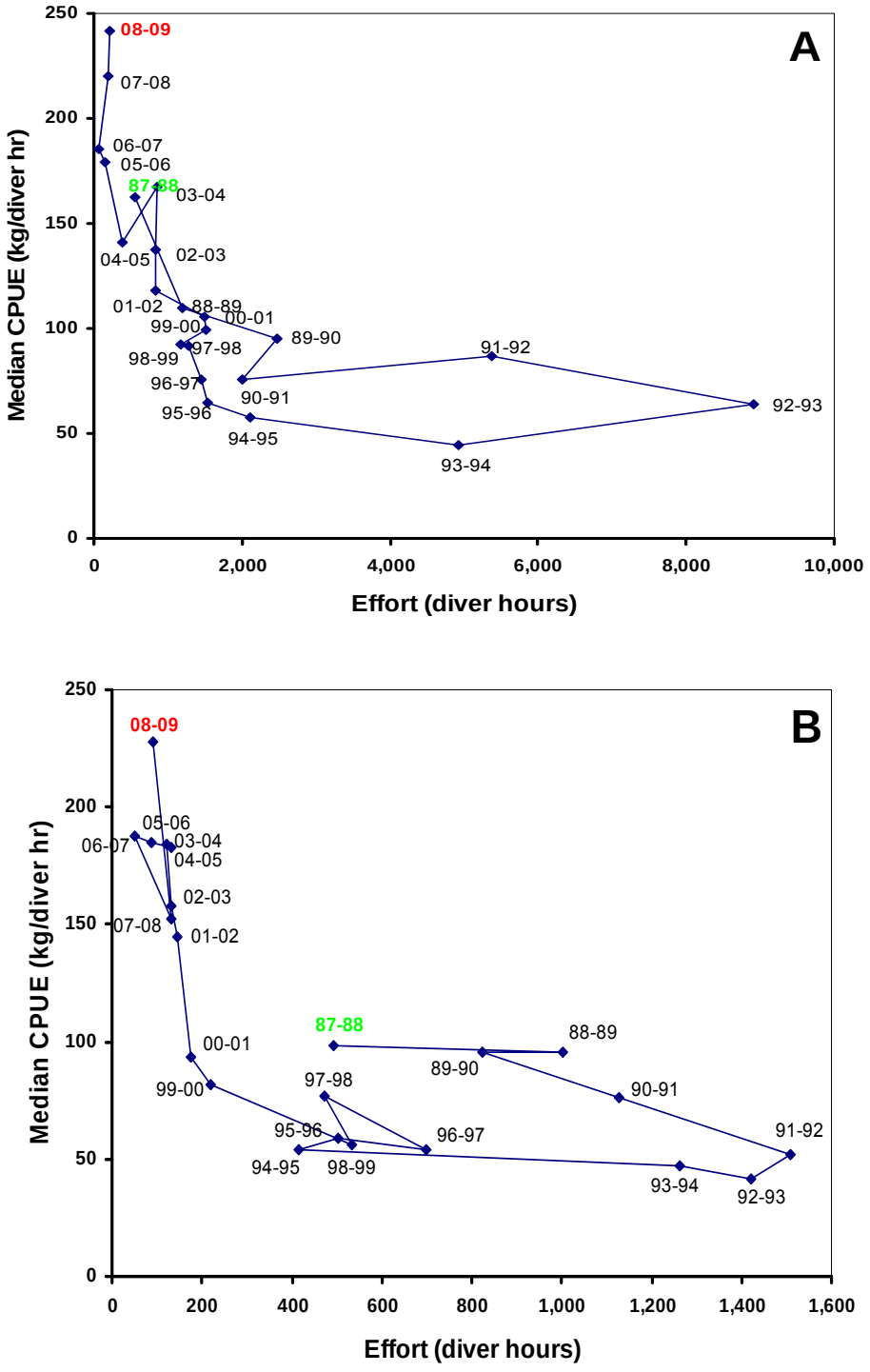

Figure 8. Trajectories of median catch per unit of effort versus effort for (a) Northeast Vancouver Island (PFMA 12 and 13) and (b) Southeast Vancouver Island (PFMA 18 and 19) regions. Fishing seasons are indicated.

3.2 FISHERY-INDEPENDENT SURVEYS

3.2.1 PFMA 12

Beginning in October, 1995, twelve fall (Oct./Nov.) surveys have been conducted at an index site at Stephenson Islets (PFMA 12, in the NEVI region), just prior to the opening of the green urchin fishing season. Densities of legal-sized urchins have increased so that by October 2008 they were at their highest levels observed, and densities of sublegal-sized urchins have remained high (Table 3). The biomass estimates for both legal (≥55 mm TD) and sublegal-sized (<55 mm TD) urchins at the Stephenson Islets have also increased to their highest levels observed in October 2008 (Fig. 9). This represents a 252% increase in biomass for legal-sized urchins and a 136% increase for sublegal-sized urchins since November, 2004. Reports on the recent surveys in PFMA 12 have been published by Waddell and Perry (2006, 2007, in prep.(a)).

Table 3. Mean densities (number of urchins/meter squared) and standard errors of legal-sized (≥55 mm test diameter), sublegal-sized (<55 mm test diameter) and all sizes combined (total) at Stephenson Islets (PFMA 12) during three most recent surveys.

Date of Survey	Legal-sized Density	Sublegal-sized Density	Total Density
November 2004	1.92 ± 0.26	7.76 ± 1.71	9.68 ± 1.77
October 2006	2.57 ± 0.67	6.38 ± 1.02	8.95 ± 1.37
October 2008	4.29 ± 0.58	7.49 ± 1.86	11.77 ± 1.87

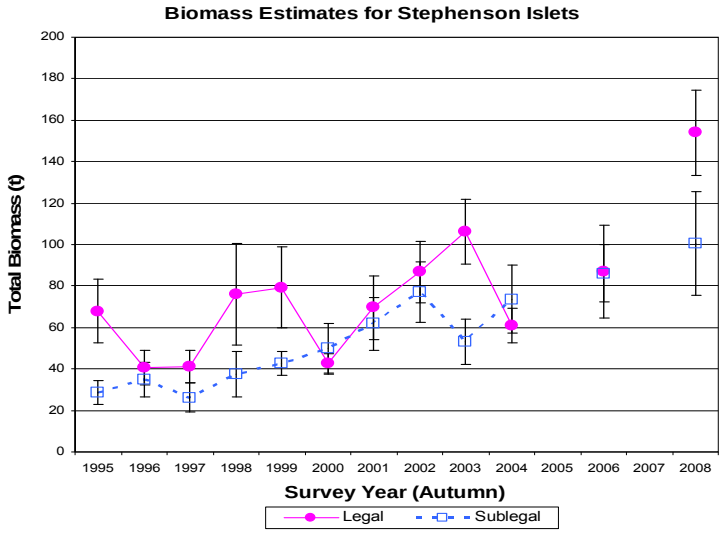

Figure 9. Biomass estimated from fishery-independent surveys conducted annually (1995 to 2004) and biennially (2006-2008) in the autumn (October or November) at Stephenson Islets off Northeast Vancouver Island (PFMA 12). Solid line: legal-sized biomass (≥55 mm test diameter); dashed line: sublegal-sized biomass. Error bars represent standard errors about the mean.

3.2.2 PFMA 19

Fishery-independent surveys were conducted at Fulford Reef (PFMA 19, in the SEVI region) in March 2008 and 2009, and in August 2009. The nearby Chain Islets were also surveyed at the same times, except inclement weather prevented surveying them

during the March 2009 survey. Results showed that the density of legal-sized urchins at Fulford Reef decreased between March 2008 and March 2009, and stayed unchanged between March 2009 and August 2009 (Table 4). Meanwhile, there was no significant change in the density of legal-sized green urchins at the Chain Islets from March 2008 to August 2009 (although not surveyed in March 2009; Table 4). Figure 10 shows that the estimated biomass of legal-sized urchins at Fulford Reef decreased between March 2008 and March 2009 by more than half, and was approximately equivalent to the commercial quota taken from PFMA 19 during that time period (Table 4, Fig. 10). This figure also demonstrates that the biomass estimate for legal-sized urchins did not change significantly between March 2009 and August 2009, when the commercial fishery was closed. Figure 11 shows that there was a much higher frequency of legal-sized urchins at Fulford Reef in March 2008 than in August 2009. A report is in preparation for these survey results following the next scheduled survey in March 2010 (Waddell and Perry, in prep.(b)).

Table 4. Mean densities (number of urchins/meter squared) and standard errors of legal-sized (≥55 mm test diameter), sublegal-sized (<55 mm test diameter) and all sizes combined (total) in PFMA 19 at Fulford Reef (FR) and the Chain Islets (CI) during three recent surveys.

Date of Survey	Location	Legal-sized Density	Sublegal-sized Density	Total Density
March 2008	**FR**	**1.91 ± 0.68**	**0.66 ± 0.16**	**2.58 ± 0.77**
	CI	3.78 ± 1.37	1.17 ± 0.41	4.95 ± 1.67
March 2009	**FR**	**0.90 ± 0.29**	**0.49 ± 0.11**	**1.39 ± 0.39**
	-	-	-	-
August 2009	**FR**	**0.90 ± 0.31**	**0.72 ± 0.20**	**1.63 ± 0.48**
	CI	3.62 ± 0.41	1.17 ± 0.74	4.78 ± 1.00

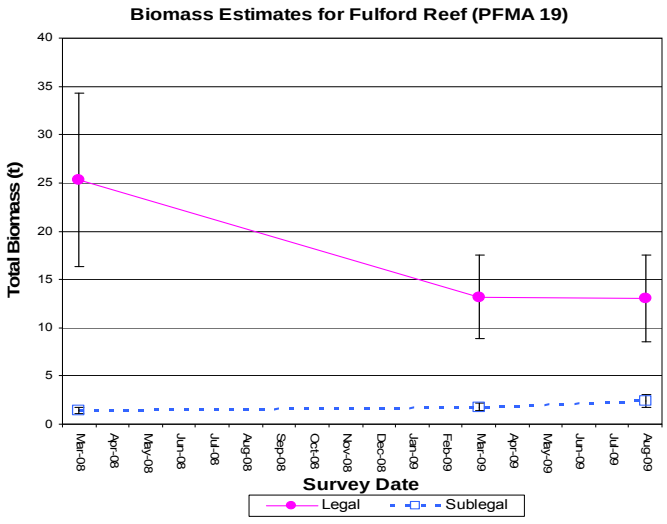

Figure 10. Biomass estimated from fishery-independent surveys conducted at Fulford Reef in Southeast Vancouver Island (PFMA 19), a heavily, commercially fished location. Solid line: legal-sized biomass (≥55 mm test diameter); dashed line: sublegal-sized (<55 mm test diameter) biomass. Error bars represent standard errors about the mean.

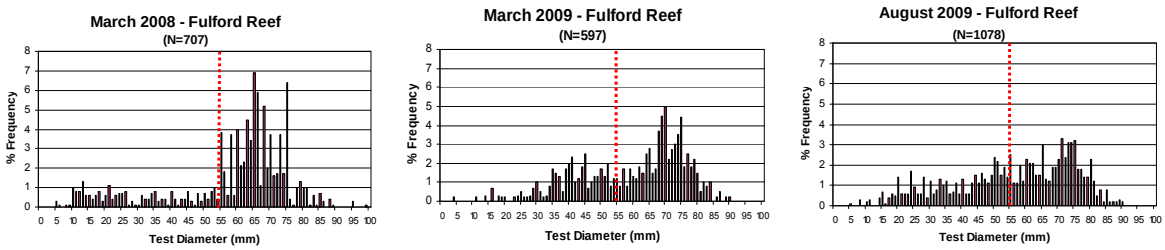

Figure 11. Size frequency distribution of green sea urchins at Fulford Reef, PFMA 19, in March 2008 (left), March 2009 (center) and in August 2009 (right). Note the legal size limit (red dotted line) is 55 mm.

Regular surveys at index sites are extremely useful to provide fishery-independent assessments of trends in green urchin abundance, and should be carried out in all PFMAs open to fishing green sea urchins. Fishery-independent surveys are the only method to obtain information about the sublegal-sized portion of the population. In addition, the data obtained from surveys are used to calculate density and biomass for both legal and sublegal-sized urchins. Information about green sea urchin habitat (density variations with depth, substrate type, and vegetation), and as well as roe quality information are also obtained from surveys. Surveys should continue every second autumn at the Stephenson Islets in PFMA, as this is the longest running series of surveys. A survey will be performed at Fulford Reef in PFMA 19 in March 2010 to determine the impact of fishing on the reef.

Surveys should also be conducted in PFMA 13 and 18. In the past, attempts to establish an index site at Boiling Reef, off Saturna Island in PFMA 18 have been difficult due to the particular oceanographic conditions of this location. There is a large population of green sea urchins in this location, but the reef is very shallow and flat with a very gentle slope, meaning the transect lines are very long. Currents in this location are somewhat unpredictable, and do not always correlate with the Canadian Hydrographic Tables. The current is usually very strong and standing waves often occur in the shallow locations, making it difficult for divers to survey. An index site also needs to be established for PFMA 13, as there is no current fishery-independent information for this area. At present, there is not enough funding or resources to carry out surveys in all four open PFMAs for this small fishery.

3.3 BIOMASS DYNAMIC MODEL

In the previous assessment (Perry et al. 2006), three versions of the biomass dynamic model were used to estimate management reference points: the "Schnute" and "time series fitting" versions, and a "Bayesian" model. Based on the results, the Bayesian model was chosen as the preferred model, because of its consistency with the other two models, the larger (and therefore more conservative) “credible intervals”, and because of its superior and explicit handling of data and model uncertainties. Therefore, only results calculated from the Bayesian model are presented in this paper.

To evaluate the difference of including or excluding PFMAs 11 and 20, (for comparison with the previous assessment), the model was run twice for each of the regions: first for only the open PFMAs (12 and 13 for NEVI, and 18 and 19 for SEVI; Fig. 12a and 12b; Table 5a), and second including the newly closed PFMAs (11, 12 and 13 for NEVI, and 18, 19 and 20 for SEVI; Fig. 12c and 12d; Table 5b). The Bayesian model includes uncertainties in observations and model structure (see below regarding

Sources of Uncertainty). The 95% credible intervals overlap for analyses with and without PFMA 11 in the NEVI region, and with and without PFMA 20 in the SEVI region (Tables 5a and 5b), indicating no significant differences. For subsequent analyses, therefore, only the results for PFMAs 12-13 and 18-19 will be considered (these are also slightly more conservative compared with the results when PFMAs 11 and 20 are included).

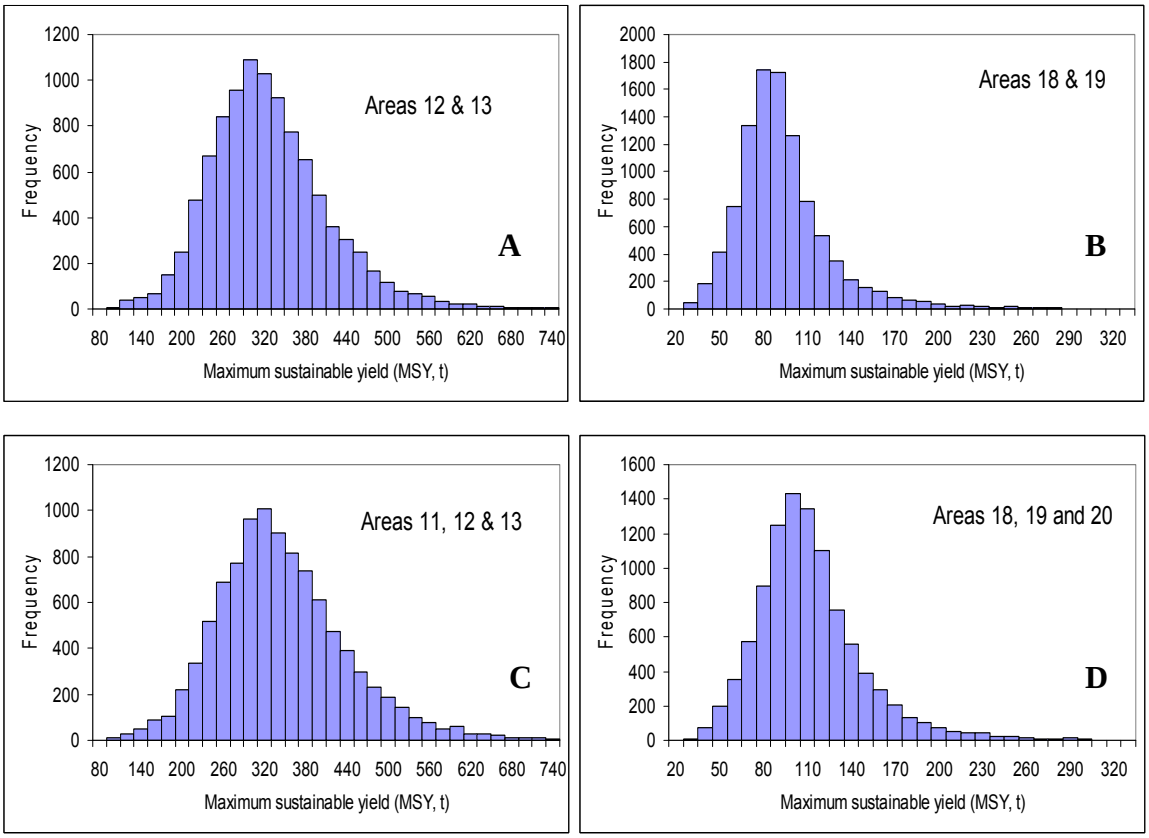

Figure 12. Probability distributions for maximum sustainable yield (MSY) estimated by the Bayesian method for open PFMAs in (a) the Northeast Vancouver Island region (PFMA 12-13) and (b) Southeast Vancouver Island (PFMA 18-19), and for historic PFMAs in (c) the Northeast Vancouver Island region (PFMAs 11–13) and in (d) Southeast Vancouver Island region (PFMAs 18-20). Probability distributions are based on 10,000 randomizations.

Table 5a. Summary of median maximum sustainable yield (median MSY) estimates and 2 standard deviations of the mean MSY (to approximate the 95% credible interval) from the Bayesian model for all currently open PFMAs.

Northeast Vancouver Island (PFMA 12, 13)		Southeast Vancouver Island (PFMA 18, 19)	
Median MSY (t)	2 Standard Deviations	Median MSY (t)	2 Standard Deviations
298	176	78	67

Table 5b. Summary of median maximum sustainable yield (median MSY) estimates and 2 standard deviations of the mean MSY (to approximate the 95% credible interval) from the Bayesian model for historic PFMAs.

Northeast Vancouver Island (PFMA 11, 12, 13)		Southeast Vancouver Island (PFMA 18, 19, 20)	
Median MSY (t)	2 Standard Deviations	Median MSY (t)	2 Standard Deviations
314	196	97	76

3.4 QUOTA OPTIONS

Traditionally, MSY values have been considered as targets which management actions should try to achieve. However, many of the assumptions of surplus production models, such as no change in gear efficiency, constant catchability (in time, space, and across ages), a linear relationship between CPUE and effort, and equal availability of the fish to the fishery may not be true in a fishery such as for green sea urchins. The present preferred approach (e.g. DFO 2006) is to define values such as MSY to be limit reference points which management actions should ensure are not exceeded. The target reference points, to which management actions should aim, should be set sufficiently far from the limit reference point so that there is a low probability that the target reference point is equal to or larger than the true limit reference point (MSY in this assessment).

The limit reference points for the NEVI (calculated for PFMA 12-13; Table 6a) and SEVI (calculated for PFMA 18-19; Table 6b) regions are represented by the medians of the posterior probability distributions of MSY's, as determined by the Bayesian model. Table 6 provides the MSY limit reference points for each region, and the target reference points that are equivalent to various reductions from the MSY values. For each of these target reference points, the probabilities that the target reference points may be equal to or larger than the true MSY are also provided, based on the Bayesian model results. For each target reference point, the allocations of quota

to each of the PFMAs are also provided based on the proportion that area contributed to aggregate landings from the 1995-96 to 2008-09 fishing seasons. This dependence on using the pattern of previous landings to set the current quotas carries a risk that some PFMAs may become more exploited than intended if the conditions that determine green urchin distributions and abundance change among areas over time. Fishery-independent surveys are being used to guard against this possibility. Quotas assigned during previous years have had a very low probability (low risk) that they were equal to or greater than the true MSY. Quotas similar to the previous three years (177.3 t in NEVI, PFMA 12-13; 25.5 t in SEVI, PFMA 18-19) have a 3.96% probability in NEVI and a 0.36% probability in SEVI of being equal to or greater than the true MSY (Table 6).

Table 6. Target reference points (as reductions from MSY), the probability the target reference point may be equal to or greater than the true MSY, and allocation of the total quota to: (a) Northeast Vancouver Island, PFMAs 12-13 and (b) Southeast Vancouver Island, PFMAs 18-19, based on the proportion that PFMA contributed to aggregate landings (on a fishing season basis) from 1995-96 to 2008-09. Limit reference point (median MSY) and probabilities (risk) that the target reference point is equal to or greater than the true MSY are derived from the Bayesian model.

(A)	Target Reference Point (Total for PFMA 12-13) (t)	Probability target reference point is => the true MSY (%)	Target Reference Point for PFMA 12 (t)	Target Reference Point for PFMA 13 (t)
Proportion caught 1995-96 to 2008-09 fishing seasons			0.633	0.367
Limit reference point (median MSY)	298	50	188	109
0.9*median MSY	268	34.1	170	98
0.8* median MSY	238	20.3	151	87
0.7* median MSY	208	9.87	132	76
0.6* median MSY	179	3.99	113	66
0.5* median MSY	149	1.59	94	55
0.4* median MSY	119	0.59	75	44
0.3* median MSY	89	0.1	57	33
0.2* median MSY	60	<0.1	38	22
0.1* median MSY	30	<<0.1	19	11
(B)	Target Reference Point (Total for PFMA 18-19) (t)	Probability target reference point is => the true MSY (%)	Target Reference Point for PFMA 18 (t)	Target Reference Point for PFMA 19 (t)
Proportion caught 1995-96 to 2008-09 fishing seasons			0.437	0.563
Limit reference point (median MSY)	78	50	34	44
0.9*median MSY	70	36	31	39
0.8* median MSY	62	23	27	35
0.7* median MSY	54	13.3	24	31
0.6* median MSY	47	7.53	20	26
0.5* median MSY	39	3.71	17	22
0.4* median MSY	31	1.43	14	18
0.3* median MSY	23	0.33	10	13
0.2* median MSY	16	<0.1	7	9
0.1* median MSY	8	<<0.1	3	4

3.5 SOURCES OF UNCERTAINTIES

The major sources of uncertainties in this assessment relate to the fishery-dependent data. These data form the core of the assessment. They are derived principally from Harvest Logbooks completed by the fishers. Landing data are measured at dockside by Port Validators as part of the Individual Quota System for this fishery. However, effort data, the number of hours spent by each diver underwater to obtain the product that is landed, can have wide uncertainty, due both to the way the logbooks are completed and to the method of fishing underwater (e.g. "surveying" versus harvesting). This is especially true for data earlier than 1995, before the Validation Program was established. These uncertainties have been dealt with in this assessment in two ways: (1) by excluding entries with blank or zeros for dive time, then calculating the median CPUE, which is more robust to outliers in the effort data than other measures of central tendency such as the mean; and (2) by use of the Bayesian model to estimate MSY and its potential range. The Bayesian model structure explicitly includes uncertainties in the fishery logbook data, in the data from the earliest 9 years of the fishery (the "gold-rush" period), and in the fishery-independent survey data. Additional drawbacks of CPUE data, such as hyper-stability (CPUE remaining high as successive aggregations are "mined") also may apply in this benthic fishery.

Fishery-independent surveys are an important source of additional information, and are included directly into the Bayesian assessment model. The approach for this fishery has been to use index sites which are surveyed once or twice a year rather than broad scale surveys. Ideally this should occur in both the NEVI and SEVI regions. The first index site was established in the Stephenson Islets area of PFMA 12 in 1995, and was sampled twice a year (prior to and just after the active fishing season) from October 1995 to March 1998, to determine how commercial fishing was impacting green sea urchins. Since the autumn of 1998, surveys at this location have been conducted annually or biennially to assess green urchin population variability. Several fishery-independent surveys have been conducted in PFMA 18, both in Active Pass (various years since 1997, and most recently in March 2008), and at Saturna Island. However, it has been difficult to identify a suitable index site in this PFMA to provide on-going time-series data because of the particular local physical and oceanographic conditions. As a result, there is no continuous time series of fishery-independent data in PFMA 18 comparable to that in PFMA 12. The Fulford Reef site in PFMA 19 has been consistently and heavily fished for the last few years, and surveying began there in March 2008. However there is no nearby reserve that can be considered the control site to compare results.

The total landed values for green sea urchins for each fishing season (Table 2) are estimates, and are calculated using both the Sales Slip data and Harvest Logbook data. An average landed value ($/t) is obtained from the Sales Slip data, and then is multiplied by the total landings (t) from the Harvest Logbook data, which are more complete than the Sales Slip data.

3.6 ADDITIONAL STAKEHOLDER PERSPECTIVES

Low fishing effort and harvest levels, particularly for the last five fishing seasons, reflect low prices in Japan. The unit price over the last 4 years (Cdn$3.15/kg to Cdn$3.55/kg) is similar to values seen in 1991-92 (Cdn$3.24/kg; Table 2). In contrast, the unit price was a high of $7.25/kg in 1994 (Table 2). As a result, fewer licence holders have been fishing in B.C., and a large portion of the total allowable catch (TAC) has

remained unfished because it was not financially viable. Less than 11% of the TAC was landed during the 2006-07 season (Table 2), B.C.'s poorest year in this fishery. These low prices are due principally to very large harvests from the Russian Far East and their importation into Japan. Visits to Japan have been conducted by members of the West Coast Green Urchin Association to underline the high quality of the product from B.C. and attempt to increase the market base. There has been a slight improvement in landings in 2007-08 and 2008-09 (Table 2). Reports from Japan also suggest that more stringent controls on the Russian harvest of sea urchins may be forthcoming, but it is unknown how effective these may be at increasing the market price of green urchins harvested in B.C.

4.0 CONCLUSIONS

Green sea urchins remain a small but important part of the B.C. dive fisheries. Overall, green urchin populations in the two major fishing regions of B.C. appear to be healthy (catch per unit of effort for NEVI and SEVI were higher in 2008-09 than at the beginning of the fishery in the late 1980s), with relatively low fishing pressure. Landings and landed value over the past five seasons have been the lowest recorded. This has been due to low product unit price resulting from oversupply in the Japanese market with urchins harvested in Russia.

Fisheries-independent surveys in PFMA 12 indicated that biomass estimates for legal and sublegal-sized urchins in October 2008 were the highest observed since surveys began in 1995. However, surveys in PFMA 19 indicated that the biomass estimates of legal-sized urchins decreased between March 2008 and March 2009 by an amount equivalent to the quota taken from PFMA 19, while the biomass estimate for sublegal-sized urchins increased slightly.

5.0 SUMMARY

- Green sea urchins remain a small but important part of the British Columbia dive fisheries.
- Overall, green urchin populations in their two major fishing regions of British Columbia (Northeast Vancouver Island and Southeast Vancouver Island) appear to be under low fishing pressure. The catch per unit of effort has been steadily increasing since 1993-94 and is now at its highest level in the 22 year history of the fishery.
- Total landings and landed value decreased by approximately 50% each fishing season from 2003-04 (167 t, worth Cdn$0.725 million) to the lowest values in 2006-07 (22 t, worth Cdn$0.073 million; preliminary data). Although there was a 3-fold increase in landings and landed value from 2006-07 to 2007-08, and another slight increase in 2008-09, the last five fishing seasons were historically the lowest on record. This was a result of poor market prices in Japan, due to competition from Russia.
- A series of quota options [target reference points expressed as reductions from the Maximum Sustainable Yield (MSY) limit reference point] are provided for each open PFMA, along with the associated levels of probability that they may be equal to or greater than the true MSY.

- Quotas established at their current 2009-10 levels (177.3 t in Northeast Vancouver Island; 25.5 t in Southeast Vancouver Island) would represent low probabilities of being equal to or greater than the true MSY (4.0% in Northeast Vancouver Island; 0.4% in Southeast Vancouver Island).

6.0 ADVICE

Advice in response to the questions posed by Fishery Managers (listed in Appendix 1) is:

1) Quota options developed using a Bayesian biomass dynamic model and interpreting maximum sustainable yield (MSY) as a limit reference point (LRP), target reference points (TRPs) set as reductions from the median MSY, and their associated probabilities that the TRP is equal to or greater than the true MSY, are provided in Table 2 for both the Northeast Vancouver Island (NEVI; PFMAs 12 and 13) and Southeast Vancouver Island (SEVI; PFMAs 18 and 19) regions.

2) Quotas established at their current (2009-10) levels (177.3 t in NEVI; 25.5 t in SEVI) would represent low probabilities that the TRP is equal to or greater than the true MSY (4.0% in NEVI; 0.4% in SEVI). Considering the lack of a time series of fishery-independent data for the SEVI region, caution should remain.

3) Fishery-independent surveys (currently conducted in PFMA 12 and PFMA 19) should be continued, on a regular basis, to provide a time series independent of the fishery for assessment of green urchin population trends. Surveys should be expanded to include all PFMA's that are open to commercial fishing of green sea urchins because there is no other method of obtaining data for sublegal-sized urchins, density and biomass information, or roe quality. However, this cannot be accomplished with current resources.

4) No additional research is recommended at this time. Laboratory experiments are nearing completion regarding the age and growth of green sea urchins in British Columbia, for development of a reliable ageing technique. Such a technique will be valuable for assessing the actual age of urchins rather than using the present technique of size-mode analysis.

7.0 ACKNOWLEDGEMENTS

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APPENDIX 1

REQUEST FOR SCIENCE INFORMATION AND/OR ADVICE

PART 1: DESCRIPTION OF THE REQUEST – TO BE FILLED BY THE CLIENT REQUESTING THE INFORMATION/ADVICE

Date *(when initial client's submission is sent to Science) (dd/mm/yyyy)***:** 05/03/2008

Directorate, Branch or group initiating the request and category of request	
Directorate/Branch/Group	Category of Request
☒ Fisheries and Aquaculture Management	☒ Stock Assessment
☐ Oceans & Habitat Management and SARA	☐ Species at Risk
☐ Policy	☐ Human impacts on Fish Habitat/ Ecosystem components
☐ Science	☐ Aquaculture
☐ Other (please specify):	☐ Ocean issues
	☐ Invasive Species
	☐ Other (please specify):

Initiating Branch Contact:	
Name: Erin Wylie/Guy Parker	Telephone Number: 250 756-7271
Email: erin.wylie@dfo-mpo.gc.ca	Fax Number:

Issue Requiring Science Advice (i.e., "the question"):
Issue posed as a question for Science response.

Quota options are needed for the Green Sea Urchin Fishery.

Rationale for Advice Request:
What is the issue, what will it address, importance, scope and breadth of interest, etc.?

- The last PSARC quota options paper prepared by MEAD was released in 2005. FAM is requesting that these quota options be updated using the information obtained from surveys and logbooks in the last few seasons. The information will be used for the development of the 2009 IFMP.
- To incorporate the recent stock assessment survey data and logbook data into the quota analysis for the green urchin fishery.
- A new 3 year IFMP (2009-2012) will be developed following advice from this paper and the PSARC committee

Questions to be addressed:

- What are the ranges of sustainable harvest rates/levels for the major commercial harvest areas on the coast (Areas 11-13, and 17-20), and other locations if data exists?
- What are the risks or uncertainties associated with the range of quota options?
- What are the recent trends in the local populations of green urchins in areas where data exists? (biomass and diver CPUE)
- What are the trends in population structure?
- Do the current annual surveys at the index locations need to be continued to provide reliable fish management data on a longer time series? Should additional sites be initiated?

- Are there additional areas of stock assessment work suggested from the latest analysis?
- Are there recommendations for additional research needed in the program?

Possibility of integrating this request with other requests in your sector or other sector's needs?

N\A

Intended Uses of the Advice, Potential Impacts of Advice within DFO, and on the Public:
Who will be the end user of the advice (e.g. DFO, another government agency or Industry?). What impact could the advice have on other sectors? Who from the Public will be impacted by the advice and to what extent?

Resource Managers, Commercial Industry Association

Date Advice Required:

Latest possible date to receive Science advice (dd/mm/yyyy): Fall 2009

Rationale justifying this date: Need information to plan for next years fishery. Paper has already been delayed.

Funding:
Specific funds may already have been identified to cover a given issue (e.g. SARCEP, Ocean Action Plan, etc.)

Source of funding: A-base / Larocque funds

Expected amount:

Initiating Branch's Approval:

Approved by Initiating Director: ☐ Date (dd/mm/yyyy):

Name of initiating Director:

Send form via email attachment following instructions below:

Regional request: Depending on the region, the coordinator of the Regional Centre for Science Advice or the Regional Director of Science will be the first contact person. Please contact the coordinator in your region to confirm the approach.

National request: At HQ, the Director of the Canadian Science Advisory Secretariat (Denis.Rivard@dfo-mpo.gc.ca) AND the Director General of the Ecosystem Science Directorate (Sylvain.Paradis@dfo-mpo.gc.ca) will be the first contact persons.

PART 2: **RESPONSE FROM SCIENCE**

In the regions: to be filled by the Regional Centre for Science Advice.
At HQ: to be filled by the Canadian Science Advisory Secretariat in collaboration with the Directors of the Science program(s) of concern.

Criteria characterising the request:	**Constraints regarding the planning of a standard peer review/Workshop:**	**Other criteria that could affect the choice of the process, the timelines, or the scale of the meeting:**
☒ Science advice is requested (rather than just information) ☒ A sound basis of peer-reviewed information and advisory precedent already exists. ☐ Inclusiveness is an issue ☒ Advice on this specific issue has been provided in the past. ☐ Urgent request. ☐ DFO is not the final advisory body. ☐ CEAA process ☐ COSEWIC process ☐ Other:	☐ External expertise required ☐ This is a scientifically controversial issue, i.e., consensus does *not* currently exist within DFO science. ☐ Extensive preparatory work is required. ☐ Determination of information availability is required (prior to provision of advice). ☐ Resources supporting this process are not available. ☐ Expected time needed for the preparatory work: ☐ Other (please specify):	☐ The response provided could be considered as a precedent that will affect other regions. ☐ The response corresponds to a new framework or will affect the framework currently in place. ☐ Expertise from other DFO regions is necessary. ☐ Other (please specify):

Recommendation regarding the advisory process and the timelines:

☐ Science Special Response Process (SSRP)	☐ Workshop	☒ Peer Review Meeting

Rationale justifying the choice of process: Review stock assessment advice

Types of publications expected and if already known, number of report for each series:

☒ Science Advisory Report (1) ☒ Research Document (1)
☐ Proceeding ( ) ☐ Science Response Report ( )
☐ Other:

Date Advice to be Provided:

☒ Date specified can be met.
☐ Date specified can NOT be met.

Alternate date, as agreed to by client Branch lead and Science lead (dd/mm/yyyy):

OR

☐ No Formal Response to be Provided by Science

Rationale:
- ☐ DFO Science Region does not have the expertise required.
- ☐ DFO Science Region does not have resources available at this time.
- ☐ The deadline can not be met.
- ☐ Not a natural science issue (e.g. socio-economic)
- ☐ Response to a similar question has been provided elsewhere:
  Reference:

Additional explanation:

Science Branch Lead:

Name: Ian Perry Telephone Number: 250-756-7137
Email: Ian.Perry@dfo-mpo.gc.ca

* Please contact Science Branch lead for additional details on this request.

Science Branch Approval:

Approved by Regional Director, Science (or their delegate authority):
☐ Date (dd/mm/yyyy):

Name of the person who approved the request:

Once part 2 completed, the form is sent via email attachment to the initiating Branch contact person.

PART 3: <u>PLANNING OF THE ADVISORY PROCESS</u>

Science Branch Approval:

Coordinator of the event:

Potential chair(s):

Suggested date (dd/mm/yyyy) / period for the meeting:

Need a preparatory meeting:

Leader of the Steering Committee: