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Identification of Provisional Reference Points and Harvest Rate Options for the Commercial Red Sea Urchin (*Mesocentrotus franciscanus*) Fishery in British Columbia

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Length-based population models and projection simulations were used to study the impacts of a range of alternative harvest rates on British Columbia (BC) Red Sea Urchin (RSU) (*Mesocentrotus franciscanus*) populations. These models were based on a large accumulation of fishery-independent survey data and published estimates of growth, natural mortality and adult RSU spine canopy protection of juveniles (Zhang et al. 2008, 2011). Data were analyzed and results presented for the following regions of the coast: Haida Gwaii (Pacific Fishery Management Areas (PFMAs) 1, 2, 101 and 102), the Mainland North Coast (PFMAs 3 to 10 and 103 to 110), and the South Coast Inside Waters between Vancouver Island and the Mainland (PFMAs 11 to 20, 28, 29 and 111).

To evaluate the impact of a range of harvest rates, the concept of serious harm was considered in the identification of a provisional Limit Reference Point (LRP) and an Upper Stock Reference (USR). Reference Points were not previously identified for BC's RSU commercial fishery, and this work aligns this fishery with the Sustainable Fisheries Framework and DFO's [Fishery Decision-Making Framework Incorporating the Precautionary Approach](#) (DFO Precautionary Approach) (DFO 2009).

An empirical approach for establishing Reference Points based on historical density estimates from areas where Sea Otters (*Enhydra lutris*) had been established for at least five years is suggested. Our compilation of historical densities revealed RSU mean densities ranging from 0 to 4.01 RSU/m^2, with a mean of 0.48 ± 0.20 (SE) and a median of 0.06 (Table 5) (Burt et al. 2018; Watson and Estes, 2011; Kvitek et al. 1989; Pearse and Hines 1987; Lowry and Pearse 1973; Faro 1970; Ebert 1968). From that range, we suggest 0.3 RSU/m^2 from Watson and Estes (2011) as a reasonable LRP. This value was identified as the LRP because it was from BC in an area where Sea Otters had been established for at least 30 years, it was the longest time series of RSU density data in Sea Otter occupied areas (19 years) and it was the highest value of the Watson and Estes data (2011). Recognizing that recruitment events can cause large fluctuations in the number of small RSU observed during surveys, we propose the 0.3 RSU/m^2 density threshold only applies to mature (≥ 50 mm TD) RSU, not RSU of all sizes. Therefore, we suggest the LRP is breached when the median of the bootstrapped sampling distribution of the mean spatial density on RSU habitat is less than 0.3 mature (≥ 50 mm TD) RSU/m^2 and the USR is breached when the median of the bootstrapped sampling distribution of the mean spatial density on RSU habitat is less than 0.6 mature (≥ 50 mm TD) RSU/m^2.

Decision Tables specifying the estimated probability of breaching the LRP and USR across a range of harvest rates are provided (Tables 12-23). Stock status was assessed at being above the USR at both the regional and coast wide spatial scales. The medians of the bootstrapped sampling distribution of the mean, mature RSU density, on all quadrats identified as RSU habitat, were estimated to be 2.51 RSU/m^2 (95% CI: 2.11-3.25) for Haida Gwaii, 1.70 RSU/m^2 (95% CI: 1.57-1.95) for the Mainland North Coast, 0.89 RSU/m^2 (95% CI: 0.81-1.06) for the South Coast Inside Waters, and 1.44 RSU/m^2 (95% CI: 1.37-1.61) for all three regions combined.

1   INTRODUCTION

The commercial dive fishery for the Red Sea Urchin (RSU) (*Mesocentrotus franciscanus*[1]) in British Columbia (BC) began on the South Coast in 1971 and expanded to the North Coast in 1984. In the 2016-2017 fishing season the fishery landed 3256 t with a total landed value of CAD$7.2 M. The fishery is managed with an annual total allowable catch, area quotas, licence limitation (110 licences) and individual quotas. Licence requirements of the commercial fishery in BC include a minimum harvestable test diameter (TD) size of 90 mm and despite no upper size limit, market pressure has led to a commercially targeted size range of 90 -140 mm TD (Campbell et al. 2001). Here we refer to 'exploitable biomass', meaning the biomass of RSU with TDs ranging from 90 -140 mm.

An annual harvest rate of 2%, applied to estimated current exploitable biomass, has been used for most of the BC coast since the enactment of the Individual Quota system in 1994 (Leus et al. 2014, Campbell et al. 2001,1999a, 1999b). The 2% harvest rate was derived using a modified Gulland surplus production model (Gulland 1971), which is a model intended for use when a stock is in the early stages of harvest. The Gulland (1971) model estimates a maximum sustainable yield (MSY), assuming MSY occurs when the maximum sustainable fishing mortality is equal to M:

$$MSY = X*M*B_0$$

Where:

X = arbitrary correction factor = 0.5

M = instantaneous natural mortality rate

B_0 = virgin biomass

The model was modified in the following way for the BC RSU fishery. The Gulland (1971) model applies a correction factor of 0.5, however for the BC RSU fishery the correction factor was lowered to 0.2 to be cautious (Campbell et al. 1999a, Garcia et al. 1989) and B_c was used as a proxy for B_0 (Leus et al. 2014, Campbell et al. 2001,1999a, 1999b).

$$MSY = X*M*B_c$$

Where:

X = arbitrary correction factor = 0.2

M = instantaneous natural mortality rate = 0.10

B_c = current exploitable biomass

Current exploitable RSU biomass (B_c) by Pacific Fisheries Management (PFM) Area and Subarea is estimated as the product of estimates of (1) linear density in kilograms of RSU (90 – 140 mm TD) per metre of shoreline from fishery-independent surveys, and (2) shoreline length of RSU habitat measured from the Canadian Hydrographic Service (CHS) charts for the high tide water line (Leus et al. 2014).

The accumulation of a substantial amount of biological information on RSU in BC warrants a re-evaluation of the impact of the 2% harvest rate derived from the modified Gulland model. The modified Gulland model assumes the RSU fishery is in the early stages of harvest, but this is no

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[1] Formerly known as *Strongylocentrotus franciscanus* (Tatarenko and Poltaraus, 1993)

longer the case. Commercial harvesting has been occurring for 48 years and fishery-independent dive surveys, to estimate RSU density and size frequencies, have been conducted since 1994. Some biological parameters, such as growth and natural mortality rates, have been estimated using BC fishery-independent data (Zhang et al. 2008). The spine canopy of adult RSU can provide shelter to juvenile RSU and may contribute to increased survival rates of juveniles due to protection from strong water currents and predators (Nishizaki and Ackerman 2007). The probabilities of RSU juvenile-adult associations in relation to size (test diameter) and RSU density have also been estimated using BC fishery-independent data (Zhang et al. 2011). All of this information can be useful in developing a new, more sophisticated model.

Fisheries and Oceans Canada (DFO) Fisheries and Aquaculture Management Branch requested advice on the following topics from DFO Science Branch:

1. Develop a new model that will simulate the response of British Columbia Red Sea Urchin populations to a range of harvest rates for the following regions of the coast: Haida Gwaii (Pacific Fishery Management Areas (PFMAs) 1, 2, 101 and 102), the Mainland North Coast (PFMAs 3 to 10 and 103 to 110), and the South Coast Inside Waters between Vancouver Island and the Mainland (PFMAs 11 to 20, 28, 29 and 111);

2. Recommend a provisional Limit Reference Point (LRP) and Upper Stock Reference (USR) compliant with the DFO Precautionary Approach for the Red Sea Urchin fishery;

3. Provide Decision Tables specifying the estimated probability of breaching the LRP and USR across a range of harvest rates, for the following regions of the coast: Haida Gwaii (PFMAs 1, 2, 101 and 102), the Mainland North Coast (PFMAs 3 to 10 and 103 to 110), and the South Coast Inside Waters between Vancouver Island and the Mainland (PFMAs 11 to 20, 28, 29 and 111);

4. Where possible, assess the current status of Red Sea Urchin populations relative to the provisional Reference Points for the following regions of the coast: Haida Gwaii (PFMAs 1 and 2, 101 and 102), the Mainland North Coast (PFMAs 3 to 10 and 103 to 110), and the South Coast Inside Waters between Vancouver Island and the Mainland (PFMAs 11 to 20, 28, 29 and 111);

5. Examine and identify uncertainties in the data and methods.

This paper uses previously published RSU parameters (Zhang et al. 2011, 2008), fishery-independent RSU data from BC and a new length-based simulation modelling approach to provide advice on the application of a range of possible RSU commercial fishery harvest rates for the regions requested. In addition, to evaluate the impact of the range of harvest rates, the concept of serious harm is considered in the identification of a provisional LRP and USR. Reference Points were not previously identified for BC's RSU commercial fishery, and this work aligns this fishery with the Sustainable Fisheries Framework and DFO's [Fishery Decision-Making Framework Incorporating the Precautionary Approach](#) (DFO Precautionary Approach) (DFO 2009). Finally, to the extent possible, the status of RSU was assessed relative to the provisional Reference Points.

2 BIOLOGY

RSU are spiny, hard shelled, spherical echinoids that live primarily on hard marine benthos from 0 to 284 m depths (Aaron Galloway, Assistant Professor, University of Oregon, Oregon Institute of Marine Biology, 2018, pers. comm.). RSU are found on the west coast of North America as far south as the tip of Baja California (including the Gulf of California), northward to the Aleutian Islands, Alaska, and along the Asiatic coast as far south as the southern tip of Hokkaido Island,

Japan (DFO 2018a, Campbell and Harbo 1992). RSU have separate sexes and will first reproduce at about 50 mm TD (Bernard & Miller 1973), which is around 3-5 years of age. Broadcast spawning typically occurs in May and June (Kramer & Nordin 1975) with planktonic larvae settling in 6-8 weeks. In the absence of Sea Otters (*Enhydra lutris*), a keystone species and primary predator of urchins, natural mortality (M) of RSU in BC is relatively low, typically ranging from $0.08y^{-1}$ to $0.12y^{-1}$ (Zhang et al. 2008). Initially thought to be relatively short-lived at 7-10 years (Sloan, 1986), Ebert and Southon (2003) have shown the largest RSU, with TD of 180 mm or more, can be in excess of 100 years old.

3 MATERIALS AND METHODS

3.1 FISHERY-INDEPENDENT SURVEY DATA

These analyses used data from RSU fishery-independent SCUBA dive surveys conducted in commercially harvested areas of BC from 1994 to 2016 (Table 1, Figure 1). Although RSU fishery-independent surveys have been conducted in BC since the 1970's (Jamieson et al. 1998a-d, Jamieson and Schwarz 1998, Breen et al. 1978, 1976), data collected prior to 1994 were not included in these analyses because they did not employ the standardized protocol (Bureau et al. 2000a, 2000b, 2000c, 2000d) used since 1994 and therefore were not comparable. The RSU fishery-independent surveys were designed to provide data that can be used to estimate density and biomass at the PFM Subarea level for the development of quota options for Fisheries Managers. Different PFM Subareas have been surveyed each year and provide an annual snapshot of RSU abundance and size in a small area of the coast. Quadrat data were used and TD from different PFM Subareas surveyed in different years were pooled by region. See below for a description of the regions, PFM Areas, years and number of quadrats (Sections 3.1.1, 3.1.2, 3.1.3).

The standard RSU dive survey protocol implemented in 1994 was followed for all surveys. The protocol uses a random-systematic design that systematically places transects every one km along the shoreline within a PFM Subarea, with a random start point, or places each transect at one random point along the shoreline for every one-to-two km of shoreline. Transects were laid perpendicular to shore from shallow water to approximately 15 m (50 feet) gauge depth (chart datum depth plus tide height) with a lead line and transect length was therefore dependent on the subtidal slope. Two SCUBA divers descended down to the start of the transect at a depth of 15 m with a 1 m² quadrat, calipers and a clipboard with plasticized data sheets for recording. Due to time limitations associated with SCUBA diving, typically every second quadrat was sampled. TD (diameter, or width, of the of the test, not including spines) in mm was recorded for all RSU and shell length (length of the longest axis) in mm for all Northern Abalone (*Haliotis kamtschatkana*) found within sampled quadrats. In some sampled quadrats where RSU abundance was high, SCUBA diving time constraints required that urchins were counted and not measured. Size frequency probabilities of counted RSU were interpolated from adjacent quadrats (Lochead et al. 2015).

General habitat characteristics were also recorded, including depth, substrate type, exposure, and types and percent cover of algae. Gauge depth was corrected to chart datum for each quadrat by subtracting tide height. The first, second and third most abundant type of substrate within each quadrat were recorded as one of twelve codes: 0 = wood; 1 = smooth bedrock; 2 = bedrock with crevices; 3 = boulders (bigger than a basketball); 4 = cobble (between 7.5cm and basketball size); 5 = gravel (between 2cm and 7.5cm); 6 = pea gravel (between 0.25cm and 2cm); 7 = sand; 8 = shell; 9 = mud; 10 = crushed shell; and 11 = whole shell. The habitat details are important in defining RSU habitat and identifying features associated with the absence of urchins, for instance sand or mud substrate and/or very sheltered exposure.

3.1.1 Haida Gwaii

The Haida Gwaii region is defined as PFM Areas 1, 2, 101 and 102. Surveys were conducted in 1994, 1995, 2010, 2014 and 2015 in 23 PFM Subareas of the Haida Gwaii. A total of 17,349 quadrats were sampled with 18,174 TD measurements taken from the 44,778 Red Sea Urchins recorded. (Table 1, Figure 1).

3.1.2 Mainland North Coast

The Mainland North Coast region is defined as PFM Areas 3 to 10, and 103 to 110. Surveys were conducted in 13 years from 1994 to 2016 in 34 PFM Subareas of the Mainland North Coast, with no surveys in PFM Area 10. A total of 38,284 quadrats were sampled with 39,411 TD measurements taken from the 80,364 Red Sea Urchins recorded. (Table 1, Figure 1).

3.1.3 South Coast Inside Waters

The South Coast Inside Waters region, between Vancouver Island and the Mainland, is defined as PFM Areas 11 to 20, 28, 29 and 111. Surveys were conducted in 17 years from 1994 to 2016 in 65 PFM Subareas of the South Coast Inside Waters with no surveys in PFM Areas 15, 16 or 28. A total of 56,614 quadrats were sampled with 38,799 TD measurements taken from the 51,149 Red Sea Urchins recorded. (Table 1, Figure 1).

3.2 REFERENCE POINTS

The minimum elements of the harvest strategy component of the DFO Precautionary Approach (DFO PA) include the establishment of three stock zones delineated by a LRP and USR (DFO 2009). Traditional model based Reference Points based on B_{msy} (biomass that produces maximum sustainable yield) or F_{msy} (fishing mortality that produces maximum sustainable yield) are not as easily estimated for benthic, broadcast spawning invertebrates. RSU have a complex spatial population structure and there is no known stock-recruitment relationship. Reproductive success could depend on many factors such as female fecundity, spawning synchrony, spatial patterns of age or size structure, the relationship between spawner density and fertilization efficiency, and the relationship between benthic settlement success and habitat suitability (Smith et al. 2012). The long time period between spawning and being able to observe recruits allows the cumulative environmental influences on survival to significantly reduce year-class strength (Smith et al. 2012). Also, because of the long pelagic larval phase of RSU, larvae may be transported long distances so that recruitment success in one area may be affected by spawning success in another area. The lack of suitable models to account for these intricacies has often resulted in the use of empirical methods to identify the types of Reference Points defined by the DFO PA policy (Smith et al. 2012).

The DFO PA suggests a number of ways of using biomass estimates, survey estimates or other proxies when model-based estimates are not available. Most of the Canadian invertebrate fisheries that have defined or proposed Reference Points use a biomass proxy (Smith et al. 2012). Here we suggest an empirical approach for establishing Reference Points based on historical density estimates. The rationale is provided below.

In DFO's Fishery Decision-Making Framework Incorporating the Precautionary Approach (DFO 2009), the LRP is defined as the stock status below which serious harm is occurring to the stock. The LRP is therefore meant to be biologically based. The framework notes that below the LRP, there may also be resultant impacts to the ecosystem, associated species and a long-term loss of fishing opportunities. Defining a LRP for the RSU stock in BC is challenging because current RSU abundance is believed to be unnaturally inflated. Historically, RSU populations were limited by Sea Otter (*Enhydra lutris*) predation. Sea Otters abundance declined due to the

fur trade so that they were rare and probably ecologically extinct from BC waters by about 1850; with the last confirmed sighting in BC in 1929 (Cowan and Guiguet 1960). Following the extirpation of Sea Otters from BC, the abundance of RSU would have increased substantially (Riedman and Estes 1990) eventually leading to the development of a coast wide commercial fishery. Current RSU populations are considered to be at historically high levels where Sea Otters are absent.

From 1969 to 1972, 89 Sea Otters were transplanted from Alaska to the west coast of Vancouver Island, with the first aerial surveys confirming their establishment in the area in 1977 (Bigg and MacAskie 1978). Sea Otters have since been recolonizing coastal BC (Nichol et al. 2015). By 2013, the BC population was almost 7000 Sea Otters with established populations along most of the west coast of Vancouver Island and portions of the central coast (Nichol et al. 2015). A highly predictable change in phase state from RSU abundance to Sea Otter abundance, is occurring in BC (Watson and Estes 2011). For this reason it is unrealistic to manage BC's RSU fishery relative to current, inflated abundance levels.

Studies have shown that in areas where Sea Otters have been long established, RSU tend to be smaller, occur at low densities, and be cryptically located under boulders and in crevices (Burt et al. 2018, Lee et al. 2016, Watson and Estes 2011, Kvitek et al. 1989, Estes and Duggins 1995, Pearse and Hines 1987, Breen et al. 1982, Estes and Palmisano 1974). Estimated RSU mean densities in areas of California, Washington, and BC, where Sea Otters have been established for at least 5 years, range from 0 to 4.01 RSU per metre squared (RSU/m^2) (Table 5).

Long-term studies in areas where Sea Otters have been continually present have shown that RSU densities can persist at low levels. Watson and Estes (2011) conducted a long-term study in Checleset Bay, on the West Coast of Vancouver Island, where Sea Otters were reintroduced in 1969 (Bigg and MacAskie 1978). RSU densities in Checleset Bay were 0.2 RSU/m^2 (0.1 SE) in 1988, 0.1 RSU/m^2 (0.0 SE) in 1994, 0.3 RSU/m^2 (0.1 SE) in 2007 (Watson and Estes 2011), and 0.01 RSU/m^2 in 2013 (Dr. Jane Watson, Professor Emeritus, Vancouver Island University, Nanaimo, BC, 2019, pers. comm.). In another long-term study at the Hopkins Marine Life Refuge, California, where Sea Otters had been present since 1962, densities of RSU remained around 0.1 RSU/m^2 (mean of annual mean densities) and did not change significantly from 1972 to 1981 (Pearse and Hines 1987).

By the 1970's, Sea Otter populations recovered from extirpation to near carrying capacity in Western Alaska (Rotterman and Simon-Jackson 1988). However in the 1990's, Sea Otter populations declined abruptly, likely due to increased predation on Sea Otters by Killer Whales (*Orcinus orca*) (Estes et al. 1998). Rapid changes in sea urchin (*Strongylocentrotus plyacanthus* and *S. droebachiensis*) size and density accompanied the Sea Otter population declines and, from 1987 to 1997, sea urchin biomass increased eight-fold from approximately 160g/m^2 to 1280g/m^2 (Estes et al. 1998).

In areas where Sea Otters are present, their predation usually limits densities of large RSU to levels well below those that could support a commercial fishery. Under these ecological and current market conditions, harvesting has become economically non-viable before there is a conservation concern to the stock. For example in BC, some quota areas on the West Coast of Vancouver Island, the Mainland Central Coast and portions of PFMA 12 have had reductions in quota or have been closed because commercially harvestable densities of RSU no longer exist in these Sea Otter occupied areas (DFO 2018a). This also occurred in California by 2004, where predation by Sea Otters lowered the density of legal sized RSU below levels required to have a viable fishery (Dewees 2003).

Here we suggest an empirical approach for establishing Reference Points based on historical RSU density estimates in areas with well established Sea Otter populations. Areas where Sea Otters have been present for several years may indicate the highest harvesting pressure under which biologically viable RSU populations can be maintained. This assumes these lower density populations can still achieve fertilization efficiency and post-dispersal recruitment success (see 4.3.6. Allee Effects). Without information based on modelling exercises of RSU larval movement in BC, it is not possible to determine which populations act as sources of recruitment for others. However, within Sea Otter inhabited areas lower abundance populations of RSU tend to be cryptically located in cracks and crevices and are also found in areas where Sea Otters do not commonly go to forage (Burt et al. 2018, Lee et al. 2016, Watson and Estes 2011, Kvitek et al. 1998, Estes and Duggins 1995, Pearse and Hines 1987, Breen et al. 1982, Estes and Palmisano 1974). These pockets of higher density populations may contribute to fertilization efficiency and post-dispersal recruitment success.

Our compilation of RSU densities from areas where Sea Otters had been established for at least five years revealed RSU mean densities, for all sizes combined, ranging from 0 to 4.01 RSU/m^2, with a mean of 0.48 ± 0.20 (SE) and a median of 0.06 (Table 5) (Burt et al. 2018, Watson and Estes 2011, Kvitek et al. 1989, Pearse and Hines 1987, Lowry and Pearse 1973, Faro 1970, Ebert 1968). The research studies presented in Table 5 spanned 51 years, from 1967 to 2018. The studies are comparable in that they targeted RSU habitat on hard substrates and characterized benthic communities within Sea Otter occupied areas (and often compared to areas of low and no Sea Otter occurrence). RSU density estimates were obtained from random quadrats within sites or along transects by SCUBA divers, within diveable depths (approximately 0 – 18 m). Table 5 presents a summary of estimated mean RSU densities (RSU/m^2) ± error estimate, year, location, sample size, years of Sea Otter occupancy, and the reference for each of the studies.

The Burt et al. (2018) study on BC's Central Mainland coast reported densities of 1.13 RSU/m^2 in 2013 and 0.82/m^2 RSU in 2014 (Table 5). In this study, the estimated mean mature (≥ 50 mm TD) RSU densities at Sea Otter "present" sites were 0.58 RSU/m^2 (± 1.70 SD) in 2013 and 0.46 RSU/m^2 (± 1.62 SD) in 2014 (Jenn Burt, PhD candidate, School of Resource and Environmental Management, Simon Fraser University/Hakai Institute, 2018, pers. comm.).

RSU densities from Lee et al. (2016) were part of a large study on the direct and indirect effects of Sea Otters, RSU and Sunflower Stars (*Pycnopodia helianthoides*) on Northern Abalone (*Haliotis kamtschatkana*) in Haida Gwaii, BC's Central Coast and West Coast Vancouver Island (WCVI) (Table 5). In this study, the mean densities for mature (≥ 50 mm TD) RSU in areas occupied by Sea Otters for 12-38 years were 0.077 mature RSU/m^2 (± 0.40 SE) on the Central Coast and 0.0069 (± 0.058 SE) on the WCVI (Dr. Lynn Lee, Marine Ecologist, Gwaii Haanas Parks Canada, Haida Gwaii, BC, 2019, pers. comm.).

From the range of mean density estimates presented in Table 5, we suggest 0.3 RSU/m^2 from Watson and Estes (2011) as a reasonable LRP for the following reasons: the mean density estimate 0.3 RSU/m^2 was from BC in an area where Sea Otters had been established for at least 30 years, it was from the longest time series of RSU density data in Sea Otter occupied areas (25 years), and it is the highest value in the Watson and Estes (2011) time series, which we feel makes this the more conservative choice. Recognizing that recruitment events can cause large fluctuations in the number of small RSU observed during surveys, we propose the 0.3 RSU/m^2 density threshold only applies to mature (≥ 50 mm TD) RSU, not RSU of all sizes, which adds an additional level of conservation. We feel that it is more appropriate to use mature-sized RSU/m^2, rather than harvestable-sized (90 – 140 mm TD) RSU/m^2 or legal-sized (≥ 90 mm TD) RSU/m^2, for the following reasons: the size range for harvestable- and legal-sized RSU could change as a result of Fisheries Management actions and they are also dependent

on market-driven factors; and mature densities are important from a biological point of view because they represent the spawning stock.

We suggest the LRP is breached when the median of the bootstrapped sampling distribution of the mean spatial density of RSU on RSU habitat is less than 0.3 mature (≥ 50 mm TD) RSU/m^2. Here we specify spatial density, which is in units of RSU/m^2, to clearly differentiate it from linear density, which is in units of RSU/m-of-shoreline, used for the calculation of quota options as described in the current assessment framework (Leus et al. 2014). We chose spatial density, as opposed to linear density, for the unit of the provisional reference points because the density estimates presented in Table 5 are spatial densities. It is not uncommon for the USR to be set at twice the value of the LRP (DFO 2018b, 2018c, 2009). For example, the Sustainable Fisheries Framework (DFO 2009) provides guidance based on international standards and suggests setting the LRP at 0.4B$_{MSY}$ and USR at 0.8B$_{MSY}$. In the recent Walleye Pollock (*Theragra chalcogramma*) (DFO 2018b) stock assessment in BC, the LRP was set at B$_{MIN}$ (the minimum spawning biomass) and the USR at 2B$_{MIN}$ (DFO 2018b). Also, in the recent Green Sea Urchin (*Strongylocentrotus droebachiensis*, GSU) stock status update in BC, the USR was set at D$_{MIN}$ (the lowest time series density from which it subsequently recovered without intervention by Fisheries Managers) and the LRP at 0.5D$_{MIN}$ (DFO 2018c). For GSU in BC the USR is 0.9 GSU/m^2 and the LRP is 0.45 GSU/m^2 (DFO 2018c). An example of recovery from a low density also exists for RSU. The lowest RSU density at 10 sites in the 2004 to 2013 time series at the Haida Gwaii RSU Research Area (Louise Island) was 0.56 RSU/m^2 in 2007, and that density subsequently increased to 2.18 RSU/m^2 in 2013 (DFO unpublished data). The RSU example is not directly comparable to the GSU example because the RSU density recovery took place in the absence of harvest, whereas the GSU density recovery took place with continued harvest. Nonetheless, the GSU and RSU examples of recovery, and the fact that the USR is often twice the LRP, helped inform our decision to set the RSU USR at two times the LRP. Therefore, we suggest the USR is breached when the median of the bootstrapped sampling distribution of the mean spatial density of RSU on RSU habitat is less than 0.6 mature (≥ 50 mm TD) RSU/m^2. The median was chosen by Fisheries Managers as the level in the distribution to be used in assessing stock status, however in our evaluation of the range of harvest rates we consider the entire sampling distribution of the mean mature spatial density.

New length-based population and simulation models were developed to quantitatively evaluate impacts of alternative harvest rates on the reduction of mature RSU densities and the probabilities of breaching the Reference Points. Parameter values for the models were formulated using biological information derived from publications and fishery-independent survey data. Growth, natural mortality rates, and juvenile–adult association for RSU in BC are described in sub-sections of 3.3.1-3.3.2, and simulation processes are presented in the remaining sub-sections.

3.3 STATISTICAL MODELS

3.3.1 Growth Models

RSU grow in a different fashion than many aquatic species. RSU exhibit sigmoidal growth, which may not be adequately modelled by the frequently used von Bertalanffy function and could, instead, be better modelled using the Tanaka and Logistic dose-response (hereby referred to as the Logistic) functions (Zhang et al. 2008, Rogers-Bennett et al. 2003, Ebert & Russell 1993). Tanaka and Logistic growth models to describe RSU growth were presented in Zhang et al. (2008). Growth model parameters estimated by Zhang et al. (2008) were used in the current study.

The Tanaka and Logistic growth models do not describe a relationship between size and age, but predict annual growth increments from initial sizes (Fig. 2). These two growth models do not impose an asymptotic size and allow the animals to continue to grow as long as they live, although the growth rate asymptotically approaches zero. The primary difference between the two models lies in the initial growth period. The Tanaka growth model (Tanaka 1988, 1982) predicts an increasing growth rate in the initial period, whereas the Logistic growth model (Rogers-Bennett et al. 2003) dictates an approximately equal growth rate in the beginning period (Figure 2 upper panel).

The Tanaka growth model has three parameters:

$$\hat{D}_{y+1} = \frac{1}{\sqrt{f}} \log \left| 2f \left(\frac{E}{4f} - \frac{a}{E} + 1 \right) + 2\sqrt{f^2 \left(\frac{E}{4f} - \frac{a}{E} + 1 \right)^2 + f \times a} \right| + d \qquad (1)$$

where $\hat{D}_{y+1}$ is the expected TD in year $y+1$, a, d and f are model parameters, and $E = \exp\left(\sqrt{f}(D_y - d)\right)$ where D_y is the TD of a RSU in year y.

The Logistic growth model also has three parameters:

$$\hat{D}_{y+1} = \frac{b}{1 + \left(D_y/c\right)^g} + D_y \qquad (2)$$

where b, c and g are the model parameters.

Actual TD deviates from the expected TD as calculated in Eqs 1 or 2:

$$D = \hat{D} + \varepsilon \qquad (3)$$

where ε is assumed to be normally distributed with a standard deviation σ_T for the Tanaka growth model and σ_L for the Logistic growth model: $\varepsilon \sim N(0, \sigma_T^2)$ and $\varepsilon \sim N(0, \sigma_L^2)$. A constraint is imposed to avoid possible negative growth in simulations. When a randomly generated value for ε is less than 5% of $\hat{D}$, this value is set to be 5% of $\hat{D}$.

Tanaka and Logistic growth model parameters were estimated for Price Island (Mainland North Coast), Louise Island (Haida Gwaii), and Alert Bay (South Coast Inside Waters) using data from RSU mark-recapture experiments conducted in these regions in the 1990's (Zhang et al. 2008). Constructed growth models for Price Island, Louise Island, and Alert Bay were initially applied to model the growth of RSU in the Mainland North Coast, Haida Gwaii, and South Coast Inside Waters, respectively. However, uses of the growth models for the Price Island and Louise Island resulted in substantially poorer model fits to length frequency data (Section 3.3). The mark-recapture data were collected from one small experimental location from Mainland North Coast or Haida Gwaii, while the length frequency data were obtained from many locations in each of these regions. The growth pattern in these small areas may not represent the growth for the entire region. The growth model for the South Coast Inside Waters happens to best fit the length frequency data all three regions, so it was chosen as the growth model in this paper. Consequently, only the growth models for Alert Bay were used for all the three regions. Means and standard deviations of growth parameters for the Alert Bay mark-recapture sites together with values for σ_T and σ_L are listed in Table 2.

In simulations, growth parameter values and normal deviates (ε) were randomly generated from the respective normal distributions.

3.3.2 Natural mortality

Estimated instantaneous natural mortality rates (M) ranged between 0.081 and 0.213 y^{-1} for RSU in Price Island (Mainland North Coast), Louise Island (Haida Gwaii), and Alert Bay (South Coast Inside Waters), using the RSU mark-recapture data from the 1990's (Zhang et al. 2008). The mean and median of the M estimates were 0.123 y^{-1} and 0.118 y^{-1}, respectively. M of 0.12 y^{-1} was used on sublegal (TD < 90 mm) RSU (Table 2). However, this estimate appears to be too high for legal RSU (see Section 3.3.4 below). M for legal RSU was determined to be substantially lower, and coefficient of variation was set to be 20% (Table 2).

In simulations, natural mortality rates were randomly generated from truncated normal distributions with the lower and upper limits of 0.03 and 12 y^{-1} for sublegal RSU, and of 0.005 and 0.08 y^{-1} for legal RSU. The means and standard deviations of these truncated normal distributions are listed in Table 2.

We applied a knife edge change in M between sublegal and legal RSU, due to a lack of data to inform the shape of the M curve between the two size categories.

3.3.3 Impact of large RSU density on recruitment density

Small RSU are often sheltered under the spines of larger individuals (Carter and VanBlaricom 2002, Sloan et al. 1987, Tegner and Dayton 1977). Sheltering under large individuals could contribute to increased survival rates for juveniles likely due to protection from both predation and damage from exposure to strong water current (Zhang et al. 2011, Nishizaki and Ackerman 2007). Suppose the number of RSU reaching the recruitment stage is R, if the density of large RSU ($\geq$ 70 mm TD) is not lower than at the current state. When the large RSU density is lower, only a proportion of R would reach the recruitment stage due to a lower degree of protection. We quantitatively modelled this proportion (r_y), using the function produced by Zhang et al. (2011):

$$\begin{cases} r_y = \exp\left(\alpha(DL_y - DL_0) + \beta(DL_y^2 - DL_0^2)\right) & (DL_y < DL_0) \\ r_y = 1 & (otherwise) \end{cases} \quad (4)$$

where DL_y is the large RSU density in year y when the population was harvested with an harvest rate > 2%, DL_0 is the large RSU density at the current state, and α and β are model parameters (see Table 1). Adjusted recruitment density in year y (DRA_y) is:

$$DRA_y = DR_y \times r_y \quad (5)$$

where DR_y is the randomly generated recruitment density for year y.

3.3.4 Recruitment test diameter range

We defined recruitment as RSU of a certain TD range, which enter the population on an annual basis. All possible TD ranges with the minimum and maximum values within 10-50 mm were tested. RSU down to 10 mm TD were considered fully vulnerable to detection in the surveys. Altogether, there are 820 ranges, namely 10-11mm; 10-12mm;…; 10-50mm; 11-12mm;…11-

50mm;…; 49-50mm. A large number (>18,000) of RSU were measured in the RSU dive surveys in each of the three regions. For each region, TD data from all surveys were pooled together. We assumed that the TD distribution of the pooled data represents the distribution at the equilibrium state realized under the assumed harvest rate of 2% of the existing abundance for the region. We determined the TD range of recruits, using an equilibrium approach. Given a recruitment size range, we first constructed an equilibrium population, deterministically using M = 0.12 y^{-1} for sublegal RSU (Zhang et al. 2008), M = 0.03 y^{-1} for legal RSU (in the Mainland North Coast and Haida Gwaii regions, see below for South Coast Inside Waters), a fixed harvest rate of 2% of the harvestable RSU between 90 and 140 mm TD, and a set of parameter values for either the Tanaka or Logistic models taken from Table 2. We then compared the TD distribution of this equilibrium population with the observed TD distribution from surveys to calculate a discrepancy. The recruitment TD range is identified as the range which produced the lowest discrepancy. The equilibrium state was reached by following one cohort throughout its life span (defined as 150 years). Once the growth model and natural mortality rates have been specified, the modelling algorithm for each region is:

1. Set an unique TD range (within 10-50 mm TD) for recruitment;

2. Select all individuals from the pooled TD data within the recruitment TD range as set in Step 1, and these individuals represent the cohort that will be followed throughout its lifespan;

3. Set a beginning year (y =1) ;

4. Calculate the number of sublegal RSU (NS) in the cohort surviving year y :

$$NS_{y+1} = NS_y \times \exp(-\hat{MS})$$ where $\hat{MS}$ is the natural mortality rate for sublegal RSU;

5. Calculate the number of harvestable RSU (NH ; between 90 and 140 mm TD) in the cohort surviving year y :

$$NH_{y+1} = 0.98 \times NH_y \times \exp(-\hat{ML})$$ where $\hat{ML}$ is the natural mortality rate for legal RSU;

6. Calculate the number of old RSU (NO ; > 140 mm TD) in the cohort surviving year y :

$$NO_{y+1} = NO_y \times \exp(-\hat{ML})$$;

7. Select surviving individuals randomly: out of NS_y sublegal RSU, NS_{y+1} individuals are selected; out of NH_y harvestable RSU, NH_{y+1} individuals are selected; out of NO_y old RSU, NO_{y+1} individuals are selected;

8. Calculate the expected TD of each RSU for year y+1, using Eq 1 if Tanaka Growth Model is specified, or Eq 2 if Logistic Growth Model is specified. Mean parameter values for the growth model are used;

9. Increment the year by one, and repeat Steps 4-8 until year 150 has been reached;

10. Combine the surviving individuals of the cohort in year 1 up to year 150 to produce a simulated population at the equilibrium state;

11. Calculate the discrepancy in number of RSU in each TD class between simulated and observed RSU populations: $0.5\sum_i (NS_{s,i} - NS_{o,i})^2 + \sum_j (NL_{s,j} - NL_{o,j})^2$ where NS and NL represent the number of sublegal and legal RSU respectively, subscripts s and o denote the simulated and observed populations respectively, and subscripts i and j indicate TD classes (20 TD classes between 40 to 140 mm with an interval of 5 mm);

12. Go back to Steps 1-11 until all possible TD ranges (within 10-50 mm TD) have been used;

13. Use the TD range of the simulated population producing the minimum discrepancy as the TD range for recruitment.

Fit to the TD classes of sublegal RSU was weighted down in an attempt to fit the TD classes of harvestable RSU better. Initially, the natural mortality rate of 0.12 y^{-1} was also applied to legal RSU. However, the model in this setting would produce substantially smaller proportions of legal RSU relative to the observed RSU samples. When M of 0.03 y^{-1} was used for legal RSU, the model fit appeared to be good for the Mainland North Coast and Haida Gwaii (Fig. 3), but not for South Coast Inside Waters.

To improve the model fit for South Coast Inside Waters, a grid search was conducted across plausible M values for legal RSU, plausible growth parameter values within their respective 95% credible intervals, and recruitment TD ranges (Table 3). Recruitment TD ranges could be any range with the minimum and maximum values within 10-50 mm. The grid search used 15 values for M; 5, 10 and 10 values for *a*, *d* and *f* parameters of the Tanaka growth model respectively (500 combinations); and 10 values for each of the Logistic growth model parameters (*b*, *c* and *g*, 1000 combinations). Model fit was evaluated in the same way as described above. Namely, TD distribution of the equilibrium population was compared with the observed TD distribution from surveys, and the discrepancy was calculated. The recruitment TD range was identified as the range which produced the lowest discrepancy. The model fit was improved when M for the legal RSU was reduced to 0.018 y^{-1} when Tanaka growth model was used, or reduced to 0.012 y^{-1} when Logistic growth model was used (Fig. 3). There were also some modifications to the growth parameter values (Table 2). Identified TD ranges for recruitment for the three regions were also listed in Table 2.

The recruitment TD range changes depending on the growth model. Given a fixed natural mortality rate and a fixed harvest rate, length frequency distribution of an equilibrium population would vary either with different recruitment size ranges or with different growth rates. Recruitment size range is determined in the study, having the resultant length frequency distribution according to the growth model used to best fit the data (observed length frequency distribution). Therefore, recruitment size range changes depending on the growth model applied in the simulation.

3.3.5 Variations in recruitment densities

The simulations require random annual recruitment densities. It was assumed the sample of recruitment densities from surveys could be used to approximate the year-to-year distribution for the entire region. We calculated densities of RSU within the recruitment TD range in each PFM Subarea and each survey year, using the 1994 – 2016 survey data. There are 80-100 such densities for each region. We assumed that the variation in these densities represents the variation in recruitment densities for the region, and fitted a lognormal probability distribution to these recruitment densities, using the maximum likelihood approach.

The model fits appeared to be adequate for the Mainland North Coast and Haida Gwaii (Fig. 4). However, the model fit was not good for South Coast Inside Waters when the recruitment TD

range was determined using the Tanaka growth model. For this case (South Coast Inside Waters with Tanaka growth model) there was a particularly high proportion of low (< 0.01 m^{-2}) recruitment densities. Therefore, we chose to use a lognormal distribution to fit recruitment densities larger than 0.01 m^{-2} only (Fig. 4), and assumed the probability (P_0) of producing a low recruitment density (< 0.01 m^{-2}) was the same as the proportion of such low densities in the survey data (Table 4).

In simulations, recruitment densities were randomly generated from a truncated lognormal probability distribution with the lower and upper limits set to be 0.01 m^{-2} and two times the maximum observed density. However, before using the truncated lognormal probability distribution as constructed for the South Coast Inside Waters using the Tanaka growth model, a Bernoulli distribution with a probability of P_0 was first used to determine if a low recruitment density occurs. If low recruitment densities occurred, the density was set to be 0.01 m^{-2}; otherwise, the truncated lognormal probability distribution was used to generate a recruitment density.

3.3.6 Realization of current population

To investigate impacts of alternative harvest rates on changes in mature RSU densities, we would ideally know the TD of each individual in the current RSU population to start the simulation process. The number of RSU in each region is excessively large. Also, the primary interest is in changes of densities rather than abundance. We, therefore, chose to generate a pseudo RSU population in an area of 20,000 m^2 (quadrats) to represent the current population in each region. Use of a larger area would not practically alter the simulation outputs.

The survey data provide information about TD distributions and densities. This information is used to produce an initial population. We first calculated the overall RSU density (OD) for each region by dividing the total number of observed RSU by the total number of surveyed quadrats over all surveys in the region. Density of RSU at each 1 mm TD increment is:

$$OD_d = P_d \times OD \tag{6}$$

where P_d is the proportion of RSU at d mm TD among the total number of observed RSU over all surveys. The number of RSU at d mm TD in the pseudo population is:

$$ON_d = \left[OD_d \times NQ \right] \tag{7}$$

where NQ is the number of quadrats (20,000), and the symbol $\left[\ \right]$ denotes to round the real number to the nearest integer.

Starting on the initial population, we conducted simulations over 100 years under a fixed annual harvest rate of 2% to produce 200 possible realizations of the pseudo population for each region. The simulation algorithm is as follows:

1. Construct the initial population having number of RSU at each TD set according to Eq. 7;

2. Set a beginning year (y =1);

3. Randomly generate a recruitment density (see Section 3.3.5);

4. Calculate the number of recruits as the product of the recruitment density and NQ, and round the number to the nearest integer;

5. Randomly generate a TD for each recruit from an uniform probability distribution within the lower and upper limits of the recruitment TD range (as determined in Section 3.4), and add these recruits to the population;

6. Calculate the number (NS) of sublegal RSU in the population surviving year y:

   $NS_{y+1} = NS_y \exp(-MS_y)$, where MS_y is a randomly generated natural mortality rate for sublegal RSU in year y (see Section 3.3.2);

7. Calculate the number (NH) of harvestable RSU surviving year y:

   $NH_{y+1} = NH_y (1-E) \exp(-ML_y)$, where ML_y is a randomly generated natural mortality rate for legal RSU in year y (see Section 3.3.2);

8. Calculate the number (NO) of old RSU (> 140 mm TD) surviving year y:

   $NO_{y+1} = NO_y \times \exp(-ML_y)$

9. Select surviving individuals randomly: out of NS_y sublegal, NH_y harvestable and NO_y old RSU, $\left[NS_{y+1}\right]$, $\left[NH_{y+1}\right]$ and $\left[NO_{y+1}\right]$ individual are randomly selected, respectively, where the symbol $\lceil\ \rceil$ denotes the rounding of the real number to the nearest integer;

10. Let the surviving RSU grow according to the growth model with the growth parameter values and deviates randomly generated for each individual (see Section 3.3.1);

11. Increment year (y) by one, and repeat Steps 3-10 until year 100 has been reached: producing one realization of the pseudo population;

12. Repeat Steps 1-11 until 200 realizations have been produced.

3.3.7 Evaluation of impacts of harvest rates

The impacts of alternative harvest rates on changes in mature RSU densities were evaluated through 100 years of simulation, starting on the pseudo population. These years are referred to as simulation years. The simulation process was repeated 200 times, one on each realization of the pseudo population, to produce 200 replicates. The simulation algorithm is similar to the one as described above. The major difference is that the effect of large ($\geq$ 70 mm TD) RSU densities on recruitment, through adult spine canopy protection of juveniles, was incorporated and adjusted recruitment density (DRA) was used in the simulation process. Also, harvest rate (E) varied between 0.02 and 0.24. The probability of breaching the reference points (see Section 3.2 Reference Points) for a given year was calculated as the proportion of the replicates in which mature RSU densities were lower than the reference points for that year. The simulation algorithm is as follows:

1. Randomly generate three matrices (200×100) to represent MS, ML (see Section 3.3.2) and recruitment densities (see Section 3.3.5) for 200 replicates of 100 years;

2. Set E being 2%;

3. Select the 1st realization of the pseudo population;

4. Set a beginning year ($y = 1$);

5. Calculate densities of mature (≥ 50 mm TD) and large (≥ 70 mm TD) RSU in the population in year y;

6. Use the natural mortality rates (MS_y, ML_y) on sublegal and legal RSU for year y and for the corresponding realization of the pseudo population from the matrices randomly generated in Step 1;

7. Use the recruitment density for year y and for the corresponding realization of the pseudo population from the matrix randomly generated in Step 1;

8. Adjust the recruitment density using Eqs. 4 and 5;

9. Calculate the number of recruits as the product of the adjusted recruitment density and NQ, and round the number to the nearest integer;

10. Randomly generate TDs for each recruit from an uniform probability distribution within the lower and upper limits of the recruitment TD range, and add these recruits to the population;

11. Calculate the number of sublegal RSU in the population surviving year y:

$$NS_{y+1} = NS_y \exp(-MS_y);$$

12. Calculate the number of harvestable RSU surviving year y:

$$NL_{y+1} = NH_y \left(1 - E\right) \exp(-ML_y)$$

13. Calculate the number of old RSU surviving year y:

$$NO_{y+1} = NO_y \exp(-ML_y)$$

14. Select surviving individuals randomly: out of NS_y sublegal, NH_y harvestable and NO_y old RSU, $\left[NS_{y+1}\right]$, $\left[NH_{y+1}\right]$ and $\left[NO_{y+1}\right]$ individual are randomly selected, respectively;

15. Let the surviving RSU grow according to the growth model with the growth parameter values and deviates randomly generated for each individual (See Section 3.3.1);

16. Increment year (y) by one, and repeat Steps 5-15 until the year 100 has been reached;

17. Select the next realization of the pseudo population, and repeat Steps 4-16 until 200th realization of the pseudo population has been used;

18. Increment E by 0.02, and repeat Steps 3-17 until E of 0.24 has been reached.

Notably, the same values of *MS*, *ML* (Step 6) and recruitment density (Step 7) were used for a given simulation year for each of the 12 values of *E*. Therefore, we could attribute different changes in mature RSU densities to differing harvest rates, mitigating side effects of impacts caused by differing natural mortality rates and recruitment densities.

3.4 ASSESSMENT OF STOCK STATUS

Our assessment of stock status used data from RSU fishery-independent SCUBA dive surveys conducted in commercially harvested areas of BC from 1996 to 2016 (Leus et al. 2014; Campbell et al. 1999a). Data issues did not allow the inclusion of 1994 or 1995 surveys. The RSU survey protocol employs a random-systematic design for transect placement (see Section 3.1), which means transects do not always fall on suitable RSU habitat. Transects also may fall only partly on RSU habitat so that some quadrats on a transect may not be on RSU habitat. In order to make our estimates of mature RSU spatial density comparable to the studies presented in Table 5, where RSU habitat was targeted, we developed a set of rules to define RSU habitat and then removed non-RSU habitat quadrats within surveyed transects from the spatial density calculations. We defined RSU habitat as a substrate of gravel or larger, where mud is not the predominant substrate. These are substrates that RSU can hold onto with their tube feet. Specifically this included any occurrence of bedrock, bedrock with crevices, boulders, cobble, gravel, shell, crushed shell, or whole shell in the primary or secondary substrate categories. Any quadrats where the primary substrate was mud, regardless of other substrate categories, were removed.

Mean mature RSU densities and their associated confidence bounds were estimated from survey data using the Red Urchin Analysis Program (RUAP), which is documented in detail in Lochead et al. (2015). RUAP applies the ratio estimator (Cochran 1977) to estimate mean density. Most commonly, RSU are sampled in every second quadrat along a transect, however diving restrictions and/or other logistical restrictions sometimes caused the quadrat spacing to be inconsistent. Where RSU are not sampled in a quadrat, linear interpolation is used to estimate TD and density. The linear interpolation accounts for changes in size distribution and density with depth when quadrat spacing along a transect is not the same for the whole transect. Transects are weighted based on transect length. Bootstrapping (Efron and Tibshirani 1993) is applied to the calculations in order to capture uncertainty in the estimated density.

4   RESULTS

4.1 PROJECTION SIMULATIONS AND REFERENCE POINTS

Median spatial densities (number per m^2) of mature RSU together with 95% confidence intervals over every fifth simulation year under alternative harvest rates, using the Tanaka and subsequently the Logistic growth model, are presented for Haida Gwaii (Tables 6, 7; Figures 5, 6), the Mainland North Coast (Tables 8, 9; Figures 7, 8) and the South Coast Inside Waters (Tables 10, 11; Figures 9, 10). Probabilities of mature RSU densities lower than the Limit Reference Point over every fifth simulation year, at alternative harvest rates, using the Tanaka and subsequently the Logistic growth model, are presented for Haida Gwaii (Table 12, 13), for Mainland North Coast (Tables 14, 15) and for South Coast Inside Waters (Tables 16, 17). Also, probabilities of mature RSU densities lower than the Upper Reference Point over every fifth simulation year, at alternative harvest rates, using the Tanaka and subsequently the Logistic growth model, are presented for Haida Gwaii (Table 18, 19), for Mainland North Coast (Tables 20, 21) and for South Coast Inside Waters (Tables 22, 23).

In the text below, we describe the results of the projection simulations over a 100 year time period, and the probabilities of breaching Reference Points at the 100th simulation year. Table 25 summarizes the probabilities of breaching the Reference Points at the 100th simulation year with alternative harvest rates for each of the three regions, using the Tanaka and the Logistic growth models. The 100th simulation year results are just examples from the zero to 100th simulation year range, and Fisheries Managers can choose to implement management actions

from the range of simulated results in Decision Tables 12-23, according to management objectives and in consideration of the uncertainties outlined in Section 4.3 along with socio-economic factors.

In all regions, at a given harvest rate, projected densities of mature RSU follow similar trajectories whether based on the Tanaka or the Logistic growth models (Tables 6-11; Figures 5-10). With a 2% harvest rate, simulated densities remain stable over the 100 year time period. As the harvest rate increases above 2%, simulated densities begin to decrease at higher rates. In general, above the 2% harvest rate, simulated densities of mature RSU drop most rapidly in the first 20 to 40 years and then level off.

Of the three regions, survey-derived density estimates were the highest in Haida Gwaii (Tables 6, 7; Figures 5, 6). Initial median density of mature Red Sea Urchins in year zero was 2.7 RSU/m^2 using the Tanaka and 2.4 RSU/m^2 using the Logistic growth model. Doubling the harvest rate from 2% to 4% results in a 0.5% and 0% chance of the mature RSU density falling below the USR and LRP, respectively, in 100 years with both the Tanaka and the Logistic growth models (Tables 12, 13, 18,19; Figures 5, 6). Increasing the harvest rate to 8% results in a 7.5% and 0% chance of the mature RSU density falling below the USR and LRP, respectively, in 100 years with both growth models. Increasing the harvest rate to 24% results in a 27% and 3-3.5% chance of the mature RSU density falling below the USR and LRP, respectively, in 100 years with both growth models.

On the Mainland North Coast, the initial median density estimate of mature Red Sea Urchins in year zero was approximately 1.9 RSU/m^2 with both growth models (Tables 8, 9; Figures 7, 8). Doubling the harvest rate from 2% to 4% results in a 0% chance of the density of mature RSU falling below the USR and LRP in 100 years with the Tanaka growth model, and a 1.5% and 0% chance with the Logistic growth model (Tables 14, 15, 20, 21; Figures 7, 8). Simulating a 24% harvest rate produces a 35% and 2-2.5% probability of the median density falling below the USR and LRP, respectively, in 100 years with both growth models.

The initial median density estimates of mature RSU in year zero were the lowest in the South Coast Inside Waters at 0.7 RSU/m^2 and 0.9 RSU/m^2 with the Tanaka and Logistic growth models, respectively (Tables 10, 11; Figures 9, 10). In this region, for a given harvest rate, the Tanaka model produces more rapid declines and lower densities. Similar to the other regions, doubling the harvest rate from 2% to 4% results in a 0% chance of the mature RSU density breaching the LRP in 100 years (Tables 16, 17, 22, 23; Figures 9,10). But, the 4% harvest rate produces a 62.5% and 35% probability of the mature RSU density falling below the USR in 100 years with the Tanaka and Logistic growth models, respectively. With a 24% harvest rate, both the Tanaka and Logistic growth models produce a 97% and 55% chance of the mature RSU density falling below the USR and LRP, respectively, in 100 years. In order to achieve an estimated ≤1% probability of breaching the USR in 100 years, the range of suitable harvest rates would be ≤4% in Haida Gwaii with both growth models, ≤4% using Tanaka growth model and ≤2% using Logistic growth model for the Mainland North Coast, and for the South Coast Inside Waters, <2% using the Tanaka growth model and ≤2% using the Logistic growth model (Tables 18-23; Figures 5-10).

4.2 STOCK STATUS

The exclusion of non-RSU habitat quadrats, based on our definition of RSU habitat using substrate data described in Section 3.4 (substrate of gravel or larger and no mud), resulted in the exclusion of 26% of the total number of quadrats and 1% of the total number of RSU.

	Quadrat (n)	Quadrat %	RSU (n)	RSU %
All quadrats	70367	100%	85852	100%
RSU habitat quadrats	52014	74%	84999	99%
Non-RSU habitat quadrats	18353	26%	853	1%

Red Sea Urchin populations are above the USR, and therefore in the Healthy Zone, when assessed at regional spatial scale and when they are combined. The medians of the bootstrapped sampling distribution of the mean, mature RSU density, on all quadrats identified as RSU habitat, were estimated to be:

- 2.51 RSU/m^2 (95% CI: 2.11-3.25) for Haida Gwaii
- 1.70 RSU/m^2 (95% CI: 1.57-1.95) for the Mainland North Coast
- 0.89 RSU/m^2 (95% CI: 0.81-1.06) for the South Coast Inside Waters
- 1.44 RSU/m^2 (95% CI: 1.37-1.61) for all three regions combined

4.3 UNCERTAINTIES

In this identification of provisional Reference Points and harvest options for BC's RSU fishery, the sources of uncertainty that were not quantitatively incorporated include:

4.3.1 Equilibrium State

The TD distribution of the pooled data was assumed to be at an equilibrium at the 2% harvest rate. This is a common assumption of fishery exploitation models and was a necessary assumption for the models developed in this paper. We do not expect the low exploitation intensity to have caused large fluctuations to population dynamics, so the equilibrium assumption should be acceptable. Other changing environmental factors such as sea water temperature, Ocean Acidification, (see 4.3.4 Climate Change) and recent decreases in predation from sea star wasting disease (Harvell et al. 2019, Burt et al. 2018, Schultz et al. 2016, Hewson et al. 2014) may have influenced different size classes of RSU to varying degrees, but we were not able to assess their impact on the state of equilibrium.

We also assumed a consistent 2% harvest rate, however this may not have been the case. From 1994-1997 harvest rates were a bit higher than 2% due to higher overall total allowable catches (TAC) and landings, and conversely from 2006-2013 there was a reduction in landings due to low marked demand (DFO 2018a). Overall, variation around the 2% harvest level was small.

4.3.2 Recruitment Variation

We assumed that the distribution of recruitment densities (the survey-observed RSU within the set recruitment TD range) in the surveyed PFM Subareas reflects the year-to-year distribution of recruitment densities for the entire region. In the simulation process, annual recruitment densities were randomly generated from lognormal probability distributions constructed based on the survey-observed RSU densities. However, there is evidence of strong pulse recruitment events followed, or proceeded, by near-zero recruitment events in some RSU populations (Dr. Henry Carson, Washington Dept. Fish and Wildlife, Olympia, WA, 2019, pers. comm). If the assumption of randomly generated recruitment events does not hold, the model outputs would

be affected. The severity of the impact would depend on the amount of discrepancy between these two distributions.

4.3.3 Observed Versus Simulated Populations

Comparison of survey-observed and simulated population size distributions showed that the models could predict the proportion of RSU smaller than 135-140 mm TD reasonably well, however, they under-estimated the proportion of RSU > 140 mm TD (Figure 3). Although the impact of the underestimation of the proportion of RSU > 140 mm TD is unknown, we have reason to believe that the impact would be relatively inconsequential. Model outputs are expressed in densities, rather than in biomass. Underestimation of the proportion of the larger RSU (> 140 mm TD) would cause underestimation of the biomass of mature RSU, as larger individuals would have higher weight on average. However, this underestimation should have little impact on the estimation of mature RSU densities.

4.3.4 Climate Change

Climate change is expected to cause a wide variety of impacts to the oceans and marine organisms. For example, increased concentrations of CO_2 (pCO_2) in the ocean resulting from increased atmospheric CO_2 from anthropogenic sources decreases ocean pH, an effect called ocean acidification (OA). Although more research is required to better understand the effects of OA, the existing evidence indicates potential negative direct and indirect effects to echinoderms (Haigh et al. 2015). For example, shell thickness was reduced with increased pCO_2 in a laboratory experiment with the sea urchin *Paracentrotus lividus* (Asnaghi et al. 2013). Lower shell thickness could lead to higher mortality from predation and storm events. Reproduction and early development may also be influenced by OA. Under OA conditions, RSU were shown to require higher sperm concentration to achieve fertilization success (Reuter et al. 2011). Female Purple Sea Urchins (*Strongylocentrotus purpuratus*) experimentally conditioned to low pH levels akin to OA produced larger offspring (Wong et al. 2018). In other studies, genetic markers have been used to infer possible physiological effects of OA. O'Donnell et al. (2009) measured the change in expression of a molecular protein in RSU, and linked the change to a reduced ability to handle temperature stress under OA.

Algae is the main food source for urchins, and urchins have higher growth rates when feeding on calicifying algae (Asnaghi et al. 2013). As OA negatively affects calcifying macroaglae by reducing growth and dissolution of their carbonate skeletons, urchin growth rates may also be reduced (Asnaghi et al. 2013). Also, as climate change brings warmer water temperatures, this may lead to reduced growth and recovery rates of kelp (Krumhansl et al. 2017). Increasing sea temperature could lead to an increase in frequency of disease outbreaks due to decreased host immunity, increased virulence of pathogens or pathogen range expansion (Burge et al. 2014).

4.3.5 Metapopulation Dynamics

RSU populations form a metapopulation. A stock-recruitment relationship cannot be defined in the traditional sense because planktonic larval duration is long, and recruitment to one location is unlikely to be linked to the reproductive capacity at the same location. Without information based on modelling exercises of RSU larval movement in BC, it is not possible to determine which populations act as sources of recruitment for others. Although the studies presented in this paper for informing the identification of Reference Points (Table 5) show persistence at low population densities, neither they, nor this paper attempt to account for source/sink population dynamics. Furthermore, larval dynamics may be affected by ecological differences in areas with and without Sea Otters. For example, increased algal abundance in Sea Otter areas could have the potential to affect larval transport and retention.

4.3.6 Allee Effects

Broadcast spawners such as RSU may be subject to both pre- and post-dispersal Allee effects (Quinn et al. 1993, Allee 1931). Low densities of adult RSU may cause the pre-dispersal effect of reduced fertilization efficiency because gametes do not meet (our model does not incorporate this). Post-dispersal recruitment success may also decline at low adult densities because adult spine canopies may protect juveniles from predators (our model does incorporate this).

Allee effects vary by location and are influenced by location-specific size frequencies, annual growth and survival (Ebert et al. 1998). Ebert et al. (1998) modelled population growth of Oregon/Washington and California RSU and found that Allee effects appeared to be more important to the population growth rate in California than in Oregon/Washington. A 99% reduction in fertilization rate changed the population growth rate by only 3% in Oregon/Washington, compared to nearly 10% in California. They conclude that the protection of large individuals would be most important for the long-term maintenance of Oregon/Washington populations, whereas large animals are less important for the maintenance of California populations. It is unknown how changes in fertilization rates would affect population growth rates in BC.

4.3.7 Sea Otters

The models presented in this paper do not take into account the impact of Sea Otter predation on RSU populations. Sea Otter abundance and range is increasing in the Central North Coast (Nichol et al. 2015) and on Haida Gwaii sightings of individual Sea Otters have increased in frequency over the past decade and more than one Sea Otter has been sighted at two locations within that time period (Dr. Lynn Lee, Marine Ecologist, Gwaii Haanas Parks Canada, Haida Gwaii, BC, 2019, pers. comm.). Sea Otter predation on RSU in areas that otters recolonize is expected to cause an important decrease in urchin abundance (Lee et al. 2018). RSU population trajectories in areas that Sea Otters recolonize is expected to differ from RSU population projections presented in this paper.

5   DISCUSSION

Data from 22 years of fishery-independent surveys and new models were used to update harvest rate options for the BC RSU fishery. This study also explored the concept of serious harm in the identification of a LRP and an USR, aligning this fishery with the Sustainable Fisheries Framework and DFO's [Fishery Decision-Making Framework Incorporating the Precautionary Approach](link) (DFO Precautionary Approach) (DFO 2009). Current stock status was assessed along regional geographical scales as well as these areas combined.

RSU are long-lived animals and in the absence of predation from Sea Otters, natural mortality is low. Most models assume a constant natural mortality rate across all sizes or ages. This is a necessary and accepted simplification, however it is most likely not true, especially for long-lived animals (Hoenig 1983).

In this study, when the instantaneous natural mortality rate (M) of 0.12 y^{-1} was applied to both sublegal and legal RSU, the model would produce substantially smaller proportions of larger, legal-sized RSU relative to field observations. Model fit was improved when M for legal RSU was reduced to 0.03 y^{-1} for the Mainland North Coast and Haida Gwaii, and to 0.012 y^{-1} (using Logistic growth model) and 0.018 y^{-1} (using Tanaka growth model) for the South Coast Inside Waters.

This reduction in natural mortality for large RSU is plausible because, in the absence of Sea Otters, large RSU have been shown to have reduced rates of predation (Burt el al. 2018,

Tegner and Dayton 1981). Sea Otters and Sunflower Stars (*Pycnopodia helianthoides*) are primary predators of RSU. Burt et al. (2018) examined the roles of the Sea Otter and the Sunflower Star, at influencing RSU abundance and size on the Central Coast of BC. Their study showed that while Sea Otters rapidly consumed 'large' RSU (> 80 mm TD), Sunflower Stars consume small and medium (10–70 mm TD) RSU. Our data were collected from locations where Sea Otters were not yet established, where larger RSU would attain a size-refuge from sea star predation, leading to a lower natural mortality rate. Note that in recent years, small and medium RSU would have also had reduced mortality when Sea Star Wasting Disease caused a mass mortality of Sunflower Stars and other sea stars, beginning in 2013 on the South Coast and spreading throughout the BC coast by 2015 (Harvell et al. 2019, Burt et al. 2018, Schultz et al. 2016, Hewson et al. 2014).

Reduced mortality of large RSU was also documented in southern California, where in the absence of Sea Otters, RSU with TD > 90 mm obtained partial size-refuge from its predators, the Spiny Lobster (*Panulirus interruptus*) and the California Sheephead Fish (*Semicossyphus pulcher*) (Tegner and Dayton 1981).

The instantaneous natural mortality rates for legal RSU that produced good fits to the observed RSU sample for the Mainland North Coast and Haida Gwaii growth models, did not produce a good fit for the South Coast Inside Waters. In order to improve the model fit for the South Coast Inside Waters, the instantaneous natural mortality for legal RSU was adjusted to about half the value that produced good fits for the Mainland North Coast and Haida Gwaii. Natural mortality was reduced to 0.012 y^{-1} (using Logistic growth model) and 0.018 y^{-1} (using Tanaka growth model) for the South Coast Inside Waters, compared to 0.03 y^{-1} for the Mainland North Coast and Haida Gwaii.

Reference Points are used in harvest strategies as quantitative conservation benchmarks from which management actions can be taken. In the identification of Reference Points for RSU in BC, this study explores the concept of serious harm as defined by DFO's Precautionary Approach as the point at which there is "a high probability that productivity will be so impaired that serious harm will occur" (DFO 2009). The objective of the Precautionary Approach is to avoid serious harm and to keep the stocks in the Healthy Zone, i.e. above the USR (DFO 2009). The impact of various harvest rates is determined as the probabilities of breaching the Upper Stock and Limit Reference Points. DFO Science provides advice on a range of harvest rates to DFO Fisheries Management, who then sets the rates based on the probabilities of breaching the Reference Points and taking into consideration their management objectives, the uncertainties outlined in Section 4.3 and socio-economic factors.

BC's RSU fishery has many aspects that promote conservation. For instance, only a portion of the stock is vulnerable to harvest. Population levels in most areas are higher than can be supported by the available food (kelp) and, as a result, many of the urchins have poor or no roe (gonad) development. Since the RSU fishery is a roe fishery, only those individuals with the highest quality roe are targeted, and there is a natural reserve of RSU that remain after commercial harvest. These individuals develop gonads as they access the food resource. There is also a natural reserve of RSU that consists of urchins smaller than the minimum size limit and urchins greater than 140 mm TD, the market-driven maximum targeted size for harvest (Campbell et al. 2001). An additional natural reserve of RSU exists with urchins that are inaccessible to harvesters due to their location in cracks and crevices and at deeper than depths of about 18 m, the maximum feasible depth for commercial harvest by SCUBA.

Consideration of abundance changes over long timescales is essential to the understanding of a stock's status (Lee et al. 2018). Empirical data may only be available from recent years or decades, however consideration of abundances over a longer time scale is required to fully

understand population trends (Lee et al. 2018). A short term view, without consideration of the past, can lead to incorrect conclusions about species status and trends (Lee et al. 2018, Pauly 1995).

Sea Otters are important keystone predators that supress urchin densities (Burt et al. 2018, Lee et al. 2016, Watson and Estes 2011, Kvitek et al. 1989, Pearse and Hines 1987, Estes and Palmisano 1974, Lowry and Pearse 1973). Archaeological evidence and Traditional Ecological Knowledge indicate that Sea Otters existed at relatively high abundances over larger areas of coastal BC prior to the fur trade and prior to European contact (Lee et al. 2018). It is reasonable then to conclude that RSU existed at relatively low abundances prior to the extirpation of Sea Otters from BC. However, it is important to recognize that First Nations hunting of Sea Otters likely resulted in localized areas of higher and lower sea urchin abundances (Corbett et al. 2008).

To determine an estimate of RSU densities in BC prior to the extirpation of Sea Otters, we looked at RSU densities from locations where Sea Otters had existed for at least five years. This is a reasonable time frame given that, in areas recolonized by Sea Otters, urchin densities decline within one to five years and then persist at low densities (Lee et al. 2016, Watson and Estes 2011, DFO unpublished data). Our compilation of RSU densities from areas where Sea Otters had been established for at least five years revealed RSU mean densities ranging from 0 to 4.01 RSU/m^2, with a mean of 0.48 ± 0.20 (SE) and a median of 0.06 (Table 5). We chose 0.3 RSU/m^2 from Watson and Estes (2011) as a reasonable LRP, because it was from the longest time series (25 years), it was the highest value in the time series and because the study was from BC. Since recruitment events can cause large fluctuations in the number of small RSU, we propose that the LRP be set at 0.3 mature (≥ 50mm TD)/m^2. Applying the density threshold to only mature RSU is more conservative.

The model outputs for the South Coast Inside Waters had higher probabilities of breaching reference points for a specified year, under a given harvest rate, then the other two regions. The South Coast Inside Waters region differs from the others in that densities are generally lower and it has a longer harvest history. It is also more protected from wind and waves, and has areas with high tidal currents.

In general, more conservative outputs (i.e. predicted mature RSU densities would be lower and probability of breaching reference points would be higher for a specified year under a given harvest rate) were produced with the Logistic model for Mainland North Coast and Haida Gwaii, and with the Tanaka model for the South Coast Inside Waters. The two growth models behave about the same for RSU > 30 mm TD, but very differently for small RSU. The Tanaka growth model indicates that growth rates get higher when small RSU TD increases, while the Logistic growth model indicates approximately same growth rates for small RSU. The two recruitment TD ranges as estimated using these two different growth models are mostly consistent for Mainland North Coast and Haida Gwaii. However, the two recruitment ranges for the South Coast Inside Waters are rather different. There is a high proportion of quadrats with low densities of small (< 30 mm TD) RSU in the South Coast Inside Waters. Different growth rates for small RSU as predicted by the two growth models likely caused such a big difference in recruitment TD ranges for the South Coast Inside Waters. Consequently, use of the two different recruitment TD ranges resulted in considerable differences in model outputs in terms of changes in RSU densities and probabilities of breaching biological reference points for a given harvest rate.

The spatial scale at which to assess stock status is influenced by population structure. Knowledge of RSU population structure in BC is limited, however a long pelagic larval period of six to eight weeks suggests the potential for widespread dispersal and that source and seed

populations may be distant. Miller et al. (2006) found no evidence of genetic sub-structuring in BC RSU populations. In acknowledgement of a genetically homogenous RSU population, we are suggesting one set of reference points for BC RSU populations. We assessed BC RSU stock status on a by-region spatial scale because these regions are large, geographically distinct, and RSU densities were quite different among them. We also assessed the stock status of all these regions combined.

The RSU stock status is above the USR and LRP in the combined regions , as well as in each of the three regions covered in this paper (Haida Gwaii, Mainland North Coast and South Coast Inside Waters), and therefore in the Healthy Zone. South Coast Inside Waters densities are generally lower than Mainland North Coast and Haida Gwaii densities, but all are above the USR. The estimate of the mean mature RSU density is over eight times the LRP at 2.51 RSU/m^2 for Haida Gwaii, almost six times the LRP at 1.70 RSU/m^2 for the Mainland North Coast, and almost three times the LRP at 0.89 RSU/m^2 for the South Coast Inside Waters. These estimates are the best available at this time, however caution should be taken in interpreting these values. Firstly, data from all surveyed locations and years (1996-2016) within a region were pooled, meaning RSU populations were assumed to be at an equilibrium in these regions at the 2% harvest rate. Also, although data presented in this paper cover a broad spatial and temporal scale, the areas chosen for survey may not represent the region, or coast, as a whole.

The RSU survey program was designed to estimate biomass at the PFM Area or Subarea level for the purpose of providing quota options, not to provide representative data for the assessment of stock status. To provide greater confidence in assessment of stock status, a new survey design that links the spatial and temporal components of population size and structure will be needed. Time series data that are representative of the regions will be required to detect changes over time. DFO is currently developing a new multispecies benthic marine invertebrate survey designed specifically to generate time-series data for use in marine invertebrate stock status monitoring and assessment. This new monitoring approach will be vetted through the Canadian Science Advice Secretariat Regional Peer Review process.

The next steps for the RSU program are linked to the DFO Science-wide initiative of Strategic Stock Assessment Planning currently being undertaken within the Department. The goals of this initiative are to:

- bring Pacific Region fisheries into compliance with the Precautionary Approach and DFO's Sustainable Fisheries Framework

- balance legal obligations of conservation and needs for sustainable fisheries, including First Nations, industry and recreational interests

- move from single species to multispecies approaches so as to incorporate ecosystem interactions and account for climate change impacts

- maximize efficiencies and avoid duplication of survey effort within Science

The initiative also includes the identification and communication to stakeholders and other interested parties, of the process for prioritizing Science activities and adjusting them in response to emerging issues.

An emerging issue for the Department relates to the amendments to the Fisheries Act that occurred in 2018, and the subsequent development of Bill C-68. Bill C-68 will soon make implementation of DFO's Precautionary Approach (DFO 2009) legislated and therefore mandatory. DFO Science will be required to report on RSU stock status relative to reference points.

Therefore, the next steps for the RSU program are to continue to develop a stock status monitoring program, which will include investigations into the appropriate spatial scale(s) at which to assess stock status. Future research will also focus on the impact of Sea Otters on RSU populations, the incorporation of environmental variables into stock assessments, and the application of an ecosystem approach to stock assessment. Research on RSU in Washington State has shown evidence of significant pulse recruitment with many years of near-zero recruitment in between (Dr. Henry Carson, Washington Dept. Fish and Wildlife, Olympia, WA, 2019, pers. comm). Future work in BC will include research on RSU recruitment patterns. In addition, the RSU program will investigate data limited and other assessment tools that may allow an evaluation of the provisional Reference Points recommended in this paper, as well as the opportunity to test harvest control rules under different management objectives through Management Strategy Evaluations.

6   RECOMMENDATIONS

1. Set the LRP at 0.3 mature (≥ 50 mm TD) RSU/m^2 on RSU habitat.

2. Set the USR at 0.6 mature (≥ 50 mm TD) RSU/m^2 on RSU habitat.

3. Consider probabilities of breaching Reference Points outlined in Decision Tables 12-23 to set regional RSU harvest rates.

4. Develop a survey design and monitoring program for RSU that allow the collection of time-series abundance and size data, in representative areas of the coast, for use in population monitoring and stock status assessments.

7   ACKNOWLEDGEMENTS

8   REFERENCES CITED

Allee, W.C. 1931. Animal aggregations. A study in general sociology. University of Chicago Press, Chicago, Ill.

Asnaghi V, Chiantore M, Mangialajo L, Gazeau F, and P. Francour P. 2013. Cascading effects of ocean acidification in a rocky subtidal community. PLoS ONE 8: e61978. doi: 10.1371/journal.pone. 0061978 PMID: 23613994

Bernard, F.R. and D.C. Miller. 1973. Preliminary investigation of the red sea urchin (*Strongylocentrotus franciscanus*, Agassiz) resources of British Columbia. Fish. Res. Board Can. Tech. Rep. 400. 37 p.

Bigg, M.A. and I.B. MacAskie. 1978. Sea Otters Re-established in British Columbia. J. Mammalogy 59:874–876.

Breen, P.A., Adkins, B.E. and D.C. Miller. 1978. Recovery rate of three exploited sea urchin populations from 1972 to 1977. Can. Manuscr. Rep. Fish. Mar. Ser. 1446: 27 p.

Breen, P., Carson, T., Foster, J. and E. Stewart. 1982. Changes in subtidal community structure associated with British Columbia Sea Otter transplants. Mar. Ecol. Prog. Ser. 7(1): 13-20.

Breen, P.A., Miller, D.C. and B.E. Adkins. 1976. An examination of harvested sea urchin populations in the Tofino area. Fish. Res. Board Can. Manuscr. Rep. 1401: 23 p.

Bureau, D., Campbell, A. and W.C. Hajas. 2000a. Survey of red sea urchin populations in the Kelsey Bay area, Johnstone Strait, British Columbia, 1999. Can. Manuscr. Rep.Fish. Aquat. Sci. 2542: 19 p.

Bureau, D., A. Campbell, and W. C. Hajas. 2000b. Survey of red sea urchin populations near Comox, Denman Island and Hornby Island, British Columbia, 1999. Can. Manuscr. Rep.Fish. Aquat. Sci. 2546: 17 p.

Bureau, D., A. Campbell, and W. C. Hajas. 2000c. Survey of red sea urchin populations in the Larsen Harbour and Kingkown Inlet areas, Banks Island, British Columbia, 1997. Can. Manuscr. Rep. Fish. Aquat. Sci. 2551: 19 p.

Bureau, D., Campbell, A., Hajas, W.C., and Ayers, C.A. 2000d. Survey of red sea urchin populations in the Gulf Islands, Strait of Georgia, British Columbia, 1998 and1999. Can. Manuscr. Rep. Fish. Aquat. Sci. 2552: 29 p.

Burt, J.M, Tinker, M.T., Okamoto, D.K., Demes, K.W., Holmes, K. and A.K. Salomon. 2018. Sudden collapse of a mesopredator reveals its complementary role in mediating rocky reef regime shifts. Proc. R. Soc. B. 285:20180553. (Accessed July 10, 2019)

Campbell, A. and R.M. Harbo. 1992. The sea urchin fisheries in British Columbia, Canada. p. 191-199. *In:* T. Yanagisawa, I. Yasumasu, C. Oguro, N. Suzuki and T. Motokawa [eds.]. Biology of Echinodermata. A.A. Balkema, Rotterdam.

Campbell, A., Boutillier, J.A. and J. Rogers. 1999a. Discussion on a Precautionary Approach for Management of the Red Sea Urchin Fishery in British Columbia. DFO Can. Stock Assess. Sec. Res. Doc 99/094. 49 p.

Campbell, A., Hajas, W.C. and D. Bureau. 1999b. Quota Options for the Red Sea Urchin Fishery in British Columbia for Fishing Season 2000/2001. DFO Can. Stock Assess. Sec. Res. Doc 99/201. 35 p.

Campbell, A., Tzotzos, D., Hajas, W.C. and L.L. Barton. 2001. Quota Options for the Red Sea Urchin Fishery in British Columbia for Fishing Season 2002/2003. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/141. 47 p.

Carter, S.K. and G.R. VanBlaricom. 2002. Effects of experimental harvest on red sea urchins (*Strongylocentrotus franciscanus*) in northern Washington. Fish.Bull. 100: 662–673.

Corbett, D. G., Clausey, D., Clementz, M., Koch, P. L., Doroff, A., Lefevre, C. and D. West. 2008. Aleut hunters, sea otters, and sea cows: three thousand years of interactions in the western Aleutian Islands, Alaska. In T. C. Rick & J. M. Erlandson (Eds.), *Human impacts on ancient marine ecosystems: A global perspective* (pp. 43–75). Berkeley and Los Angeles, CA: University of California Press.

Cowan, I.M. and C.J. Guiguet. 1960. The Mammals of British Columbia. Second edition. British Columbia Provincial Museum, Victoria, British Columbia, Canada.

Dewees, C.M. 2003. Sea Urchin Fisheries: A California Perspective. In: J.M. Lawrence and O. Guzman (Editors). Sea Urchins: Fisheries and Ecology. Lancaster, PA: DEStech Pubs. pp 37-55.

DFO. 2009. A fishery decision-making framework incorporating the precautionary approach. (Accessed March 22, 2018).

DFO. 2018a. Pacific Region 2018-19 Red Sea Urchin Integrated Fisheries Management Plan. (Accessed Jan. 5, 2019).

DFO. 2018b. Walleye Pollock (*Theragra chalcogramma*) stock assessment for British Columbia in 2017. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/020. (Accessed July 10, 2019)

DFO. 2018. Stock Status Update for Green Sea Urchin (*Strongylocentrotus droebachiensis*) in British Columbia and Harvest Options for the Fishery in 2018 to 2021. DFO Can. Sci. Advis. Sec. Sci. Resp. 2018/054. (Accessed July 10, 2019)

Ebert, E.E. 1968. California sea otter – census and habitat survey. Underwater Naturalist 5(3): 20-23.

Ebert, T.A. and M.P Russell. 1993. Growth and mortality of subtidal Red Sea Urchins (*Strongylocentrotus franciscanus*) at San Nicolas Island, California, USA: problems with models. Marine Biology 117(1):79-89.

Ebert, T.A. and J.R. Southon. 2003. Red sea urchins *Strongylocentrotus franciscanus* can live over 100 years: confirmation with A-bomb [14]carbon. Fish. Bull. 101(4): 915-922.

Ebert, T.A., Schroeter, S.C. and J.D. Dixon. 1998. An analysis of the importance of Allee effects in management of the red sea urchin *Strongylocentrotus franciscanus*. p. 425. In R. Mooi and M. Telford (eds). California and the World Ocean '97: Ocean Resources: An Agenda for the Future.

Efron, B. and R.J. Tibshirani. 1993. An introduction to the bootstrap. Chapman & Hall, New York, New York.

Estes, J., and D.O. Duggins. 1995. Sea Otters and Kelp Forests in Alaska: Generality and Variation in a Community Ecological Paradigm. Ecological Monographs, 65(1), 75-100.

Estes, J.A. and J.F. Palmisano. 1974. Sea Otters: their role in structuring nearshore communities. Science 185: 1058-1060.

Estes, J.A., Tinker, M.T., Williams, T.M. and D.F. Doak. 1998. Killer whale predation on sea otters linking oceanic and nearshore ecosystems. Science 282: 473-476.

Faro. J.B. 1970. A survey of subtidal sea otter habitat off Point Piňos, California. M.S. thesis. Humboldt State College. 278 pp.

Garcia, S., Sparre, P. and J. Csirke. 1989. Estimating surplus production and maximum sustainable yield from biomass data when catch and effort time series are not available. Fish. Res. 8(1): 13-23.

Gulland, J.A. 1971. The fish resources of the ocean. Fishing News (Books), West Byfleet. 255 p.

Haigh R, Ianson D, Holt C.A., Neate H.E. and A.M. Edwards. 2015. Effects of Ocean Acidification on Temperate Coastal Marine Ecosystems and Fisheries in the Northeast Pacific. PLoS ONE 10(2): e011753. (Accessed July 10, 2019).

Harvell, C.D., Montecino-Latorre, D., Caldwell, J.M., Burt, J.M., Bosley, K., Keller, A., Heron, S.F., Salomon, A.K., Lee, L., Pontier, O., Pattengill-Semmens, C., and J.K. Gaydos. 2019. Disease epidemic and a marine heat wave are associated with the continental-scale collapse of a pivotal predator (*Pycnopodia helianthoides*). Science Advances 5: eaau7042.

Hewson, I., Button J. B., Gudenkauf B. M. , Miner B., Newton A. L., Gaydos J.K., Wynne J., Groves C.L., Hendler G., Murray, M., Fradkin, S., Breitbart, M., Fahsbender, E., Lafferty, K., Kilpatrick, A.M., Miner, C.M., Raimondi, P., Lahner, L., Friedman, C.S., Daniels, S., Haulena, M., Marliave, J., Burge, C.A., Eisenlord, M.E. and C.D. Harvell. 2014. Densovirus associated with sea-star wasting disease and mass mortality. Proc. Natl. Acad. Sci. U S A 111: 17278–17283.

Hoenig, J.M. (1983). Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 81: 898-903.

Jamieson, G.S. and C.J. Schwarz. 1998. Survey protocol considerations for the 1995 sea urchin surveys. pp. 69-81. *In:* B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Jamieson, G.S., Sandoval, W., Schwarz, C.J., Taylor C. and R. Routledge. 1998a. Analysis of the 1994 red sea urchin surveys conducted in Heiltsuk Traditional Territory, Pacific Fishery Management Area 7, subareas 18 and 25. pp. 19-31. *In:* B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Jamieson, G.S., Scarf, G., Schwarz, C.J., Taylor, C. and R. Routledge. 1998b. Analysis of 1994 red sea urchin surveys conducted in Aweena K'ola Traditional Territory, subareas of Pacific Fishery Management Area 12. pp. 33-56. *In:* B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Jamieson, G.S., Jones, R., Martel, G, Schwarz, C.J., Taylor, C. and R. Routledge. 1998c. Analysis of 1994 red sea urchin survey conducted in Haida Pacific Fishery Management Area 1. pp. 3-18. *In*: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Jamieson, G.S., Cripps, K., Gijssen, M., Greba, L., Jones, R., Martel, G., Sandoval, W., Schwarz, C.J., Taylor, C. and R. Routledge. 1998d. Reanalyses of 1993 red sea urchin surveys in Haida, Heiltsuk, Kitasoo and Tsimshian traditional territories. pp. 57-68. *In:* B. J. Waddell, G. E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Kramer, D.E. and D.M.A. Nordin. 1975. Physical data from a study of size, weight and gonad quality for the red sea urchin (*Strongylocentrotus franciscanus* (Agassiz)) over a one-year period. Fish. Res. Board Can. MS Rep. 1372: 91pp.

Krumhansl, K.A, Bergman, J.N. and A.K. Salomon. 2017. Assessing the ecosystem-level consequences of a small-scale artisanal kelp fishery within the context of climate-change. Ecological Applications. 27(3): 799-813.

Kvitek, R.G, Shull, D., Canestro, D., Bowlby, E.C. and B. L. Troutman. 1989. Sea Otters and benthic prey communities in Washington State. Marine Mammal Science 5(3): 266-280.

Lance, M. M., Richardson, S.A. and H.L. Allen. 2004. Washington state recovery plan for the Sea Otter. Washington Department of Fish and Wildlife, Olympia. 91 pp.

Lee, L.C., Thorley, J., Watson, J., Reid, M. and A.K. Salomon. 2018. Diverse knowledge systems reveal social-ecological dynamics that inform species conservation status. Conservation Letters. (Accessed July 10, 2019)

Lee, L.C., Watson, J.C., Trebilco, R. and A.K. Salomon. 2016. Indirect effects and prey behavior mediate interactions between an endangered prey and recovering predator. Ecosphere, 7, e01604.

Leus, D., Campbell, A., Merner, E., Hajas, W.C., and Barton, L.L. 2014. Framework for Estimating Quota Options for the Red Sea Urchin (*Strongylocentrotus franciscanus*) Fishery in British Columbia Using Shoreline Length and Linear Density Estimates. DFO. Can. Sci. Advis. Sec. Res. Doc. 2013/094. vi + 68 p.

Lochead, J., Hajas, W., and Leus, D. 2015. Calculation of mean abundance in the Red Urchin Analysis Program and Green Urchin Analysis Program. Can. Manuscr. Rep. Fish. Aquat.Sci. 3065: vi + 41 p

Lowry, L.F. and J.S. Pearse. 1973. Abalones and Sea Urchins in an area inhabited by Sea Otters. Mar. Biol. 23(3): 213-219.

Miller, K.M, Supernault, K.J., Li, S. and R.E. Withler. 2006. Population structure in two marine invertebrate species (*Panopea abrupta* and *strongylocentrotus franciscanus*) targeted for aquaculture and enhancement in British Columbia. J. of Shellfish Research 25(1): 33-42.

Nichol, L.M., Watson J.C., Abernethy, R., Rechsteiner, E. and J. Towers. 2015. Trends in the abundance and distribution of sea otters (*Enhydra lutris*) in British Columbia updated with 2013 survey results. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/039. vii + 31 p.

Nishizaki, M.T. and J.D. Ackerman. 2007. Juvenile–adult associations in sea urchins (*Strongylocentrotus franciscanus* and *S. droebachiensis*): protection from predation and hydrodynamics in *S. franciscanus*. Mar. Biol. 151:135–145.

O'Donnell, M.J., Hammond, L.M., and G.E. Hofmann. 2009. Predicted impact of ocean acidification on a marine invertebrate: elevated CO2 alters response to thermal stress in sea urchin larvae. Mar Biol 156: 439–446. (Accessed July 10, 2019)

Pauly, D. (1995). Anecdotes and the shifting baseline syndrome of fisheries. Trends in ecology & evolution. 10(10): 430.

Pearse. J.S. and A.H. Hines. 1987. Long-term population dynamics of sea urchins in a central California kelp forest: rare recruitment and rapid decline. Mar. Ecol. Prog. Ser. 39: 275-283.

Quinn, J.F., Wing, S.R. and L.W. Botsford. 1993. Harvest refugia in marine invertebrate fisheries: models and applications to the Red Sea Urchin, *Strongylocentrotus franciscanus*. Amer. Zool. 33(6): 537-550.

Reuter K.E., Lotterhos K.E., Crim R.N., Thompson C.A. and C.D.G. Harley. 2011. Elevated pCO2 increases sperm limitation and risk of polyspermy in the red sea urchin *Strongylocentrotus franciscanus*. Glob Change Biol 17: 163–171. (Accessed July 10, 2019)

Riedman, M.L. and J.A. Estes. 1990. The sea otter (*Enhydra lutris*): behaviour, ecology and natural history. US Fish and Wildl. Serv. Biol. Rep. 90(14).126 p.

Rogers-Bennett, L., Rogers, D.W., Bennett, W.A. and T.A. Ebert. 2003. Modeling Red Sea Urchin (*Strongylocentrotus franciscanus*) growth using six growth functions. Fishery Bulletin 101(3): 614-626.

Rotterman, L.M. and T. Simon-Jackson. 1988. Sea Otter. *In* Selected marine mammals of Alaska: species accounts with research and management recommendations. Edited by J.W. Lentfer. Marine Mammal Commission. Washington, DC. 237-275 pp.

Schultz, J.A., Cloutier, R.N. and I.M. Côté. 2016. [Evidence for a trophic cascade on rocky reefs following sea star mass mortality in British Columbia](). PeerJ 4:e1980. (Accessed July 10, 2019)

Smith, S.J., H. Bourdages, J. Choi, E. Dawe, J.S. Dunham, L. Gendron, D. Hardie, M. Moriyasu, D. Orr, D. Roddick, D. Rutherford, B. Sainte-Marie, L. Savard, P. Shelton, D. Stansbury, M.J. Tremblay, and Z. Zhang. 2012. Technical Guidelines for the Provision of Scientific Advice on the Precautionary Approach for Canadian Fish Stocks: Section 7 – Invertebrate Species. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/117. iv + 30 p.

Sloan, N.A. 1986. Underwater world: Red Sea Urchin. Ottawa: Fisheries and Oceans Canada. ISBN 0662142128; 9780662142126.

Sloan, N.A., Lauridsen C.P. and R.M. Harbo. 1987. Recruitment characteristics of the commercially harvested red sea urchin *Strongylocentrotus franciscanus* in southern British Columbia, Canada. Fish. Res. 5: 55-69.

Tanaka, M. 1988. Eco-physiological meaning of parameters of ALOG growth curve. Publs Amakusa Mar. Biol. Lab. 9: 103–106.

Tanaka, M. 1982. A new growth curve which express infinite increase. Publs Amakusa Mar. Biol. Lab. 6(2): 167–177.

Tegner, M.J. and P.K. Dayton. 1977. Sea urchin recruitment patterns and implications of commercial fishing. Science 196: 324-326.

Watson, J. and J.A. Estes. 2011. Stability, resilience, and phase shifts in rocky subtidal communities along the west coast of Vancouver island, Canada. Ecological Monographs 81(2): 215-239.

Wong, J.M, Johnson, K.M., Kelly M.W. and G.E. Hofmann. 2018. Transcriptomics reveal transgenerational effects in purple sea urchin embryos: adult acclimation to upwelling conditions alters the response of their progeny to differential pCO_2 levels. Molecular Ecology 27(5): 1120-1137.

Zhang, Z., Campbell A. and D. Bureau. 2008. Growth and natural mortality rates of Red Sea Urchin (*Strongylocentrotus Franciscanus*) in British Columbia. J. Shellfish Res. 27(5): 1291-1299.

Zhang, Z., Campbell, A., Leus, D. and D. Bureau. 2011. Recruitment patterns and juvenile–adult associations of red sea urchins in three areas of British Columbia. Fisheries Res. 109: 276–284.

9 TABLES

Table 1. Summary of quadrat and RSU count (n) by region, Pacific Fishery Management Area/Subarea and year from RSU fishery-independent SCUBA dive surveys conducted in commercially harvested areas of BC from 1994 to 2016.

Haida Gwaii

Pacific Fisheries Management		Year	Quadrats (n)	RSU (n)
Area	Subarea			
1	1	1994	896	3666
1	2	1994	1553	8366
1	3	1994	1795	2797
1	7	1994	2859	2251
2	17	2010	2982	3346
2	17	2014	2690	4485
2	18	1995	451	1398
2	19	1995	142	407
2	31	1995	253	1033
2	32	1995	20	4
2	33	1995	2	0
2	35	1995	123	207
2	36	1995	67	229
2	68	1995	121	893
2	68	2014-15	879	3035
2	69	1995	36	0
2	71	1995	63	498
2	73	1995	101	340
2	75	1995	199	1037
2	78	1995	4	0
2	79	1995	195	1038
2	79	2015	306	2851
2	80	1995	85	350
2	80	2015	136	461
2	82	1995	96	126
2	82	2015	454	1485
2	85	2015	223	603
2	87	2014-15	618	3872

Mainland North Coast

Pacific Fisheries Management Area	Subarea	Year	Quadrats (n)	RSU (n)
3	1	2003	304	832
3	2	2003	106	87
4	1	2003	1145	1405
4	2	1995	948	2999
4	4	1995	108	91
4	5	2003	308	141
4	9	1995	562	1067
4	13	2007	1718	4547
5	4	2002	3	0
5	10	2002	476	874
5	10	2008	92	12
5	11	1997	190	204
5	11	2009	1408	333
5	11	2016	429	153
5	12	2002	298	400
5	13	1997	198	118
5	13	2008-09	3265	1913
5	13	2016	190	153
5	20	1997	1081	3218
5	20	2009	1122	1296
5	20	2016	1046	2606
5	21	1997	1334	3479
6	5	2004	15	110
6	10	1994	3769	11567
6	10	2004	1111	3375
6	12	1994	114	198
6	14	2000	1387	871
6	15	2000	689	1281
6	16	1995	582	2110
6	16	2000	228	408
6	17	1995	180	752
7	1	1995	28	118
7	1	1997	210	71
7	1	2001	38	219
7	2	1995	34	349
7	2	2001	160	1446
7	3	2001	165	1065
7	18	1994	1719	6648
7	18	1995	1032	3391
7	18	1996	5043	10520
7	18	1997	971	1982
7	19	1997	25	227
7	25	1994	1060	2066
7	25	1995	346	1278
7	25	1997	1272	68
7	26	1995	19	0
7	26	1997	236	4
7	31	1995	338	2300
7	31	2001	151	853
8	3	2001	49	131
8	4	2001	605	556
8	16	2001	367	471
9	12	2001	10	1

South Coast Inside Waters

| Pacific Fisheries Management | | Year | Quadrats | RSU |
Area	Subarea		(n)	(n)
11	2	1996	1128	2124
12	1	1999	199	281
12	1	2011	344	313
12	1	2016	317	182
12	2	1999	238	149
12	2	2016	8	9
12	3	1994	292	710
12	3	2001	1032	877
12	3	2009	15	5
12	4	1994	86	90
12	4	2009	63	26
12	5	1994	706	572
12	5	2009	121	23
12	6	1994	1165	369
12	6	1995	8	25
12	7	1994	203	158
12	7	1995	188	98
12	8	1994	485	356
12	8	2009	1890	182
12	9	1994	66	233
12	9	2000	20	70
12	11	1994	460	1932
12	11	2004	1203	4844
12	12	1994	69	447
12	13	1995	390	1207
12	13	1996	332	850
12	13	2000	958	3046
12	14	1996	380	2266
12	15	1994	57	341
12	16	1994	1250	844
12	16	2004	510	724
12	17	1994	443	0
12	17	2009	1000	49
12	18	1994	765	1207
12	18	2009	1490	540
12	19	1994	464	258
12	19	2009	1150	762
12	20	1994	59	209
12	21	1994	28	69
12	21	2001	157	87
12	24	1999	19	30
12	39	1994	494	45
12	39	1995	154	118
12	41	1995	106	148
13	1	2002	1100	2379
13	1	2008	1194	1765
13	2	2002	1376	2550
13	2	2007-08	1858	2179
13	9	2006	489	197
13	10	2013	908	742
13	25	2006	544	292
13	28	2006	659	587
13	30	1999	34	44
13	30	2011	119	64
13	30	2016	125	19
13	31	1999	117	314
13	31	2011	144	571
13	31	2016	129	332
13	32	1999	371	804
13	32	2011	497	1030

Pacific Fisheries Management Area	Subarea	Year	Quadrats (n)	RSU (n)
13	32	2016	541	631
13	33	1999	235	580
13	33	2011	348	872
13	33	2016	344	560
13	35	1999	119	120
13	35	2011	249	177
13	35	2016	220	117
14	5	1999	102	97
14	7	1999	427	504
14	8	1999	364	304
14	9	1999	1091	1171
14	10	1999	71	45
14	11	1999	191	176
14	12	1999	327	151
14	13	1999	67	60
14	13	2002	438	317
14	13	2007-08	1740	236
17	1	1998	103	0
17	1	2009	92	14
17	2	1998	62	9
17	2	2009	913	68
17	3	2009	296	355
17	10	2009	1079	514
17	12	2009	337	122
17	16	2009	526	0
17	17	2009	444	82
18	1	1998	186	34
18	1	2010	35	0
18	2	1998	149	41
18	2	2010	642	166
18	3	1998	318	23
18	3	2009	20	36
18	4	1999	218	77
18	5	1999	135	47
18	5	2010	2464	289
18	6	1999	1084	571
18	6	2010	3343	420
18	7	2011	94	231
18	9	1998	23	0
18	9	2010	146	0
18	11	1998	90	73
18	11	2010	425	325
19	3	2009	1881	148
19	4	2009	1881	383
19	5	2009	526	0
20	5	2001	935	210
29	4	2010	236	26
29	5	2009	881	23

Table 2. Parameter values and associated standard deviations for the Tanaka Growth model (Tanaka) and Logistic Growth model (Logistic), natural mortality rates for sublegal (< 90 mm test diameter(TD)) and legal (≥ 90 mm TD) Red Sea Urchin (RSU) in Mainland North Coast (NC), Haida Gwaii (HG) and South Coast Inside Waters (SC), parameter values and associated standard deviations for large RSU-recruitment Impact Model, and TD ranges for recruitment as calculated from using the Tanaka and Logistic.

Parameter	Symbol	Mean or Range	Standard Deviation
Tanaka	a	0.0042	0.00009
Growth	d	125.4	1.8
Model	f	0.00348	0.00014
	σ_T	0.87	-
Adjusted by grid search for SC	$\tilde{a}$	0.00437	0.00009
	$\tilde{d}$	128.9	1.8
	$\tilde{f}$	0.00321	0.00014
Logistic	b	14.38	0.1488
Growth	c	64.42	0.6934
Model	g	6.707	0.2373
	σ_L	1.181	-
Adjusted by grid search for SC	$\tilde{b}$	14.606	0.1488
	$\tilde{c}$	65.8	0.6934
	$\tilde{g}$	6.263	0.2373
Natural Mortality Rate:			
Sublegal RSU	-	0.12	0.04
Legal RSU (NC, HG)	-	0.03	0.006
Legal RSU (Tanaka: SC)	-	0.018	0.0036
Legal RSU (Logistic: SC)	-	0.012	0.0024
Large RSU-recruitment	α	0.33	0.185
Impact Model	β	-0.008	0.00625
Recruitment TD Range:			
NC(Tanaka)	-	15-38	-
HG(Tanaka)	-	24-35	-
SC(Tanaka)	-	14-30	-
NC(Logistic)	-	15-37	-
HG(Logistic)	-	20-31	-
SC(Logistic)	-	28-40	-

Table 3. Settings of parameter values for grid search for the South Coast Inside Waters region for the model used to determine recruitment size (test diameter) range. Natural mortality rate values (M) are for legal RSU, 15 values of M were tested. Ten values were tested for each of the other parameters except for parameter a for which only 5 values were tested. Total of 500 parameter combinations for Tanaka growth model and 1000 parameter combinations for Logistic growth model.

Growth Model	Parameter	Minimum	Maximum	Increment
	M	0.002	0.03	0.002
Tanaka	a	0.00403	0.00437	0.000085
Growth	d	122.1	128.9	0.76
Model	f	0.00321	0.00376	0.000061
Logistic	b	14.09	14.67	0.064
Growth	c	63.08	65.80	0.302
Model	g	6.26	7.19	0.103

Table 4. Means and standard deviations on the log scale of the lognormal probability distributions for modelling recruitment density variations in Mainland North Coast, Haida Gwaii, and South Coast Inside Waters, together with probability (P_0) of occurrence of very low recruitment density (<0.01 m^{-2}) for South Coast Inside Waters. Recruitment density variations resulting from the use of the Tanaka growth model differed from those using the Logistic growth model for the same region (see Figure 4).

Parameter	Tanka Growth Model	Logistic Growth Model
Mainland North Coast		
mean	-2.355	-2.398
sd	1.309	1.340
Haida Gwaii		
mean	-2.081	-2.269
sd	1.322	1.434
South Coast Inside Waters		
mean	-2.978	-3.831
sd	1.113	1.200
P_0	0.412	-

Table 5. Summary of estimated mean Red Sea Urchin densities (RSU/m²) ± error estimate (SE = standard error; SD = standard deviation), year, location, sample size (TR = transect, Q = quadrat), number of years of Sea Otter occupancy, and the reference from SCUBA surveys conducted within diveable depths (approximately 0 – 18 m) in areas occupied by Sea Otters for at least 5 years.

Year(s)	Mean density (RSU/m²)	Error	Location	Sample Size	Sea Otter occupancy (Years)	Reference
1967	<0.01	Not provided	Point Piňos, California	16 100x15 foot TR	5	Ebert 1968 *in* Lowry and Pearse 1973
1967	0.03	Not provided	Point Piňos, California	65 circular 30.2 m² plots + 52 line-point TR	5	Faro 1970 *in* Lowry and Pearse 1973
1972-1973	0.01	Not provided	Pacific Grove, California	45 1x10 m TR	10-11	Lowry and Pearse 1973
1972-1981	0.1	± 0.08 (SE)	Pacific Grove, California	10 to 20 circular 10 m² plots	10-11	Pearse and Hines 1987
1987	0.02	± 0.14 (SD)	Cape Alava, Olympic Peninsula, Washington	5 TR; 20 random Q/TR	18	Kvitek et al. 1989
1987	0.0	± 0.0 (SD)	Cape Johnson, Olympic Peninsula, Washington	Unspecified number of 25 or 50 m TR	18	Kvitek et al. 1989
1993	4.01	0.83 (SE)	Urchin Management District 5 (Neah Bay)	11 Fixed Index Stations (83.6 m² transects)	7	H. Carson pers. comm.[1]; Sea Otter occupancy from Lance et al. 2004
1994	2.54	0.71 (SE)	Urchin Management District 5 (Neah Bay)	11 Fixed Index Stations (83.6 m² transects)	8	H. Carson pers. comm.[1]; Sea Otter occupancy from Lance et al. 2004
1995	0.77	0.28 (SE)	Urchin Management District 5 (Neah Bay)	10 Fixed Index Stations (83.6 m² transects)	9	H. Carson pers. comm.[1]; Sea Otter occupancy from Lance et al. 2004
1997	0.03	0.012 (SE)	Urchin Management District 5 (Neah Bay)	10 Fixed Index Stations (83.6 m² transects)	11	H. Carson pers. comm.[1]; Sea Otter occupancy from Lance et al. 2004

Year(s)	Mean density (RSU/m^2)	Error	Location	Sample Size	Sea Otter occupancy (Years)	Reference
2006	0.01	0.005 (SE)	Urchin Management District 5 (Neah Bay)	11 Fixed Index Stations (83.6 m² transects)	20	H. Carson pers. comm.[1]; Sea Otter occupancy from Lance et al. 2004
2018	0.46	0.15 (SE)	Urchin Management District 5 (Neah Bay)	8 Random Stratified Sites (784.5 m² mean transect area)	32 approximately	H. Carson pers. comm.[1]
1997	0.05	± 0.03 (SE)	Goose Group, Central Coast of BC	38 TR	8	D. Bureau, pers. comm.[2]
1988	0.2	± 0.1 (SE)	Checleset Bay, WCVI	20 sites; 20-30 0.5m^2 (0.7x0.7m) Q/site	11	Watson and Estes 2011
1994	0.1	± 0.0 (SE)	Checleset Bay, WCVI	20 sites; 20-30 0.5m^2 (0.7x0.7m) Q/site	17	Watson and Estes 2011
2007	0.3	± 0.1 (SE)	Checleset Bay, WCVI	20 sites; 20-30 0.5m^2 (0.7x0.7m) Q/site	30	Watson and Estes 2011
2013	0.01	± 0.00 (SE)	Checleset Bay, WCVI	20 sites; 30 0.5m^2 (0.7x0.7m) Q/site	36	J. Watson, pers. comm.[3]
2007	0.01	± 0.0 (SE)	Kyuquot Sound, WCVI	20 sites; 20-30 0.5m^2 (0.7x0.7m) Q/site	17	Watson and Estes 2011
2013	0	± 0 (SE)	Kyuquot Sound, WCVI	20 sites; 30 0.5m^2 (0.7x0.7m) Q/site	23	J. Watson, pers. comm.[3]
2010-2011	0.25	± 1.54 (SE)	Central Coast of BC	5 sites, 6-9 TR/site (41 TR total)	12 - 30	Lee et al. 2016 ; pers. comm.[4]
2010-2011	0.06	± 0.28 (SE)	WCVI	6 sites, 6TR/site (36 TR total)	22 - 38	Lee et al. 2016 ; pers. comm.[4]
2012	0.04	± 0.03 (SE)	Tofino, WCVI	8 sites; 5 random TR/site	6	D. Leus, pers. comm.[5]

Year(s)	Mean density (RSU/m²)	Error	Location	Sample Size	Sea Otter occupancy (Years)	Reference
2013	1.13	± 0.31 (SE)	Central Coast of BC	5 sites; 18 random Q/site	~ 23	Burt et al. 2018
2014	0.82	± 0.62 (SE)	Central Coast of BC	5 sites; 18 random Q/site	~ 24	Burt et al. 2018

[1]Dominique Bureau, Aquatic Science Biologist, DFO, Nanaimo, BC, 2018, pers. comm.; [2]Dr. Jane Watson, Professor Emeritus, Vancouver Island University, Nanaimo, BC, January 2019, pers comm.; [3]Dr. Lynn Lee, Marine Ecologist, Gwaii Haanas Parks Canada, Haida Gwaii, BC, 2019, pers. comm.; [4]Dan Leus, Aquatic Science Biologist, DFO, Nanaimo, BC, 2017, pers. comm.

Table 6. Median densities (number per m²) of mature (≥ 50 mm TD) Red Sea Urchin together with 95% confidence intervals over every 5th Simulation Year under alternative harvest rates (2% to 24%) in Haida Gwaii, using Tanaka Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	2.73	2.61	2.51	2.4	2.3	2.21	2.13	2.04	1.96	1.9	1.84	1.79
	(1.83, 4.70)	(1.72, 4.56)	(1.62, 4.43)	(1.53, 4.31)	(1.45, 4.19)	(1.40, 4.08)	(1.34, 3.96)	(1.27, 3.84)	(1.21, 3.73)	(1.16, 3.63)	(1.10, 3.54)	(1.05, 3.48)
10	2.65	2.41	2.21	2.01	1.88	1.74	1.63	1.53	1.45	1.37	1.3	1.24
	(1.81, 4.64)	(1.62, 4.04)	(1.47, 3.71)	(1.31, 3.53)	(1.18, 3.40)	(1.05, 3.22)	(0.95, 3.06)	(0.88, 2.96)	(0.83, 2.87)	(0.77, 2.79)	(0.72, 2.73)	(0.68, 2.67)
15	2.72	2.31	2.04	1.82	1.64	1.5	1.37	1.26	1.18	1.1	1.04	1
	(1.74, 4.62)	(1.48, 4.18)	(1.28, 3.89)	(1.12, 3.57)	(0.98, 3.39)	(0.86, 3.25)	(0.77, 3.09)	(0.69, 2.91)	(0.64, 2.80)	(0.59, 2.70)	(0.55, 2.63)	(0.52, 2.57)
20	2.73	2.2	1.88	1.65	1.48	1.34	1.23	1.15	1.08	1.03	0.99	0.96
	(1.67, 4.38)	(1.26, 3.64)	(1.01, 3.16)	(0.82, 2.90)	(0.69, 2.65)	(0.60, 2.47)	(0.52, 2.36)	(0.47, 2.26)	(0.44, 2.20)	(0.41, 2.14)	(0.38, 2.08)	(0.37, 2.03)
25	2.73	2.14	1.8	1.57	1.4	1.26	1.16	1.08	1.01	0.98	0.94	0.92
	(1.63, 4.50)	(1.16, 3.78)	(0.93, 3.24)	(0.75, 2.98)	(0.63, 2.74)	(0.56, 2.58)	(0.51, 2.46)	(0.46, 2.36)	(0.42, 2.29)	(0.40, 2.23)	(0.37, 2.19)	(0.35, 2.15)
30	2.66	2.02	1.67	1.44	1.28	1.16	1.08	1.01	0.96	0.92	0.88	0.86
	(1.69, 4.71)	(1.11, 3.82)	(0.85, 3.34)	(0.68, 2.94)	(0.56, 2.67)	(0.49, 2.52)	(0.45, 2.40)	(0.40, 2.33)	(0.36, 2.27)	(0.34, 2.23)	(0.33, 2.19)	(0.31, 2.16)
35	2.69	1.96	1.59	1.36	1.2	1.1	1.02	0.96	0.91	0.88	0.85	0.83
	(1.76, 4.62)	(1.03, 3.90)	(0.77, 3.63)	(0.61, 3.41)	(0.52, 3.22)	(0.45, 3.05)	(0.41, 2.96)	(0.38, 2.85)	(0.36, 2.75)	(0.34, 2.68)	(0.32, 2.61)	(0.31, 2.56)
40	2.7	1.93	1.57	1.35	1.19	1.11	1.05	0.99	0.95	0.91	0.89	0.87
	(1.66, 4.77)	(0.96, 3.98)	(0.75, 3.63)	(0.59, 3.42)	(0.53, 3.25)	(0.46, 3.03)	(0.44, 2.80)	(0.42, 2.66)	(0.39, 2.57)	(0.37, 2.47)	(0.36, 2.40)	(0.34, 2.34)
45	2.74	1.86	1.51	1.32	1.18	1.06	1	0.95	0.92	0.89	0.87	0.86
	(1.76, 4.65)	(0.96, 3.59)	(0.73, 3.13)	(0.60, 2.77)	(0.54, 2.59)	(0.50, 2.44)	(0.45, 2.33)	(0.43, 2.25)	(0.42, 2.18)	(0.40, 2.13)	(0.39, 2.09)	(0.39, 2.07)
50	2.76	1.88	1.52	1.34	1.2	1.11	1.02	0.97	0.93	0.9	0.87	0.84
	(1.73, 4.41)	(0.84, 3.56)	(0.67, 3.21)	(0.58, 2.94)	(0.52, 2.80)	(0.48, 2.71)	(0.43, 2.66)	(0.40, 2.57)	(0.38, 2.47)	(0.35, 2.40)	(0.34, 2.33)	(0.32, 2.28)
55	2.74	1.88	1.55	1.32	1.17	1.07	0.99	0.93	0.88	0.85	0.83	0.81
	(1.61, 4.72)	(0.81, 3.70)	(0.61, 3.34)	(0.49, 3.04)	(0.43, 2.76)	(0.38, 2.52)	(0.35, 2.41)	(0.33, 2.35)	(0.31, 2.31)	(0.29, 2.27)	(0.28, 2.24)	(0.27, 2.21)
60	2.75	1.81	1.45	1.25	1.12	1.03	0.97	0.93	0.9	0.87	0.86	0.84
	(1.77, 4.34)	(0.81, 3.39)	(0.61, 2.90)	(0.48, 2.63)	(0.43, 2.41)	(0.39, 2.24)	(0.37, 2.15)	(0.35, 2.07)	(0.34, 2.03)	(0.31, 2.00)	(0.29, 1.94)	(0.27, 1.88)
65	2.7	1.74	1.42	1.24	1.11	1.03	0.97	0.93	0.9	0.87	0.85	0.84
	(1.71, 4.45)	(0.81, 3.53)	(0.64, 3.07)	(0.55, 2.77)	(0.51, 2.58)	(0.44, 2.44)	(0.41, 2.34)	(0.38, 2.27)	(0.35, 2.22)	(0.33, 2.18)	(0.31, 2.15)	(0.30, 2.12)
70	2.62	1.7	1.38	1.2	1.09	1	0.93	0.89	0.86	0.83	0.81	0.79
	(1.78, 4.58)	(0.81, 3.59)	(0.64, 3.16)	(0.55, 2.88)	(0.48, 2.66)	(0.42, 2.54)	(0.38, 2.48)	(0.35, 2.44)	(0.33, 2.41)	(0.31, 2.33)	(0.30, 2.29)	(0.28, 2.27)
75	2.71	1.7	1.37	1.21	1.1	1.04	0.99	0.95	0.92	0.89	0.87	0.86
	(1.77, 4.53)	(0.90, 3.66)	(0.72, 3.26)	(0.59, 2.99)	(0.51, 2.79)	(0.47, 2.62)	(0.43, 2.57)	(0.40, 2.49)	(0.38, 2.44)	(0.36, 2.39)	(0.35, 2.35)	(0.34, 2.31)
80	2.75	1.72	1.43	1.25	1.14	1.06	1	0.95	0.91	0.88	0.86	0.83
	(1.71, 4.57)	(0.81, 3.45)	(0.65, 2.92)	(0.55, 2.61)	(0.48, 2.35)	(0.44, 2.23)	(0.41, 2.09)	(0.39, 2.05)	(0.37, 2.00)	(0.36, 1.96)	(0.34, 1.92)	(0.33, 1.89)
85	2.78	1.83	1.47	1.27	1.17	1.08	1.02	0.97	0.94	0.91	0.88	0.85
	(1.71, 4.47)	(0.84, 3.35)	(0.64, 2.94)	(0.52, 2.75)	(0.48, 2.67)	(0.45, 2.61)	(0.43, 2.57)	(0.40, 2.53)	(0.38, 2.51)	(0.37, 2.47)	(0.35, 2.42)	(0.34, 2.37)
90	2.77	1.77	1.47	1.27	1.16	1.09	1.04	1	0.96	0.93	0.9	0.89
	(1.76, 4.33)	(0.75, 3.38)	(0.61, 2.94)	(0.50, 2.71)	(0.44, 2.53)	(0.40, 2.37)	(0.37, 2.26)	(0.35, 2.18)	(0.33, 2.13)	(0.32, 2.10)	(0.31, 2.08)	(0.30, 2.06)
95	2.62	1.73	1.43	1.26	1.13	1.06	0.99	0.93	0.89	0.86	0.84	0.81
	(1.83, 4.49)	(0.82, 3.44)	(0.66, 2.99)	(0.56, 2.72)	(0.49, 2.55)	(0.45, 2.43)	(0.42, 2.35)	(0.38, 2.29)	(0.34, 2.24)	(0.32, 2.20)	(0.31, 2.16)	(0.30, 2.13)
100	2.65	1.72	1.38	1.2	1.1	1.03	0.97	0.92	0.88	0.85	0.82	0.8
	(1.74, 4.23)	(0.75, 3.39)	(0.57, 2.91)	(0.50, 2.63)	(0.44, 2.46)	(0.41, 2.33)	(0.37, 2.23)	(0.35, 2.16)	(0.33, 2.05)	(0.31, 1.97)	(0.30, 1.96)	(0.29, 1.93)

Table 7. Median densities (number per m²) of mature (≥ 50 mm TD) Red Sea Urchin together with 95% confidence intervals over every 5th Simulation Year under alternative harvest rates (2% to 24%) in Haida Gwaii, using Logistic Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	2.35	2.23	2.13	2.05	1.97	1.9	1.84	1.76	1.7	1.64	1.59	1.55
	(1.47, 4.09)	(1.39, 3.88)	(1.32, 3.72)	(1.26, 3.62)	(1.21, 3.54)	(1.16, 3.46)	(1.10, 3.38)	(1.04, 3.30)	(0.99, 3.23)	(0.94, 3.15)	(0.90, 3.08)	(0.85, 3.03)
10	2.37	2.12	1.95	1.8	1.68	1.57	1.48	1.39	1.32	1.27	1.23	1.19
	(1.46, 4.37)	(1.33, 3.86)	(1.21, 3.51)	(1.11, 3.31)	(1.03, 3.15)	(0.96, 3.07)	(0.89, 3.01)	(0.81, 2.95)	(0.75, 2.89)	(0.70, 2.78)	(0.64, 2.69)	(0.60, 2.65)
15	2.4	2.08	1.86	1.68	1.53	1.41	1.31	1.22	1.15	1.08	1.03	1
	(1.45, 4.17)	(1.23, 3.75)	(1.06, 3.40)	(0.93, 3.22)	(0.83, 2.99)	(0.75, 2.85)	(0.68, 2.73)	(0.61, 2.62)	(0.55, 2.53)	(0.52, 2.48)	(0.49, 2.43)	(0.47, 2.40)
20	2.35	1.94	1.69	1.5	1.36	1.25	1.15	1.08	1.03	0.99	0.95	0.93
	(1.47, 4.24)	(1.15, 3.79)	(0.98, 3.46)	(0.82, 3.14)	(0.69, 2.90)	(0.61, 2.81)	(0.55, 2.64)	(0.50, 2.55)	(0.46, 2.47)	(0.43, 2.41)	(0.40, 2.35)	(0.39, 2.30)
25	2.36	1.87	1.59	1.39	1.25	1.14	1.06	1	0.96	0.93	0.9	0.87
	(1.40, 4.32)	(1.04, 3.84)	(0.84, 3.50)	(0.71, 3.23)	(0.61, 2.99)	(0.53, 2.79)	(0.48, 2.63)	(0.43, 2.53)	(0.40, 2.47)	(0.38, 2.43)	(0.36, 2.39)	(0.35, 2.35)
30	2.35	1.85	1.57	1.36	1.23	1.12	1.06	0.99	0.95	0.92	0.9	0.86
	(1.47, 4.25)	(1.04, 3.70)	(0.84, 3.45)	(0.68, 3.25)	(0.60, 3.10)	(0.54, 2.90)	(0.50, 2.74)	(0.46, 2.63)	(0.43, 2.54)	(0.41, 2.47)	(0.39, 2.41)	(0.38, 2.36)
35	2.37	1.77	1.46	1.28	1.15	1.04	0.97	0.92	0.9	0.88	0.85	0.83
	(1.46, 4.07)	(0.99, 3.62)	(0.78, 3.24)	(0.65, 2.90)	(0.55, 2.71)	(0.50, 2.58)	(0.46, 2.49)	(0.44, 2.44)	(0.41, 2.41)	(0.40, 2.36)	(0.39, 2.34)	(0.38, 2.33)
40	2.32	1.7	1.44	1.26	1.15	1.06	0.99	0.94	0.91	0.89	0.86	0.85
	(1.46, 4.06)	(0.93, 3.59)	(0.77, 3.24)	(0.66, 2.97)	(0.56, 2.81)	(0.48, 2.68)	(0.44, 2.62)	(0.41, 2.58)	(0.39, 2.54)	(0.37, 2.49)	(0.36, 2.44)	(0.34, 2.37)
45	2.39	1.73	1.45	1.26	1.15	1.08	1.02	0.99	0.95	0.92	0.9	0.88
	(1.44, 4.01)	(0.83, 3.37)	(0.62, 3.00)	(0.50, 2.73)	(0.43, 2.55)	(0.40, 2.43)	(0.37, 2.32)	(0.35, 2.27)	(0.33, 2.23)	(0.32, 2.17)	(0.31, 2.11)	(0.30, 2.10)
50	2.39	1.73	1.45	1.25	1.13	1.05	1	0.96	0.93	0.9	0.88	0.87
	(1.55, 3.91)	(0.90, 3.15)	(0.70, 2.80)	(0.57, 2.60)	(0.52, 2.47)	(0.48, 2.40)	(0.46, 2.34)	(0.44, 2.29)	(0.41, 2.25)	(0.38, 2.22)	(0.37, 2.20)	(0.36, 2.18)
55	2.39	1.7	1.45	1.27	1.14	1.07	1.02	0.98	0.95	0.92	0.91	0.89
	(1.48, 4.23)	(0.83, 3.46)	(0.66, 3.14)	(0.57, 2.85)	(0.52, 2.67)	(0.48, 2.56)	(0.45, 2.46)	(0.42, 2.40)	(0.40, 2.35)	(0.38, 2.33)	(0.37, 2.29)	(0.36, 2.26)
60	2.43	1.62	1.39	1.23	1.13	1.06	1	0.96	0.92	0.9	0.88	0.87
	(1.55, 4.03)	(0.92, 3.36)	(0.71, 2.99)	(0.57, 2.74)	(0.49, 2.58)	(0.44, 2.46)	(0.40, 2.39)	(0.38, 2.35)	(0.36, 2.30)	(0.35, 2.27)	(0.34, 2.23)	(0.33, 2.21)
65	2.45	1.71	1.41	1.24	1.14	1.05	1	0.95	0.91	0.88	0.86	0.85
	(1.52, 3.91)	(0.81, 3.29)	(0.63, 2.98)	(0.54, 2.65)	(0.49, 2.46)	(0.44, 2.34)	(0.40, 2.30)	(0.37, 2.28)	(0.36, 2.26)	(0.36, 2.25)	(0.35, 2.24)	(0.35, 2.23)
70	2.41	1.75	1.47	1.3	1.2	1.13	1.07	1.01	0.97	0.95	0.93	0.91
	(1.50, 4.22)	(0.86, 3.30)	(0.67, 2.92)	(0.56, 2.72)	(0.49, 2.62)	(0.46, 2.55)	(0.43, 2.51)	(0.41, 2.46)	(0.40, 2.42)	(0.39, 2.40)	(0.37, 2.38)	(0.36, 2.35)
75	2.35	1.62	1.36	1.22	1.12	1.04	0.98	0.93	0.91	0.88	0.86	0.84
	(1.50, 4.36)	(0.86, 3.44)	(0.67, 3.09)	(0.59, 2.97)	(0.54, 2.88)	(0.50, 2.68)	(0.47, 2.53)	(0.45, 2.40)	(0.43, 2.30)	(0.42, 2.23)	(0.40, 2.16)	(0.39, 2.13)
80	2.34	1.57	1.31	1.16	1.06	0.99	0.94	0.89	0.87	0.85	0.83	0.82
	(1.54, 4.44)	(0.80, 3.57)	(0.64, 3.21)	(0.54, 3.00)	(0.47, 2.83)	(0.43, 2.69)	(0.40, 2.58)	(0.38, 2.49)	(0.37, 2.42)	(0.36, 2.37)	(0.35, 2.33)	(0.33, 2.29)
85	2.32	1.59	1.32	1.12	1.02	0.95	0.9	0.86	0.84	0.81	0.8	0.78
	(1.50, 4.15)	(0.79, 3.20)	(0.60, 2.91)	(0.51, 2.77)	(0.44, 2.67)	(0.41, 2.58)	(0.38, 2.51)	(0.36, 2.45)	(0.34, 2.40)	(0.32, 2.37)	(0.31, 2.35)	(0.29, 2.32)
90	2.33	1.57	1.31	1.18	1.07	1	0.96	0.92	0.89	0.86	0.85	0.83
	(1.50, 4.00)	(0.71, 3.27)	(0.55, 3.03)	(0.47, 2.84)	(0.41, 2.74)	(0.37, 2.65)	(0.35, 2.54)	(0.32, 2.45)	(0.31, 2.39)	(0.30, 2.32)	(0.28, 2.28)	(0.28, 2.24)
95	2.36	1.57	1.27	1.14	1.03	0.96	0.91	0.88	0.86	0.84	0.82	0.8
	(1.37, 3.84)	(0.73, 3.03)	(0.57, 2.74)	(0.49, 2.54)	(0.44, 2.39)	(0.40, 2.29)	(0.37, 2.19)	(0.36, 2.14)	(0.34, 2.09)	(0.33, 2.05)	(0.32, 2.02)	(0.30, 1.99)
100	2.33	1.52	1.29	1.13	1.02	0.95	0.91	0.86	0.83	0.81	0.79	0.77
	(1.35, 3.85)	(0.67, 3.16)	(0.52, 2.85)	(0.45, 2.61)	(0.41, 2.42)	(0.37, 2.25)	(0.34, 2.18)	(0.31, 2.12)	(0.30, 2.08)	(0.29, 2.04)	(0.28, 2.01)	(0.27, 1.99)

Table 8. Median densities (number per m²) of mature (≥ 50 mm TD) Red Sea Urchin together with 95% confidence intervals over every 5th Simulation Year under alternative harvest rates (2% to 24%) in Mainland North Coast, using Tanaka Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	1.92	1.84	1.77	1.7	1.63	1.57	1.52	1.47	1.41	1.36	1.32	1.27
	(1.20, 3.09)	(1.16, 2.98)	(1.12, 2.88)	(1.07, 2.78)	(1.02, 2.70)	(0.97, 2.61)	(0.92, 2.54)	(0.88, 2.46)	(0.85, 2.40)	(0.82, 2.34)	(0.79, 2.31)	(0.76, 2.28)
10	1.92	1.73	1.6	1.49	1.38	1.29	1.22	1.14	1.08	1.04	1	0.96
	(1.22, 3.23)	(1.08, 3.02)	(0.99, 2.82)	(0.90, 2.63)	(0.82, 2.49)	(0.76, 2.42)	(0.70, 2.35)	(0.66, 2.29)	(0.61, 2.22)	(0.58, 2.15)	(0.54, 2.09)	(0.50, 2.04)
15	1.95	1.69	1.51	1.36	1.24	1.16	1.09	1.03	0.98	0.94	0.91	0.88
	(1.27, 2.86)	(1.09, 2.59)	(0.93, 2.43)	(0.83, 2.31)	(0.72, 2.20)	(0.64, 2.12)	(0.58, 2.04)	(0.53, 1.96)	(0.50, 1.90)	(0.47, 1.83)	(0.44, 1.76)	(0.41, 1.70)
20	1.93	1.61	1.42	1.25	1.14	1.06	0.98	0.91	0.87	0.84	0.81	0.79
	(1.27, 3.05)	(1.01, 2.63)	(0.85, 2.38)	(0.72, 2.19)	(0.62, 2.05)	(0.55, 1.94)	(0.50, 1.86)	(0.46, 1.78)	(0.42, 1.70)	(0.40, 1.65)	(0.37, 1.63)	(0.36, 1.61)
25	1.86	1.53	1.29	1.14	1.02	0.93	0.87	0.82	0.78	0.74	0.71	0.69
	(1.34, 2.99)	(0.96, 2.65)	(0.78, 2.45)	(0.64, 2.20)	(0.56, 2.04)	(0.48, 1.92)	(0.43, 1.80)	(0.40, 1.68)	(0.36, 1.58)	(0.34, 1.53)	(0.33, 1.49)	(0.31, 1.46)
30	1.91	1.49	1.26	1.11	1	0.92	0.87	0.82	0.79	0.77	0.75	0.73
	(1.27, 3.01)	(0.92, 2.61)	(0.74, 2.32)	(0.61, 2.09)	(0.52, 1.94)	(0.45, 1.82)	(0.40, 1.73)	(0.36, 1.67)	(0.34, 1.63)	(0.32, 1.57)	(0.31, 1.53)	(0.30, 1.49)
35	1.86	1.42	1.2	1.06	0.96	0.9	0.85	0.8	0.77	0.74	0.73	0.71
	(1.23, 3.05)	(0.88, 2.61)	(0.69, 2.35)	(0.57, 2.18)	(0.48, 2.06)	(0.42, 1.96)	(0.38, 1.87)	(0.36, 1.83)	(0.34, 1.78)	(0.32, 1.74)	(0.31, 1.71)	(0.30, 1.69)
40	1.92	1.5	1.26	1.1	1	0.93	0.87	0.83	0.8	0.78	0.76	0.74
	(1.16, 3.10)	(0.83, 2.60)	(0.64, 2.30)	(0.52, 2.10)	(0.44, 1.99)	(0.40, 1.90)	(0.37, 1.82)	(0.35, 1.76)	(0.33, 1.72)	(0.31, 1.69)	(0.30, 1.67)	(0.29, 1.65)
45	1.98	1.53	1.26	1.1	1.02	0.95	0.9	0.86	0.83	0.8	0.79	0.78
	(1.26, 2.94)	(0.85, 2.51)	(0.66, 2.27)	(0.54, 2.10)	(0.47, 1.94)	(0.44, 1.79)	(0.41, 1.66)	(0.39, 1.56)	(0.37, 1.51)	(0.36, 1.48)	(0.35, 1.46)	(0.34, 1.44)
50	1.93	1.43	1.18	1.04	0.94	0.88	0.84	0.8	0.76	0.75	0.73	0.72
	(1.25, 2.95)	(0.81, 2.48)	(0.65, 2.20)	(0.56, 1.98)	(0.51, 1.82)	(0.47, 1.75)	(0.43, 1.68)	(0.41, 1.59)	(0.39, 1.55)	(0.37, 1.52)	(0.36, 1.49)	(0.35, 1.47)
55	1.94	1.42	1.16	1.03	0.94	0.87	0.83	0.79	0.77	0.75	0.73	0.72
	(1.25, 3.07)	(0.79, 2.55)	(0.64, 2.27)	(0.55, 2.12)	(0.49, 1.99)	(0.45, 1.89)	(0.42, 1.83)	(0.41, 1.79)	(0.39, 1.75)	(0.37, 1.73)	(0.36, 1.71)	(0.35, 1.69)
60	1.87	1.36	1.13	0.98	0.89	0.82	0.77	0.74	0.71	0.69	0.67	0.67
	(1.26, 2.88)	(0.79, 2.48)	(0.63, 2.18)	(0.54, 2.05)	(0.48, 1.96)	(0.44, 1.89)	(0.41, 1.82)	(0.39, 1.77)	(0.37, 1.73)	(0.36, 1.69)	(0.36, 1.67)	(0.34, 1.64)
65	1.85	1.35	1.11	0.97	0.88	0.81	0.77	0.74	0.72	0.69	0.67	0.65
	(1.23, 2.90)	(0.76, 2.24)	(0.59, 2.01)	(0.51, 1.85)	(0.45, 1.76)	(0.42, 1.69)	(0.39, 1.64)	(0.36, 1.58)	(0.34, 1.56)	(0.33, 1.53)	(0.32, 1.51)	(0.31, 1.49)
70	1.9	1.34	1.1	0.98	0.9	0.84	0.81	0.78	0.76	0.74	0.73	0.71
	(1.22, 2.89)	(0.73, 2.31)	(0.59, 2.00)	(0.51, 1.84)	(0.45, 1.71)	(0.41, 1.63)	(0.38, 1.57)	(0.36, 1.52)	(0.34, 1.48)	(0.33, 1.44)	(0.32, 1.42)	(0.31, 1.40)
75	1.9	1.36	1.13	0.99	0.91	0.85	0.8	0.77	0.75	0.73	0.7	0.69
	(1.26, 2.80)	(0.76, 2.24)	(0.61, 1.96)	(0.54, 1.79)	(0.49, 1.71)	(0.43, 1.66)	(0.40, 1.62)	(0.39, 1.56)	(0.37, 1.51)	(0.36, 1.46)	(0.34, 1.42)	(0.33, 1.38)
80	1.94	1.4	1.18	1.05	0.95	0.89	0.84	0.81	0.79	0.76	0.74	0.72
	(1.22, 2.95)	(0.73, 2.36)	(0.57, 2.10)	(0.50, 1.95)	(0.44, 1.82)	(0.41, 1.71)	(0.39, 1.66)	(0.37, 1.62)	(0.36, 1.59)	(0.34, 1.57)	(0.33, 1.55)	(0.33, 1.53)
85	1.86	1.3	1.08	0.96	0.88	0.82	0.78	0.75	0.72	0.7	0.68	0.66
	(1.15, 3.04)	(0.67, 2.45)	(0.55, 2.24)	(0.45, 2.11)	(0.40, 1.96)	(0.36, 1.85)	(0.33, 1.78)	(0.31, 1.72)	(0.29, 1.67)	(0.29, 1.64)	(0.27, 1.60)	(0.27, 1.58)
90	1.91	1.33	1.11	0.98	0.9	0.84	0.8	0.76	0.74	0.72	0.7	0.7
	(1.28, 2.92)	(0.70, 2.46)	(0.57, 2.18)	(0.50, 1.96)	(0.44, 1.80)	(0.40, 1.74)	(0.37, 1.66)	(0.35, 1.59)	(0.34, 1.56)	(0.32, 1.55)	(0.31, 1.54)	(0.31, 1.53)
95	1.87	1.29	1.09	0.96	0.89	0.84	0.79	0.76	0.73	0.71	0.69	0.68
	(1.24, 2.90)	(0.77, 2.25)	(0.61, 2.03)	(0.52, 1.89)	(0.46, 1.77)	(0.42, 1.71)	(0.39, 1.63)	(0.37, 1.57)	(0.35, 1.51)	(0.33, 1.47)	(0.32, 1.44)	(0.31, 1.43)
100	1.85	1.34	1.14	1	0.91	0.84	0.8	0.77	0.74	0.73	0.71	0.7
	(1.33, 2.98)	(0.71, 2.40)	(0.59, 2.05)	(0.51, 1.87)	(0.48, 1.77)	(0.45, 1.73)	(0.41, 1.67)	(0.39, 1.62)	(0.37, 1.58)	(0.37, 1.56)	(0.35, 1.54)	(0.35, 1.52)

Table 9. Median densities (number per m²) of mature (≥ 50 mm TD) Red Sea Urchin together with 95% confidence intervals over every 5th Simulation Year under alternative harvest rates (2% to 24%) in Mainland North Coast, using Logistic Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	1.88	1.8	1.75	1.68	1.61	1.56	1.49	1.44	1.38	1.33	1.29	1.24
	(1.24, 2.95)	(1.18, 2.87)	(1.13, 2.80)	(1.08, 2.73)	(1.03, 2.67)	(0.98, 2.61)	(0.94, 2.57)	(0.89, 2.53)	(0.86, 2.50)	(0.83, 2.45)	(0.80, 2.40)	(0.77, 2.35)
10	1.85	1.69	1.57	1.46	1.36	1.28	1.21	1.14	1.09	1.05	1.01	0.97
	(1.19, 3.03)	(1.07, 2.78)	(0.98, 2.60)	(0.90, 2.45)	(0.82, 2.38)	(0.76, 2.31)	(0.70, 2.23)	(0.65, 2.15)	(0.61, 2.09)	(0.58, 2.03)	(0.56, 1.98)	(0.53, 1.94)
15	1.85	1.6	1.44	1.3	1.18	1.1	1.03	0.98	0.93	0.9	0.87	0.83
	(1.20, 3.17)	(1.04, 2.88)	(0.90, 2.67)	(0.79, 2.56)	(0.72, 2.42)	(0.65, 2.30)	(0.59, 2.22)	(0.54, 2.16)	(0.50, 2.10)	(0.47, 2.06)	(0.45, 2.02)	(0.43, 1.99)
20	1.87	1.54	1.34	1.21	1.11	1.03	0.96	0.91	0.87	0.85	0.82	0.8
	(1.17, 2.90)	(0.96, 2.60)	(0.83, 2.41)	(0.72, 2.30)	(0.63, 2.21)	(0.56, 2.12)	(0.50, 2.03)	(0.46, 1.95)	(0.43, 1.89)	(0.40, 1.84)	(0.38, 1.81)	(0.37, 1.78)
25	1.86	1.54	1.33	1.19	1.08	1.01	0.95	0.9	0.87	0.84	0.82	0.8
	(1.25, 3.13)	(0.96, 2.80)	(0.77, 2.54)	(0.65, 2.34)	(0.57, 2.20)	(0.51, 2.10)	(0.46, 2.01)	(0.43, 1.94)	(0.41, 1.88)	(0.39, 1.84)	(0.38, 1.80)	(0.37, 1.77)
30	1.87	1.5	1.27	1.12	1.01	0.95	0.89	0.84	0.81	0.79	0.77	0.75
	(1.20, 2.85)	(0.88, 2.42)	(0.72, 2.25)	(0.60, 2.07)	(0.52, 1.97)	(0.46, 1.89)	(0.42, 1.82)	(0.39, 1.78)	(0.37, 1.72)	(0.35, 1.68)	(0.34, 1.63)	(0.33, 1.60)
35	1.81	1.42	1.17	1.04	0.93	0.87	0.81	0.77	0.74	0.72	0.7	0.7
	(1.26, 2.78)	(0.88, 2.41)	(0.70, 2.19)	(0.59, 2.01)	(0.50, 1.90)	(0.46, 1.81)	(0.43, 1.75)	(0.41, 1.71)	(0.39, 1.68)	(0.37, 1.64)	(0.35, 1.60)	(0.34, 1.57)
40	1.8	1.36	1.13	0.99	0.89	0.84	0.79	0.75	0.72	0.71	0.69	0.67
	(1.20, 2.82)	(0.83, 2.40)	(0.69, 2.21)	(0.58, 2.09)	(0.52, 1.98)	(0.46, 1.88)	(0.44, 1.79)	(0.42, 1.72)	(0.40, 1.67)	(0.38, 1.63)	(0.37, 1.59)	(0.36, 1.56)
45	1.78	1.35	1.14	1	0.91	0.84	0.79	0.76	0.74	0.72	0.7	0.69
	(1.17, 2.75)	(0.79, 2.23)	(0.65, 1.98)	(0.54, 1.81)	(0.49, 1.70)	(0.44, 1.61)	(0.41, 1.56)	(0.39, 1.53)	(0.37, 1.49)	(0.36, 1.46)	(0.34, 1.43)	(0.33, 1.41)
50	1.78	1.3	1.1	0.97	0.88	0.83	0.78	0.75	0.72	0.71	0.7	0.68
	(1.20, 3.14)	(0.77, 2.63)	(0.60, 2.36)	(0.51, 2.17)	(0.44, 2.05)	(0.39, 1.98)	(0.36, 1.92)	(0.35, 1.88)	(0.33, 1.85)	(0.32, 1.82)	(0.31, 1.80)	(0.31, 1.78)
55	1.77	1.26	1.05	0.92	0.84	0.78	0.74	0.72	0.7	0.68	0.67	0.65
	(1.18, 2.91)	(0.74, 2.33)	(0.56, 2.09)	(0.48, 1.98)	(0.41, 1.91)	(0.37, 1.85)	(0.34, 1.78)	(0.32, 1.72)	(0.31, 1.68)	(0.30, 1.63)	(0.29, 1.59)	(0.29, 1.56)
60	1.81	1.27	1.07	0.95	0.89	0.83	0.8	0.76	0.75	0.73	0.72	0.71
	(1.13, 2.88)	(0.73, 2.33)	(0.57, 2.12)	(0.50, 1.93)	(0.45, 1.82)	(0.42, 1.73)	(0.39, 1.66)	(0.38, 1.61)	(0.36, 1.58)	(0.35, 1.56)	(0.33, 1.54)	(0.33, 1.52)
65	1.77	1.26	1.06	0.94	0.87	0.82	0.78	0.75	0.73	0.71	0.69	0.68
	(1.22, 2.73)	(0.78, 2.31)	(0.63, 2.08)	(0.54, 1.93)	(0.48, 1.82)	(0.44, 1.75)	(0.40, 1.69)	(0.38, 1.64)	(0.36, 1.59)	(0.34, 1.56)	(0.33, 1.53)	(0.32, 1.51)
70	1.78	1.25	1.06	0.95	0.89	0.84	0.8	0.76	0.74	0.72	0.7	0.69
	(1.22, 2.74)	(0.72, 2.36)	(0.58, 2.13)	(0.52, 1.98)	(0.46, 1.88)	(0.42, 1.79)	(0.38, 1.73)	(0.37, 1.69)	(0.35, 1.65)	(0.34, 1.62)	(0.33, 1.59)	(0.31, 1.56)
75	1.77	1.29	1.1	0.98	0.9	0.85	0.82	0.79	0.76	0.74	0.73	0.72
	(1.28, 2.67)	(0.74, 2.26)	(0.60, 2.04)	(0.52, 1.85)	(0.46, 1.78)	(0.42, 1.71)	(0.39, 1.64)	(0.37, 1.60)	(0.35, 1.56)	(0.34, 1.52)	(0.33, 1.49)	(0.31, 1.47)
80	1.82	1.31	1.11	1.01	0.93	0.88	0.84	0.82	0.79	0.77	0.75	0.74
	(1.26, 2.99)	(0.71, 2.39)	(0.57, 2.10)	(0.50, 1.89)	(0.47, 1.80)	(0.44, 1.75)	(0.41, 1.70)	(0.39, 1.66)	(0.37, 1.64)	(0.36, 1.62)	(0.35, 1.62)	(0.34, 1.61)
85	1.85	1.33	1.14	1.02	0.95	0.89	0.84	0.81	0.79	0.77	0.75	0.74
	(1.17, 2.95)	(0.75, 2.30)	(0.59, 2.05)	(0.50, 1.91)	(0.43, 1.81)	(0.40, 1.75)	(0.38, 1.71)	(0.37, 1.67)	(0.35, 1.65)	(0.33, 1.63)	(0.33, 1.61)	(0.31, 1.59)
90	1.87	1.36	1.16	1.03	0.94	0.89	0.85	0.83	0.81	0.78	0.76	0.74
	(1.17, 2.74)	(0.70, 2.18)	(0.59, 1.97)	(0.51, 1.85)	(0.45, 1.73)	(0.41, 1.67)	(0.39, 1.62)	(0.37, 1.58)	(0.35, 1.55)	(0.34, 1.53)	(0.33, 1.51)	(0.32, 1.49)
95	1.86	1.35	1.13	1.01	0.93	0.88	0.84	0.81	0.78	0.76	0.74	0.72
	(1.17, 2.92)	(0.68, 2.32)	(0.54, 2.02)	(0.47, 1.90)	(0.42, 1.83)	(0.38, 1.78)	(0.37, 1.74)	(0.35, 1.71)	(0.35, 1.69)	(0.33, 1.67)	(0.32, 1.65)	(0.30, 1.63)
100	1.84	1.32	1.13	0.99	0.91	0.85	0.81	0.78	0.75	0.73	0.72	0.7
	(1.16, 2.99)	(0.60, 2.54)	(0.50, 2.31)	(0.44, 2.15)	(0.42, 2.06)	(0.39, 2.00)	(0.37, 1.94)	(0.36, 1.90)	(0.34, 1.86)	(0.33, 1.84)	(0.32, 1.82)	(0.31, 1.79)

Table 10. Median densities (number per m²) of mature (≥ 50 mm TD) Red Sea Urchin together with 95% confidence intervals over every 5th Simulation Year under alternative harvest rates (2% to 24%) in South Coast Inside Waters, using Tanaka Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0.76	0.72	0.69	0.67	0.64	0.61	0.59	0.57	0.54	0.52	0.5	0.49
	(0.52, 1.18)	(0.49, 1.15)	(0.46, 1.11)	(0.44, 1.09)	(0.42, 1.06)	(0.40, 1.03)	(0.38, 1.00)	(0.36, 0.97)	(0.34, 0.95)	(0.33, 0.93)	(0.31, 0.91)	(0.30, 0.89)
10	0.78	0.71	0.65	0.6	0.56	0.52	0.5	0.47	0.45	0.43	0.41	0.4
	(0.51, 1.20)	(0.45, 1.11)	(0.41, 1.05)	(0.37, 1.00)	(0.34, 0.95)	(0.31, 0.92)	(0.29, 0.89)	(0.27, 0.87)	(0.26, 0.85)	(0.25, 0.82)	(0.23, 0.80)	(0.22, 0.79)
15	0.77	0.66	0.6	0.54	0.5	0.46	0.43	0.41	0.39	0.38	0.37	0.36
	(0.51, 1.15)	(0.44, 1.06)	(0.38, 0.97)	(0.34, 0.92)	(0.30, 0.87)	(0.27, 0.83)	(0.24, 0.80)	(0.22, 0.77)	(0.21, 0.75)	(0.20, 0.74)	(0.19, 0.72)	(0.18, 0.71)
20	0.76	0.64	0.56	0.5	0.45	0.42	0.39	0.37	0.36	0.34	0.33	0.33
	(0.50, 1.24)	(0.41, 1.10)	(0.35, 0.98)	(0.30, 0.89)	(0.26, 0.85)	(0.24, 0.82)	(0.22, 0.79)	(0.20, 0.77)	(0.19, 0.76)	(0.18, 0.75)	(0.17, 0.73)	(0.17, 0.73)
25	0.77	0.63	0.54	0.47	0.43	0.4	0.38	0.36	0.35	0.34	0.33	0.32
	(0.54, 1.15)	(0.44, 0.98)	(0.37, 0.88)	(0.32, 0.82)	(0.28, 0.77)	(0.25, 0.73)	(0.23, 0.69)	(0.21, 0.67)	(0.20, 0.65)	(0.19, 0.64)	(0.18, 0.63)	(0.18, 0.62)
30	0.76	0.61	0.51	0.45	0.41	0.38	0.36	0.34	0.33	0.32	0.32	0.31
	(0.52, 1.21)	(0.39, 1.03)	(0.31, 0.93)	(0.27, 0.85)	(0.24, 0.80)	(0.22, 0.77)	(0.20, 0.74)	(0.19, 0.72)	(0.18, 0.70)	(0.17, 0.68)	(0.17, 0.67)	(0.16, 0.66)
35	0.77	0.61	0.51	0.44	0.4	0.37	0.35	0.34	0.33	0.32	0.31	0.3
	(0.49, 1.17)	(0.36, 0.98)	(0.29, 0.87)	(0.25, 0.77)	(0.22, 0.72)	(0.20, 0.69)	(0.19, 0.66)	(0.17, 0.64)	(0.17, 0.62)	(0.16, 0.61)	(0.16, 0.60)	(0.15, 0.59)
40	0.74	0.57	0.48	0.42	0.38	0.36	0.34	0.33	0.31	0.3	0.3	0.29
	(0.51, 1.13)	(0.37, 0.95)	(0.29, 0.84)	(0.24, 0.77)	(0.21, 0.69)	(0.19, 0.64)	(0.18, 0.62)	(0.17, 0.60)	(0.16, 0.59)	(0.16, 0.57)	(0.15, 0.56)	(0.14, 0.56)
45	0.75	0.58	0.48	0.42	0.38	0.35	0.34	0.32	0.31	0.3	0.29	0.28
	(0.51, 1.13)	(0.36, 0.94)	(0.28, 0.82)	(0.24, 0.74)	(0.22, 0.69)	(0.20, 0.66)	(0.18, 0.64)	(0.17, 0.62)	(0.16, 0.61)	(0.15, 0.60)	(0.15, 0.59)	(0.14, 0.58)
50	0.75	0.56	0.47	0.42	0.38	0.35	0.33	0.32	0.31	0.3	0.29	0.28
	(0.50, 1.16)	(0.36, 0.91)	(0.28, 0.78)	(0.23, 0.71)	(0.20, 0.67)	(0.19, 0.64)	(0.18, 0.62)	(0.17, 0.61)	(0.16, 0.59)	(0.15, 0.58)	(0.14, 0.57)	(0.14, 0.57)
55	0.73	0.54	0.45	0.39	0.36	0.34	0.32	0.31	0.3	0.29	0.29	0.28
	(0.52, 1.22)	(0.35, 1.02)	(0.27, 0.93)	(0.23, 0.88)	(0.20, 0.84)	(0.18, 0.82)	(0.17, 0.79)	(0.16, 0.78)	(0.15, 0.76)	(0.15, 0.75)	(0.14, 0.74)	(0.14, 0.74)
60	0.75	0.55	0.46	0.4	0.37	0.34	0.33	0.31	0.3	0.29	0.28	0.28
	(0.52, 1.22)	(0.35, 1.03)	(0.28, 0.93)	(0.23, 0.86)	(0.21, 0.82)	(0.19, 0.78)	(0.17, 0.75)	(0.16, 0.73)	(0.16, 0.72)	(0.15, 0.70)	(0.15, 0.70)	(0.14, 0.69)
65	0.8	0.59	0.49	0.42	0.39	0.36	0.35	0.33	0.32	0.31	0.31	0.3
	(0.49, 1.27)	(0.35, 1.09)	(0.27, 0.97)	(0.22, 0.89)	(0.20, 0.85)	(0.18, 0.81)	(0.17, 0.78)	(0.17, 0.77)	(0.16, 0.76)	(0.16, 0.75)	(0.15, 0.74)	(0.15, 0.73)
70	0.79	0.59	0.49	0.43	0.39	0.37	0.35	0.34	0.32	0.31	0.31	0.3
	(0.53, 1.20)	(0.35, 0.94)	(0.27, 0.85)	(0.23, 0.78)	(0.20, 0.74)	(0.18, 0.70)	(0.17, 0.68)	(0.16, 0.65)	(0.16, 0.64)	(0.15, 0.63)	(0.14, 0.62)	(0.14, 0.62)
75	0.79	0.58	0.48	0.42	0.38	0.36	0.34	0.33	0.31	0.3	0.29	0.29
	(0.53, 1.21)	(0.33, 0.99)	(0.26, 0.89)	(0.22, 0.84)	(0.19, 0.79)	(0.17, 0.76)	(0.16, 0.73)	(0.15, 0.72)	(0.15, 0.70)	(0.14, 0.69)	(0.14, 0.68)	(0.14, 0.66)
80	0.79	0.58	0.48	0.42	0.38	0.36	0.34	0.33	0.32	0.31	0.31	0.3
	(0.51, 1.19)	(0.34, 0.96)	(0.26, 0.87)	(0.22, 0.81)	(0.20, 0.78)	(0.17, 0.75)	(0.16, 0.73)	(0.15, 0.72)	(0.14, 0.71)	(0.14, 0.70)	(0.13, 0.69)	(0.12, 0.69)
85	0.78	0.57	0.47	0.41	0.37	0.34	0.33	0.31	0.3	0.3	0.29	0.28
	(0.52, 1.19)	(0.34, 0.94)	(0.27, 0.82)	(0.22, 0.75)	(0.19, 0.71)	(0.17, 0.69)	(0.16, 0.67)	(0.15, 0.66)	(0.14, 0.65)	(0.14, 0.64)	(0.13, 0.63)	(0.13, 0.62)
90	0.79	0.57	0.47	0.42	0.39	0.37	0.34	0.33	0.32	0.31	0.3	0.3
	(0.53, 1.20)	(0.34, 0.95)	(0.27, 0.83)	(0.23, 0.76)	(0.20, 0.71)	(0.19, 0.68)	(0.18, 0.67)	(0.17, 0.66)	(0.16, 0.65)	(0.15, 0.64)	(0.15, 0.63)	(0.15, 0.62)
95	0.8	0.58	0.49	0.43	0.4	0.37	0.35	0.33	0.32	0.31	0.3	0.3
	(0.52, 1.20)	(0.34, 0.96)	(0.27, 0.83)	(0.23, 0.77)	(0.20, 0.73)	(0.18, 0.70)	(0.17, 0.68)	(0.16, 0.67)	(0.15, 0.65)	(0.15, 0.64)	(0.14, 0.63)	(0.14, 0.63)
100	0.77	0.56	0.46	0.4	0.37	0.35	0.33	0.32	0.31	0.3	0.29	0.29
	(0.55, 1.20)	(0.35, 0.95)	(0.28, 0.83)	(0.24, 0.77)	(0.20, 0.72)	(0.18, 0.69)	(0.16, 0.66)	(0.15, 0.65)	(0.15, 0.64)	(0.14, 0.63)	(0.14, 0.62)	(0.13, 0.62)

Table 11. Median densities (number per m²) of mature (≥ 50 mm TD) Red Sea Urchin together with 95% confidence intervals over every 5th Simulation Year under alternative harvest rates (2% to 24%) in South Coast Inside Waters, using Logistic Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0.93	0.88	0.85	0.81	0.78	0.75	0.72	0.7	0.67	0.64	0.62	0.6
	(0.72, 1.29)	(0.68, 1.25)	(0.66, 1.22)	(0.63, 1.19)	(0.61, 1.15)	(0.58, 1.12)	(0.56, 1.09)	(0.53, 1.07)	(0.51, 1.04)	(0.49, 1.02)	(0.48, 1.00)	(0.46, 0.98)
10	0.94	0.85	0.78	0.72	0.67	0.62	0.59	0.56	0.53	0.51	0.49	0.47
	(0.71, 1.35)	(0.65, 1.26)	(0.60, 1.18)	(0.55, 1.11)	(0.52, 1.05)	(0.48, 1.00)	(0.45, 0.97)	(0.43, 0.92)	(0.40, 0.90)	(0.38, 0.88)	(0.36, 0.87)	(0.35, 0.85)
15	0.91	0.79	0.7	0.64	0.58	0.54	0.5	0.48	0.46	0.44	0.42	0.41
	(0.69, 1.34)	(0.60, 1.18)	(0.53, 1.07)	(0.48, 1.00)	(0.44, 0.95)	(0.41, 0.90)	(0.38, 0.86)	(0.36, 0.82)	(0.34, 0.79)	(0.33, 0.77)	(0.31, 0.75)	(0.30, 0.73)
20	0.93	0.78	0.68	0.6	0.55	0.51	0.48	0.46	0.44	0.42	0.41	0.4
	(0.73, 1.28)	(0.61, 1.11)	(0.52, 1.01)	(0.45, 0.93)	(0.41, 0.88)	(0.37, 0.83)	(0.34, 0.80)	(0.32, 0.78)	(0.31, 0.76)	(0.30, 0.74)	(0.29, 0.73)	(0.28, 0.72)
25	0.91	0.75	0.64	0.57	0.52	0.49	0.46	0.44	0.42	0.41	0.39	0.39
	(0.72, 1.31)	(0.58, 1.13)	(0.49, 0.99)	(0.43, 0.90)	(0.38, 0.83)	(0.35, 0.79)	(0.32, 0.75)	(0.30, 0.72)	(0.29, 0.70)	(0.28, 0.69)	(0.27, 0.67)	(0.27, 0.66)
30	0.92	0.74	0.62	0.55	0.5	0.46	0.43	0.41	0.4	0.39	0.38	0.37
	(0.71, 1.37)	(0.56, 1.17)	(0.46, 1.05)	(0.39, 0.97)	(0.34, 0.91)	(0.31, 0.87)	(0.29, 0.84)	(0.28, 0.81)	(0.26, 0.80)	(0.26, 0.78)	(0.25, 0.77)	(0.25, 0.77)
35	0.91	0.71	0.59	0.52	0.46	0.43	0.4	0.39	0.37	0.36	0.36	0.35
	(0.70, 1.30)	(0.54, 1.09)	(0.45, 0.95)	(0.38, 0.86)	(0.34, 0.79)	(0.31, 0.74)	(0.29, 0.72)	(0.28, 0.70)	(0.27, 0.69)	(0.26, 0.68)	(0.25, 0.67)	(0.24, 0.66)
40	0.92	0.7	0.58	0.5	0.46	0.43	0.41	0.39	0.37	0.36	0.36	0.35
	(0.72, 1.27)	(0.54, 1.04)	(0.43, 0.93)	(0.37, 0.83)	(0.34, 0.76)	(0.31, 0.72)	(0.29, 0.70)	(0.28, 0.68)	(0.27, 0.67)	(0.26, 0.66)	(0.25, 0.65)	(0.24, 0.64)
45	0.92	0.69	0.57	0.5	0.45	0.42	0.4	0.38	0.37	0.36	0.35	0.34
	(0.72, 1.40)	(0.53, 1.06)	(0.42, 0.94)	(0.37, 0.87)	(0.32, 0.82)	(0.30, 0.79)	(0.28, 0.77)	(0.27, 0.75)	(0.26, 0.73)	(0.25, 0.72)	(0.24, 0.71)	(0.24, 0.71)
50	0.91	0.67	0.55	0.48	0.45	0.42	0.4	0.38	0.37	0.36	0.35	0.34
	(0.71, 1.33)	(0.50, 1.07)	(0.40, 0.94)	(0.34, 0.87)	(0.31, 0.82)	(0.28, 0.78)	(0.26, 0.75)	(0.25, 0.74)	(0.24, 0.73)	(0.24, 0.72)	(0.23, 0.71)	(0.23, 0.70)
55	0.94	0.71	0.58	0.5	0.46	0.43	0.41	0.39	0.38	0.37	0.36	0.35
	(0.73, 1.35)	(0.51, 1.12)	(0.40, 0.94)	(0.35, 0.87)	(0.31, 0.83)	(0.29, 0.80)	(0.28, 0.77)	(0.26, 0.76)	(0.26, 0.74)	(0.25, 0.73)	(0.24, 0.73)	(0.24, 0.72)
60	0.95	0.7	0.57	0.5	0.46	0.42	0.4	0.39	0.37	0.36	0.35	0.34
	(0.70, 1.35)	(0.47, 1.04)	(0.38, 0.89)	(0.32, 0.82)	(0.30, 0.78)	(0.27, 0.75)	(0.26, 0.74)	(0.25, 0.71)	(0.24, 0.69)	(0.23, 0.66)	(0.22, 0.65)	(0.22, 0.65)
65	0.94	0.68	0.56	0.48	0.44	0.41	0.38	0.37	0.36	0.35	0.34	0.33
	(0.70, 1.33)	(0.47, 1.06)	(0.36, 0.91)	(0.31, 0.82)	(0.28, 0.77)	(0.26, 0.73)	(0.24, 0.70)	(0.23, 0.68)	(0.23, 0.67)	(0.22, 0.66)	(0.21, 0.65)	(0.21, 0.65)
70	0.94	0.68	0.55	0.48	0.44	0.41	0.39	0.37	0.36	0.35	0.34	0.33
	(0.72, 1.24)	(0.49, 0.97)	(0.39, 0.80)	(0.33, 0.72)	(0.29, 0.67)	(0.28, 0.63)	(0.26, 0.61)	(0.24, 0.59)	(0.23, 0.58)	(0.22, 0.57)	(0.21, 0.56)	(0.21, 0.56)
75	0.94	0.67	0.54	0.47	0.42	0.39	0.37	0.35	0.34	0.33	0.32	0.31
	(0.70, 1.31)	(0.49, 0.99)	(0.38, 0.85)	(0.32, 0.78)	(0.28, 0.74)	(0.26, 0.72)	(0.25, 0.70)	(0.23, 0.69)	(0.23, 0.67)	(0.22, 0.67)	(0.21, 0.66)	(0.20, 0.65)
80	0.94	0.66	0.53	0.47	0.42	0.39	0.37	0.36	0.35	0.33	0.33	0.32
	(0.73, 1.38)	(0.48, 1.07)	(0.37, 0.89)	(0.32, 0.80)	(0.29, 0.75)	(0.27, 0.71)	(0.25, 0.68)	(0.24, 0.66)	(0.23, 0.65)	(0.22, 0.63)	(0.22, 0.62)	(0.21, 0.62)
85	0.95	0.66	0.53	0.46	0.42	0.39	0.37	0.35	0.34	0.33	0.33	0.32
	(0.72, 1.36)	(0.47, 1.07)	(0.37, 0.92)	(0.32, 0.85)	(0.28, 0.82)	(0.26, 0.78)	(0.24, 0.75)	(0.23, 0.73)	(0.22, 0.71)	(0.21, 0.70)	(0.20, 0.69)	(0.20, 0.68)
90	0.95	0.65	0.53	0.46	0.42	0.39	0.37	0.36	0.35	0.34	0.33	0.32
	(0.73, 1.40)	(0.49, 1.14)	(0.37, 1.00)	(0.31, 0.89)	(0.28, 0.81)	(0.26, 0.77)	(0.24, 0.75)	(0.23, 0.73)	(0.22, 0.71)	(0.21, 0.70)	(0.21, 0.68)	(0.20, 0.67)
95	0.95	0.66	0.52	0.45	0.41	0.38	0.36	0.35	0.33	0.32	0.32	0.31
	(0.72, 1.37)	(0.46, 1.02)	(0.37, 0.88)	(0.30, 0.81)	(0.27, 0.76)	(0.26, 0.73)	(0.24, 0.71)	(0.24, 0.70)	(0.23, 0.68)	(0.22, 0.67)	(0.21, 0.66)	(0.21, 0.65)
100	0.93	0.64	0.5	0.43	0.39	0.36	0.34	0.33	0.32	0.31	0.3	0.29
	(0.74, 1.32)	(0.48, 1.04)	(0.36, 0.86)	(0.30, 0.78)	(0.27, 0.73)	(0.25, 0.68)	(0.23, 0.64)	(0.22, 0.61)	(0.21, 0.58)	(0.20, 0.57)	(0.20, 0.56)	(0.19, 0.55)

Table 12. Probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities lower than the Limit Reference Point over every 5th Simulation Year at alternative harvest rates (2% to 24%) for Haida Gwaii, using Tanaka Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0.01	0.01
30	0	0	0	0	0	0	0	0.005	0.005	0.005	0.01	0.015
35	0	0	0	0	0	0	0	0	0	0.005	0.005	0.015
40	0	0	0	0	0	0	0	0.005	0.005	0.01	0.015	0.02
45	0	0	0	0	0	0	0.005	0.005	0.005	0.005	0.01	0.01
50	0	0	0	0	0	0.005	0.01	0.01	0.015	0.02	0.02	0.02
55	0	0	0	0	0	0	0.01	0.015	0.02	0.03	0.03	0.03
60	0	0	0	0	0	0.005	0.015	0.025	0.025	0.025	0.03	0.035
65	0	0	0	0	0	0.005	0.01	0.015	0.015	0.02	0.025	0.035
70	0	0	0	0.005	0.005	0.005	0.01	0.01	0.02	0.025	0.03	0.04
75	0	0	0	0	0	0.005	0.005	0.01	0.015	0.015	0.015	0.02
80	0	0	0	0	0.005	0.005	0.005	0.005	0.01	0.015	0.015	0.015
85	0	0	0	0	0	0	0	0.005	0.005	0.01	0.01	0.01
90	0	0	0	0	0	0	0.005	0.01	0.01	0.01	0.02	0.03
95	0	0	0	0	0	0.005	0.005	0.005	0.005	0.01	0.015	0.025
100	0	0	0	0	0	0.005	0.005	0.01	0.015	0.02	0.03	0.03

Table 13. Probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities lower than the Limit Reference Point over every 5th Simulation Year at alternative harvest rates (2% to 24%) for Haida Gwaii, using Logistic Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0.005
25	0	0	0	0	0	0	0	0.005	0.005	0.005	0.005	0.01
30	0	0	0	0	0	0	0	0	0	0	0.005	0.005
35	0	0	0	0	0	0	0.005	0.005	0.005	0.005	0.01	0.01
40	0	0	0	0	0	0	0	0	0	0.005	0.01	0.015
45	0	0	0	0	0	0	0.005	0.005	0.02	0.02	0.025	0.03
50	0	0	0	0	0	0.005	0.005	0.005	0.005	0.005	0.005	0.005
55	0	0	0	0	0	0	0	0.005	0.005	0.005	0.005	0.015
60	0	0	0	0	0	0	0.005	0.01	0.015	0.025	0.025	0.025
65	0	0	0	0	0	0	0	0.005	0.005	0.005	0.015	0.015
70	0	0	0	0	0	0	0	0	0	0	0.005	0.01
75	0	0	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01
80	0	0	0	0	0	0	0.005	0.005	0.005	0.005	0.01	0.02
85	0	0	0	0	0	0	0	0.005	0.01	0.01	0.015	0.03
90	0	0	0	0	0.01	0.01	0.02	0.02	0.02	0.035	0.04	0.045
95	0	0	0	0.015	0.015	0.015	0.015	0.02	0.025	0.025	0.025	0.025
100	0	0	0	0	0.015	0.015	0.015	0.015	0.03	0.03	0.035	0.035

Table 14. Probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities lower than the Limit Reference Point over every 5th Simulation Year at alternative harvest rates (2% to 24%) for Mainland North Coast, using Tanaka Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0.005
20	0	0	0	0	0	0	0	0	0	0	0	0.005
25	0	0	0	0	0	0	0	0	0	0	0.015	0.02
30	0	0	0	0	0	0	0	0	0	0.005	0.025	0.025
35	0	0	0	0	0	0	0	0	0.005	0.015	0.025	0.025
40	0	0	0	0	0	0.005	0.005	0.005	0.02	0.02	0.02	0.04
45	0	0	0	0	0	0.005	0.005	0.01	0.01	0.01	0.01	0.01
50	0	0	0	0	0	0	0	0	0.005	0.005	0.005	0.005
55	0	0	0	0	0	0	0	0	0	0	0.005	0.005
60	0	0	0	0	0	0	0	0	0.005	0.005	0.005	0.005
65	0	0	0	0	0	0	0.005	0.01	0.015	0.015	0.02	0.025
70	0	0	0	0	0	0	0	0	0.005	0.015	0.015	0.02
75	0	0	0	0	0	0.005	0.005	0.01	0.01	0.01	0.01	0.01
80	0	0	0	0	0	0.005	0.005	0.01	0.01	0.01	0.015	0.015
85	0	0	0	0	0	0.005	0.015	0.025	0.03	0.03	0.03	0.03
90	0	0	0	0	0	0.005	0.005	0.01	0.02	0.02	0.025	0.025
95	0	0	0	0	0	0	0	0	0	0.005	0.005	0.015
100	0	0	0	0	0	0.005	0.005	0.01	0.01	0.01	0.01	0.02

Table 15. Probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities lower than the Limit Reference Point over every 5th Simulation Year at alternative harvest rates (2% to 24%) for Mainland North Coast, using Logistic Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0.005	0.005	0.005	0.005
30	0	0	0	0	0	0.005	0.005	0.01	0.01	0.01	0.01	0.01
35	0	0	0	0	0	0	0	0	0	0	0.005	0.015
40	0	0	0	0	0	0	0	0	0	0.005	0.005	0.005
45	0	0	0	0	0	0	0	0	0.01	0.01	0.01	0.01
50	0	0	0	0	0	0	0.005	0.01	0.01	0.02	0.02	0.025
55	0	0	0	0	0.005	0.005	0.01	0.01	0.015	0.025	0.03	0.03
60	0	0	0	0	0	0.005	0.005	0.01	0.01	0.015	0.015	0.015
65	0	0	0	0	0	0	0	0	0.005	0.01	0.01	0.01
70	0	0	0	0	0	0	0	0.005	0.005	0.005	0.005	0.015
75	0	0	0	0	0	0	0	0.01	0.01	0.01	0.01	0.015
80	0	0	0	0	0	0	0.005	0.01	0.01	0.01	0.01	0.01
85	0	0	0	0	0	0	0	0.005	0.005	0.01	0.015	0.02
90	0	0	0	0	0	0	0.005	0.005	0.005	0.005	0.005	0.015
95	0	0	0	0	0.005	0.005	0.005	0.01	0.015	0.02	0.025	0.025
100	0	0	0	0.005	0.005	0.005	0.01	0.015	0.025	0.025	0.025	0.025

Table 16. Probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities lower than the Limit Reference Point over every 5th Simulation Year at alternative harvest rates (2% to 24%) for South Coast Inside Waters, using Tanaka Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0	0	0	0	0	0	0	0	0.005	0.015	0.025	0.035
10	0	0	0	0	0.005	0.02	0.035	0.05	0.085	0.145	0.16	0.2
15	0	0	0	0.005	0.025	0.085	0.125	0.18	0.235	0.255	0.295	0.33
20	0	0	0	0.03	0.075	0.145	0.21	0.25	0.31	0.36	0.405	0.42
25	0	0	0	0.02	0.08	0.165	0.22	0.27	0.315	0.36	0.4	0.43
30	0	0	0.005	0.07	0.13	0.235	0.32	0.36	0.39	0.41	0.43	0.46
35	0	0	0.035	0.1	0.175	0.24	0.315	0.36	0.425	0.455	0.475	0.48
40	0	0	0.035	0.11	0.205	0.3	0.345	0.38	0.445	0.48	0.515	0.54
45	0	0.005	0.04	0.115	0.19	0.275	0.33	0.39	0.45	0.485	0.535	0.555
50	0	0	0.065	0.145	0.27	0.325	0.385	0.43	0.485	0.505	0.54	0.555
55	0	0.01	0.06	0.16	0.26	0.335	0.365	0.425	0.495	0.52	0.545	0.555
60	0	0.01	0.055	0.155	0.295	0.34	0.41	0.45	0.5	0.525	0.56	0.57
65	0	0.005	0.08	0.19	0.27	0.33	0.37	0.405	0.44	0.46	0.48	0.505
70	0	0.005	0.05	0.175	0.245	0.3	0.335	0.39	0.42	0.455	0.47	0.495
75	0	0.01	0.06	0.145	0.25	0.325	0.39	0.43	0.485	0.5	0.53	0.55
80	0	0	0.065	0.145	0.25	0.33	0.385	0.435	0.46	0.475	0.49	0.5
85	0	0.005	0.065	0.185	0.265	0.32	0.395	0.46	0.485	0.51	0.525	0.54
90	0	0	0.055	0.165	0.24	0.32	0.355	0.38	0.43	0.465	0.48	0.525
95	0	0	0.06	0.14	0.245	0.295	0.345	0.38	0.42	0.46	0.495	0.515
100	0	0	0.045	0.145	0.25	0.29	0.355	0.44	0.465	0.505	0.515	0.545

Table 17. Probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities lower than the Limit Reference Point over every 5th Simulation Year at alternative harvest rates (2% to 24%) for South Coast Inside Waters, using Logistic Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0.005	0.015	0.02
20	0	0	0	0	0	0	0	0	0.015	0.045	0.065	0.085
25	0	0	0	0	0	0.005	0.015	0.02	0.065	0.085	0.11	0.13
30	0	0	0	0	0	0.015	0.04	0.055	0.09	0.12	0.14	0.155
35	0	0	0	0	0	0.015	0.04	0.075	0.1	0.165	0.185	0.205
40	0	0	0	0	0.015	0.02	0.045	0.065	0.135	0.19	0.21	0.23
45	0	0	0	0	0.01	0.03	0.085	0.125	0.165	0.19	0.23	0.265
50	0	0	0	0	0.025	0.06	0.115	0.15	0.195	0.235	0.265	0.305
55	0	0	0	0	0.015	0.05	0.09	0.13	0.17	0.205	0.245	0.255
60	0	0	0	0.005	0.035	0.075	0.115	0.17	0.205	0.24	0.27	0.315
65	0	0	0	0	0.045	0.085	0.14	0.18	0.22	0.265	0.315	0.38
70	0	0	0	0.005	0.035	0.11	0.145	0.23	0.29	0.315	0.375	0.4
75	0	0	0	0.015	0.045	0.09	0.14	0.17	0.235	0.29	0.325	0.355
80	0	0	0	0.02	0.05	0.115	0.2	0.26	0.315	0.355	0.385	0.41
85	0	0	0	0.01	0.085	0.13	0.165	0.23	0.265	0.33	0.365	0.39
90	0	0	0.005	0.015	0.05	0.125	0.205	0.255	0.315	0.34	0.385	0.4
95	0	0	0	0.025	0.055	0.14	0.24	0.285	0.35	0.405	0.44	0.465
100	0	0	0	0.02	0.095	0.18	0.275	0.35	0.395	0.43	0.495	0.55

Table 18. Probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities lower than the Upper Stock Reference over every 5th Simulation Year at alternative harvest rates (2% to 24%) for Haida Gwaii, using Tanaka Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0.005	0.035	0.085	0.1
20	0	0	0	0	0	0.03	0.04	0.08	0.11	0.13	0.135	0.16
25	0	0	0	0	0.01	0.05	0.09	0.12	0.16	0.19	0.225	0.25
30	0	0	0	0.01	0.045	0.085	0.11	0.16	0.195	0.205	0.225	0.225
35	0	0	0.005	0.025	0.055	0.09	0.13	0.155	0.19	0.22	0.23	0.255
40	0	0	0	0.03	0.065	0.115	0.12	0.15	0.165	0.195	0.205	0.22
45	0	0	0.01	0.03	0.065	0.075	0.11	0.155	0.18	0.2	0.215	0.23
50	0	0	0.02	0.03	0.085	0.14	0.175	0.185	0.195	0.21	0.235	0.255
55	0	0	0.02	0.06	0.105	0.125	0.19	0.215	0.23	0.25	0.275	0.29
60	0	0	0.025	0.045	0.08	0.105	0.135	0.17	0.19	0.225	0.24	0.26
65	0	0	0.015	0.06	0.095	0.145	0.17	0.195	0.22	0.255	0.28	0.29
70	0	0.005	0.02	0.055	0.085	0.115	0.145	0.165	0.19	0.22	0.245	0.26
75	0	0	0.01	0.03	0.06	0.105	0.13	0.165	0.185	0.205	0.25	0.265
80	0	0.005	0.015	0.06	0.08	0.105	0.14	0.175	0.195	0.22	0.235	0.255
85	0	0	0.015	0.05	0.095	0.125	0.15	0.17	0.2	0.215	0.23	0.24
90	0	0	0.025	0.06	0.095	0.12	0.145	0.15	0.175	0.195	0.205	0.225
95	0	0.005	0.01	0.06	0.105	0.145	0.18	0.195	0.215	0.235	0.26	0.275
100	0	0.005	0.035	0.075	0.115	0.135	0.16	0.195	0.22	0.24	0.26	0.27

Table 19. Probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities lower than the Upper Stock Reference over every 5th Simulation Year at alternative harvest rates (2% to 24%) for Haida Gwaii, using Logistic Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0.005	0.01	0.015	0.03
15	0	0	0	0	0	0	0.005	0.025	0.04	0.07	0.09	0.12
20	0	0	0	0	0	0.025	0.055	0.1	0.115	0.135	0.145	0.17
25	0	0	0	0.005	0.02	0.06	0.085	0.1	0.12	0.16	0.195	0.22
30	0	0	0	0.01	0.03	0.075	0.1	0.12	0.15	0.17	0.2	0.23
35	0	0	0.005	0.01	0.05	0.09	0.125	0.18	0.205	0.225	0.26	0.265
40	0	0	0.01	0.025	0.055	0.105	0.15	0.17	0.18	0.185	0.225	0.23
45	0	0	0.02	0.04	0.105	0.13	0.14	0.17	0.195	0.205	0.225	0.235
50	0	0	0.005	0.035	0.07	0.105	0.125	0.14	0.165	0.175	0.195	0.235
55	0	0	0.01	0.03	0.085	0.135	0.16	0.18	0.205	0.215	0.235	0.245
60	0	0	0.01	0.03	0.075	0.12	0.15	0.165	0.185	0.21	0.215	0.225
65	0	0	0.01	0.04	0.075	0.105	0.145	0.155	0.19	0.205	0.205	0.225
70	0	0	0.01	0.055	0.07	0.09	0.12	0.14	0.2	0.23	0.255	0.26
75	0	0.005	0.01	0.03	0.08	0.095	0.115	0.155	0.17	0.195	0.225	0.245
80	0	0	0.025	0.055	0.085	0.11	0.155	0.165	0.185	0.225	0.265	0.28
85	0	0	0.025	0.08	0.1	0.13	0.165	0.2	0.225	0.25	0.26	0.29
90	0	0.01	0.04	0.06	0.1	0.145	0.175	0.205	0.23	0.245	0.255	0.27
95	0	0.015	0.035	0.085	0.13	0.145	0.185	0.2	0.23	0.245	0.26	0.285
100	0	0.015	0.05	0.085	0.135	0.18	0.205	0.23	0.28	0.305	0.325	0.35

Table 20. Probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities lower than the Upper Stock Reference over every 5th Simulation Year at alternative harvest rates (2% to 24%) for Mainland North Coast, using Tanaka Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0.005	0.005	0.02	0.065	0.075	0.105
15	0	0	0	0	0.005	0.02	0.04	0.06	0.08	0.11	0.145	0.18
20	0	0	0	0	0.02	0.035	0.07	0.1	0.125	0.165	0.2	0.255
25	0	0	0	0.01	0.05	0.095	0.145	0.2	0.235	0.27	0.305	0.33
30	0	0	0	0.02	0.085	0.135	0.205	0.255	0.3	0.325	0.35	0.37
35	0	0	0.005	0.05	0.1	0.165	0.215	0.27	0.305	0.335	0.365	0.395
40	0	0.005	0.025	0.07	0.115	0.17	0.205	0.225	0.26	0.27	0.28	0.29
45	0	0	0.015	0.065	0.105	0.15	0.2	0.22	0.235	0.275	0.285	0.305
50	0	0.005	0.01	0.055	0.095	0.15	0.19	0.22	0.235	0.265	0.305	0.305
55	0	0	0.02	0.065	0.11	0.145	0.2	0.23	0.28	0.31	0.32	0.345
60	0	0	0.02	0.065	0.11	0.185	0.225	0.25	0.31	0.35	0.38	0.395
65	0	0.005	0.03	0.115	0.16	0.205	0.255	0.295	0.33	0.37	0.385	0.395
70	0	0.005	0.04	0.095	0.155	0.21	0.24	0.28	0.305	0.34	0.37	0.395
75	0	0.005	0.025	0.08	0.14	0.21	0.23	0.28	0.295	0.31	0.33	0.35
80	0	0	0.035	0.075	0.135	0.17	0.24	0.28	0.31	0.35	0.355	0.365
85	0	0.01	0.06	0.09	0.155	0.205	0.24	0.28	0.32	0.35	0.375	0.39
90	0	0.005	0.04	0.07	0.115	0.17	0.205	0.225	0.275	0.31	0.335	0.355
95	0	0	0.02	0.09	0.14	0.185	0.22	0.265	0.295	0.32	0.385	0.405
100	0	0	0.03	0.04	0.08	0.175	0.215	0.24	0.255	0.305	0.32	0.35

Table 21. Probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities lower than the Upper Stock Reference over every 5th Simulation Year at alternative harvest rates (2% to 24%) for Mainland North Coast, using Logistic Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0.005	0.01	0.015	0.03
15	0	0	0	0	0	0	0.005	0.025	0.04	0.07	0.09	0.12
20	0	0	0	0	0	0.025	0.055	0.1	0.115	0.135	0.145	0.17
25	0	0	0	0.005	0.02	0.06	0.085	0.1	0.12	0.16	0.195	0.22
30	0	0	0	0.01	0.03	0.075	0.1	0.12	0.15	0.17	0.2	0.23
35	0	0	0.005	0.01	0.05	0.09	0.125	0.18	0.205	0.225	0.26	0.265
40	0	0	0.01	0.025	0.055	0.105	0.15	0.17	0.18	0.185	0.225	0.23
45	0	0	0.02	0.04	0.105	0.13	0.14	0.17	0.195	0.205	0.225	0.235
50	0	0	0.005	0.035	0.07	0.105	0.125	0.14	0.165	0.175	0.195	0.235
55	0	0	0.01	0.03	0.085	0.135	0.16	0.18	0.205	0.215	0.235	0.245
60	0	0	0.01	0.03	0.075	0.12	0.15	0.165	0.185	0.21	0.215	0.225
65	0	0	0.01	0.04	0.075	0.105	0.145	0.155	0.19	0.205	0.205	0.225
70	0	0	0.01	0.055	0.07	0.09	0.12	0.14	0.2	0.23	0.255	0.26
75	0	0.005	0.01	0.03	0.08	0.095	0.115	0.155	0.17	0.195	0.225	0.245
80	0	0	0.025	0.055	0.085	0.11	0.155	0.165	0.185	0.225	0.265	0.28
85	0	0	0.025	0.08	0.1	0.13	0.165	0.2	0.225	0.25	0.26	0.29
90	0	0.01	0.04	0.06	0.1	0.145	0.175	0.205	0.23	0.245	0.255	0.27
95	0	0.015	0.035	0.085	0.13	0.145	0.185	0.2	0.23	0.245	0.26	0.285
100	0	0.015	0.05	0.085	0.135	0.18	0.205	0.23	0.28	0.305	0.325	0.35

Table 22. Probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities lower than the Upper Stock Reference over every 5th Simulation Year at alternative harvest rates (2% to 24%) for South Coast Inside Waters, using Tanaka Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0.145	0.185	0.24	0.305	0.4	0.455	0.545	0.615	0.68	0.72	0.755	0.775
10	0.11	0.2	0.32	0.49	0.6	0.69	0.725	0.78	0.805	0.815	0.825	0.84
15	0.125	0.3	0.505	0.63	0.715	0.8	0.835	0.87	0.89	0.905	0.91	0.93
20	0.125	0.395	0.58	0.715	0.825	0.87	0.895	0.925	0.94	0.95	0.955	0.955
25	0.09	0.425	0.67	0.805	0.845	0.875	0.9	0.92	0.94	0.94	0.945	0.95
30	0.12	0.46	0.685	0.79	0.85	0.875	0.9	0.91	0.93	0.93	0.93	0.935
35	0.13	0.455	0.695	0.8	0.86	0.89	0.915	0.93	0.945	0.96	0.97	0.975
40	0.15	0.6	0.78	0.9	0.94	0.96	0.97	0.975	0.975	0.975	0.975	0.98
45	0.105	0.555	0.805	0.875	0.915	0.935	0.95	0.96	0.965	0.975	0.98	0.985
50	0.15	0.6	0.805	0.895	0.93	0.95	0.96	0.965	0.975	0.975	0.98	0.98
55	0.14	0.625	0.79	0.875	0.895	0.905	0.925	0.945	0.945	0.945	0.945	0.955
60	0.14	0.59	0.785	0.84	0.88	0.91	0.915	0.925	0.945	0.945	0.955	0.955
65	0.155	0.515	0.71	0.8	0.85	0.89	0.905	0.92	0.92	0.935	0.935	0.94
70	0.13	0.52	0.76	0.86	0.91	0.925	0.945	0.95	0.955	0.955	0.965	0.965
75	0.14	0.57	0.785	0.865	0.895	0.905	0.915	0.94	0.95	0.955	0.96	0.96
80	0.125	0.545	0.765	0.88	0.905	0.91	0.93	0.935	0.94	0.945	0.95	0.95
85	0.15	0.575	0.75	0.84	0.89	0.93	0.935	0.94	0.95	0.955	0.965	0.965
90	0.12	0.56	0.775	0.875	0.89	0.935	0.95	0.955	0.96	0.965	0.965	0.965
95	0.11	0.55	0.785	0.86	0.9	0.92	0.93	0.95	0.95	0.96	0.965	0.97
100	0.08	0.625	0.805	0.895	0.91	0.92	0.935	0.955	0.955	0.96	0.97	0.97

Table 23. Probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities lower than the Upper Stock Reference over every 5th Simulation Year at alternative harvest rates (2% to 24%) for South Coast Inside Waters, using Logistic Growth model.

Year	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
5	0	0	0.005	0.01	0.025	0.07	0.125	0.18	0.24	0.31	0.42	0.5
10	0	0.005	0.025	0.115	0.225	0.405	0.57	0.645	0.72	0.745	0.76	0.805
15	0	0.025	0.115	0.345	0.545	0.695	0.795	0.84	0.865	0.9	0.91	0.92
20	0	0.02	0.23	0.485	0.665	0.785	0.825	0.845	0.89	0.9	0.91	0.92
25	0	0.055	0.315	0.56	0.74	0.82	0.855	0.875	0.895	0.915	0.925	0.945
30	0	0.1	0.38	0.67	0.825	0.88	0.9	0.905	0.915	0.92	0.92	0.93
35	0	0.15	0.505	0.775	0.865	0.9	0.915	0.93	0.935	0.95	0.955	0.955
40	0	0.16	0.59	0.775	0.855	0.89	0.905	0.915	0.94	0.95	0.955	0.965
45	0	0.175	0.61	0.785	0.865	0.905	0.925	0.93	0.935	0.935	0.945	0.95
50	0	0.21	0.62	0.795	0.87	0.9	0.915	0.925	0.94	0.94	0.945	0.945
55	0	0.225	0.575	0.765	0.84	0.89	0.9	0.91	0.925	0.93	0.93	0.935
60	0	0.24	0.595	0.78	0.84	0.895	0.91	0.925	0.925	0.945	0.945	0.945
65	0	0.225	0.615	0.795	0.86	0.895	0.92	0.945	0.945	0.95	0.955	0.955
70	0	0.27	0.65	0.805	0.895	0.94	0.965	0.975	0.985	0.985	0.985	0.985
75	0	0.24	0.705	0.86	0.905	0.93	0.95	0.97	0.97	0.97	0.97	0.97
80	0	0.285	0.69	0.84	0.89	0.915	0.94	0.95	0.955	0.96	0.965	0.97
85	0	0.25	0.715	0.835	0.895	0.92	0.935	0.94	0.945	0.95	0.95	0.95
90	0	0.285	0.705	0.85	0.89	0.91	0.93	0.945	0.95	0.95	0.955	0.955
95	0	0.315	0.78	0.875	0.92	0.935	0.95	0.955	0.965	0.965	0.965	0.965
100	0	0.35	0.77	0.88	0.93	0.95	0.965	0.97	0.975	0.975	0.975	0.975

Table 24. Summary table of probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities breaching the Upper Stock Reference (USR) and the Limit Reference Point (LRP) after the 100th simulation year at alternative harvest rates (2% to 24%) for Haida Gwaii, Mainland North Coast and South Coast Inside Waters, using the Tanaka and the Logistic Growth models.

Region	Growth Model	Reference Point	Probability of reaching reference point after 100 years, by harvest rate											
			2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
Haida Gwaii	Tanaka	USR	0	0.005	0.035	0.075	0.115	0.135	0.16	0.195	0.22	0.24	0.26	0.27
		LRP	0	0	0	0	0	0.005	0.005	0.01	0.015	0.02	0.03	0.03
	Logistic	USR	0	0.015	0.05	0.085	0.135	0.18	0.205	0.23	0.28	0.305	0.325	0.35
		LRP	0	0	0	0	0.015	0.015	0.015	0.015	0.03	0.03	0.035	0.035
North Coast	Tanaka	USR	0	0	0.03	0.04	0.08	0.175	0.215	0.24	0.255	0.305	0.32	0.35
		LRP	0	0	0	0	0	0.005	0.005	0.01	0.01	0.01	0.01	0.02
	Logistic	USR	0	0.015	0.05	0.085	0.135	0.18	0.205	0.23	0.28	0.305	0.325	0.35
		LRP	0	0	0	0.005	0.005	0.005	0.01	0.015	0.025	0.025	0.025	0.025
South Coast	Tanaka	USR	0.08	0.625	0.805	0.895	0.91	0.92	0.935	0.955	0.955	0.96	0.97	0.97
		LRP	0	0	0.045	0.145	0.25	0.29	0.355	0.44	0.465	0.505	0.515	0.545
	Logistic	USR	0	0.35	0.77	0.88	0.93	0.95	0.965	0.97	0.975	0.975	0.975	0.975
		LRP	0	0	0	0.02	0.095	0.18	0.275	0.35	0.395	0.43	0.495	0.55
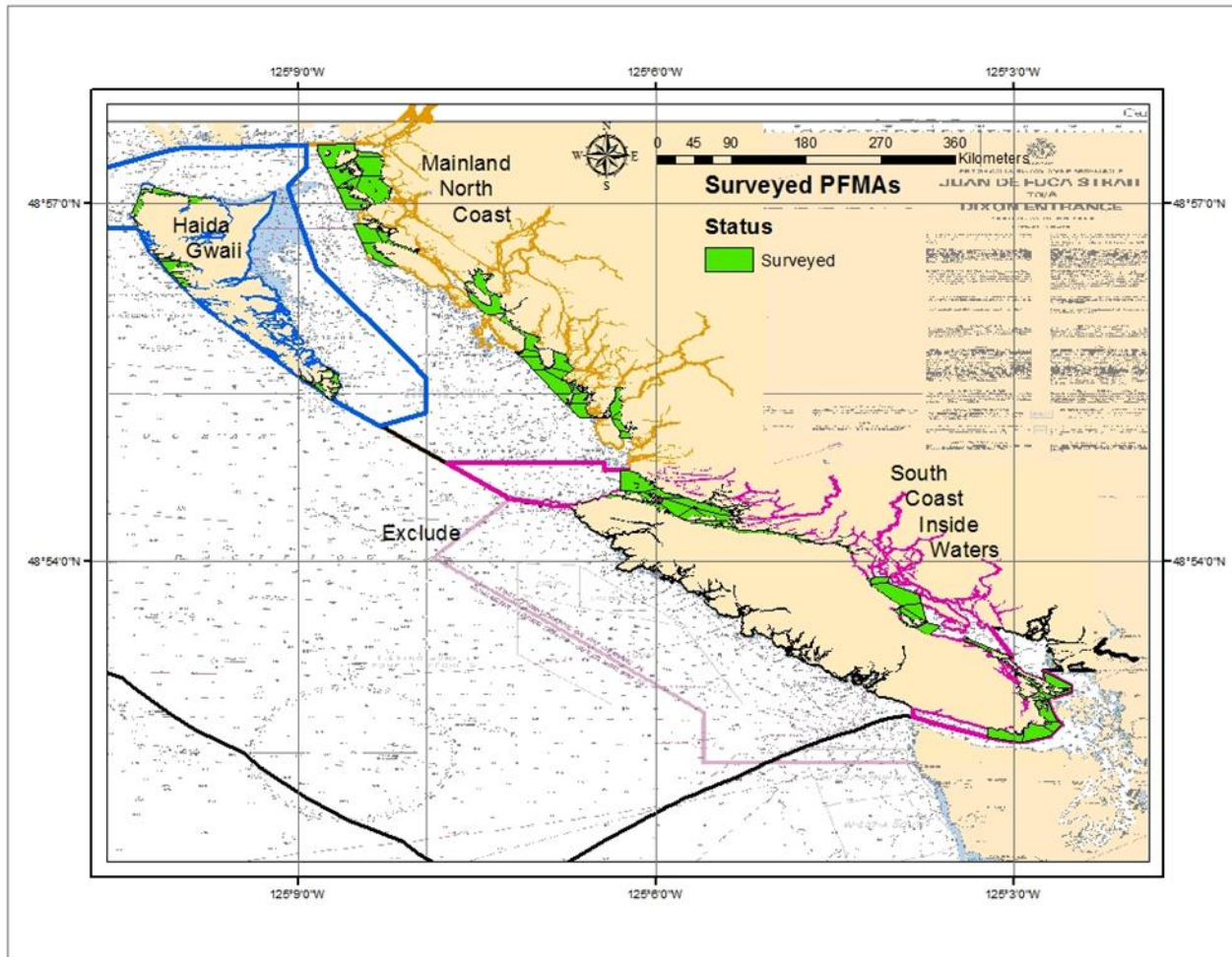
Figure 1. Map of British Columbia showing the location of the Pacific Fisheries Management Subareas where Red Sea Urchin fishery-independent SCUBA dive surveys were conducted from 1994 to 2016. Haida Gwaii region is outlined in blue, Mainland North Coast region in orange, and South Coast Inside Waters in pink.
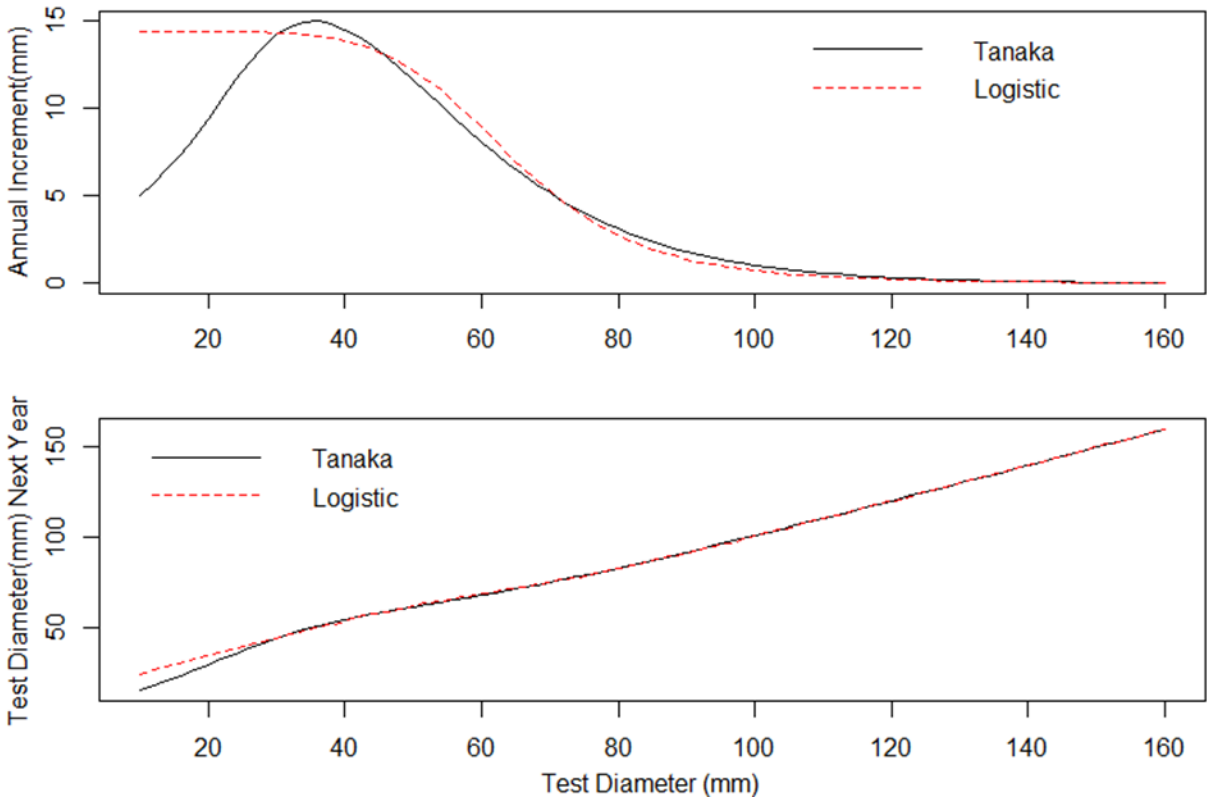
Figure 2. Tanaka and Logistic growth models for Alert Bay, allowing for prediction of annual test diameter increment or test diameter of a Red Sea Urchin based on its test diameter in the previous year.
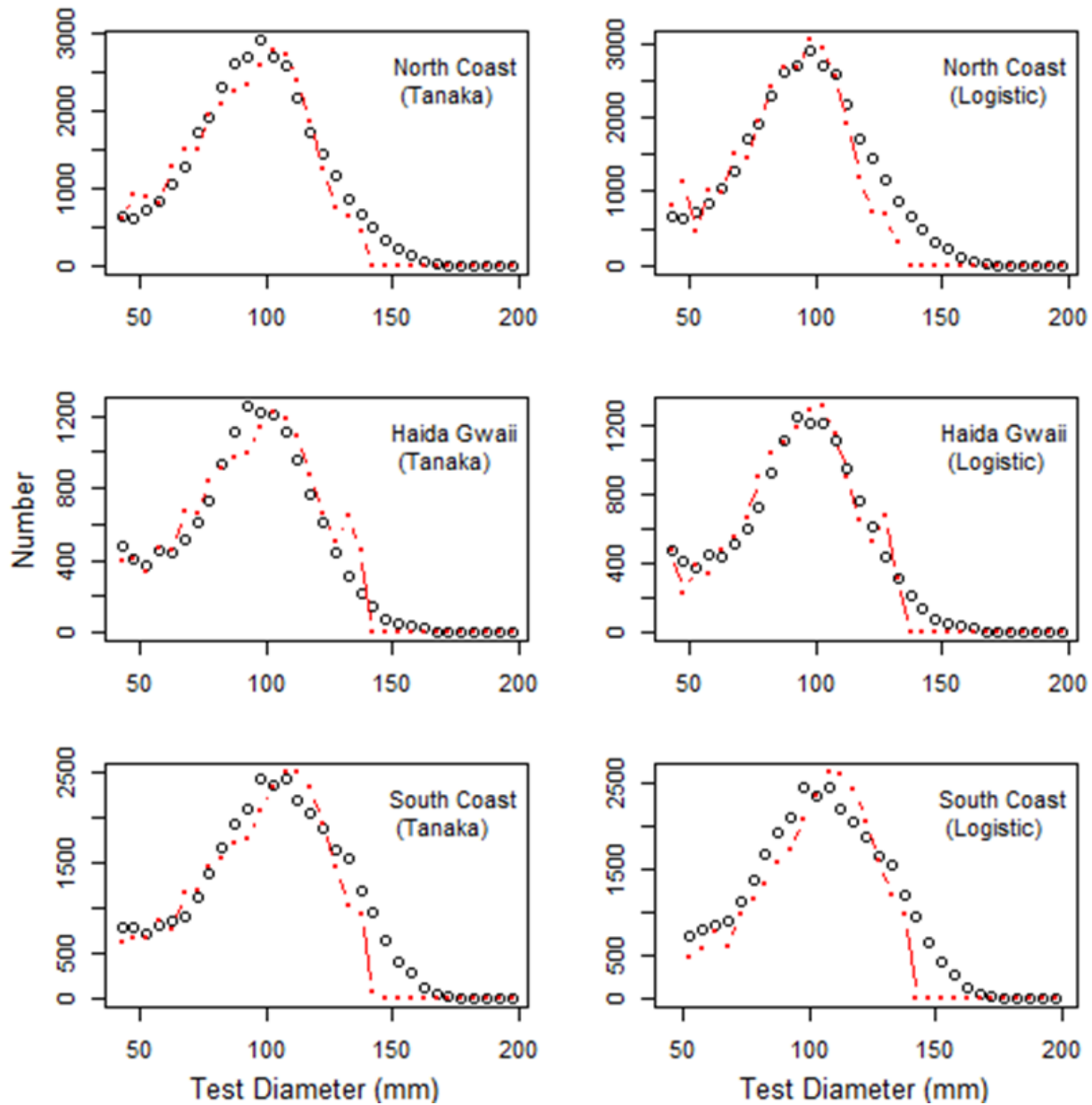
Figure 3. Comparison of model-derived (red dots) and observed number (black circles) of Red Sea Urchin (RSU) at various test diameter intervals for Mainland North Coast, Haida Gwaii and South Coast Inside Waters. The model employs either the Tanaka Growth model (Tanaka) or Logistic Growth model (Logistic) with a fixed harvest rate of 0.02 for RSU 90-140mm TD. Growth parameter values are adjusted for South Coast Inside Waters (see text for detailed explanation).
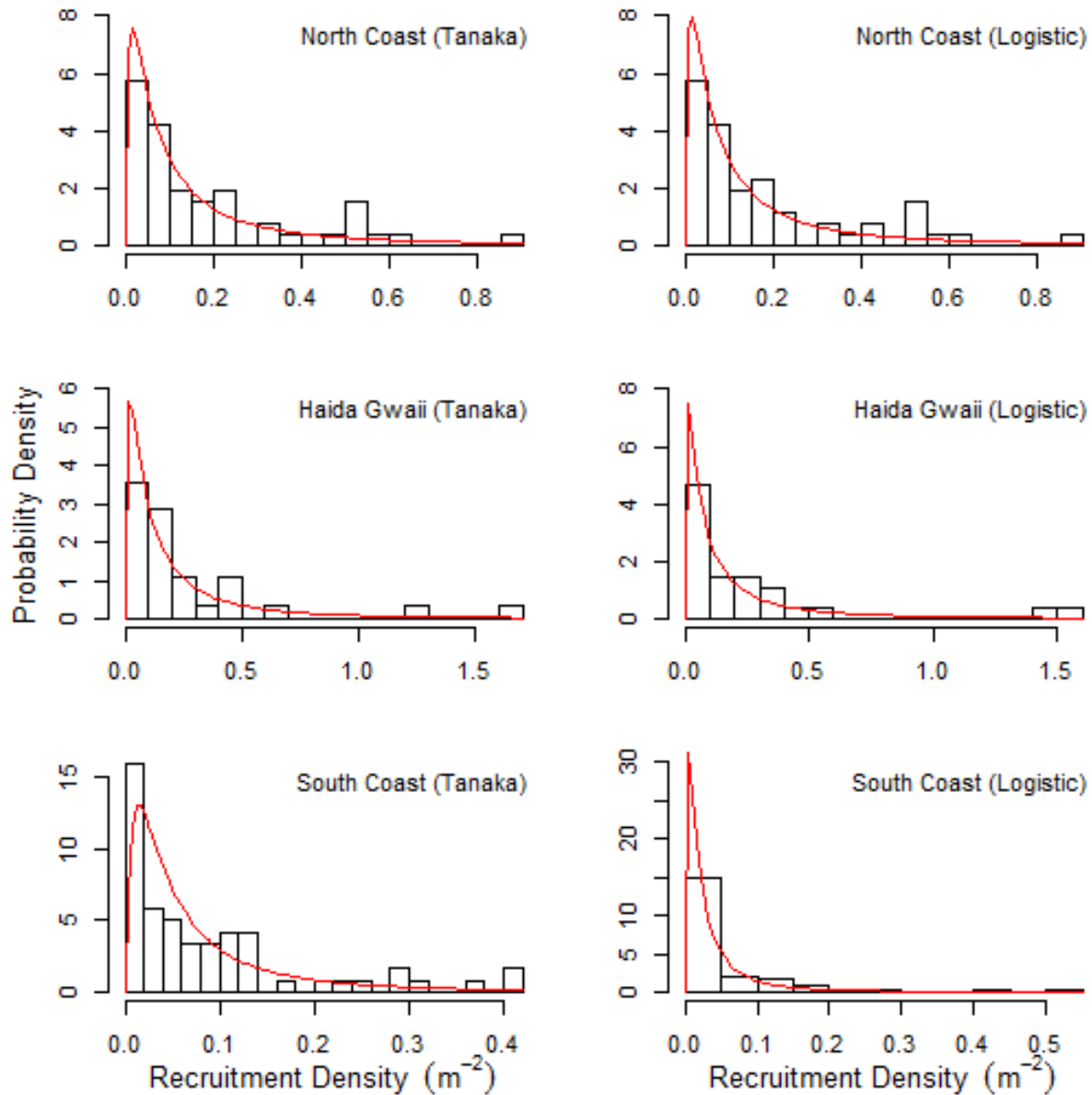
Figure 4. Fit of lognormal probability distributions (red lines) to recruitment densities in Mainland North Coast, Haida Gwaii and South Coast Inside Waters. Recruitment densities denote densities of Red Sea Urchin within recruitment test diameter ranges as determined using the Tanaka Growth model (Tanaka) or Logistic Growth model (Logistic). The lognormal probability distribution is only fitted to recruitment densities larger than 0.01 m^{-2} for South Coast Inside Waters, when the recruitment test diameter range was determined using the Tanaka Growth model.
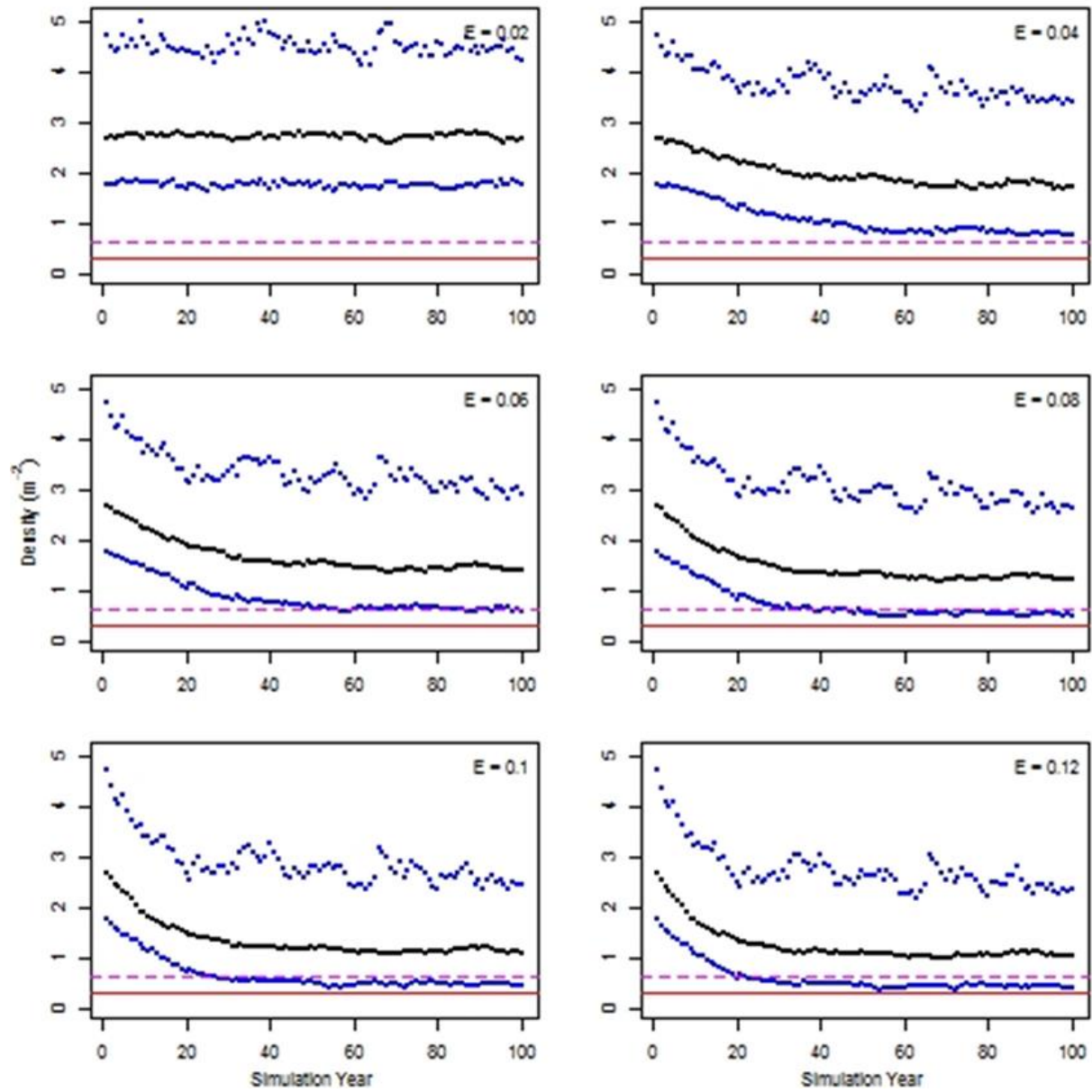
Figure 5. Median spatial densities of mature Red Sea Urchin (RSU/m^2: black lines) together with 95% confidence intervals (blue lines) under alternative harvest rates (E) over the simulation years for Haida Gwaii, using Tanaka Growth model. The broken and solid red lines denote the Upper Stock Reference Point and Limit Reference Point, respectively(continued on next page).
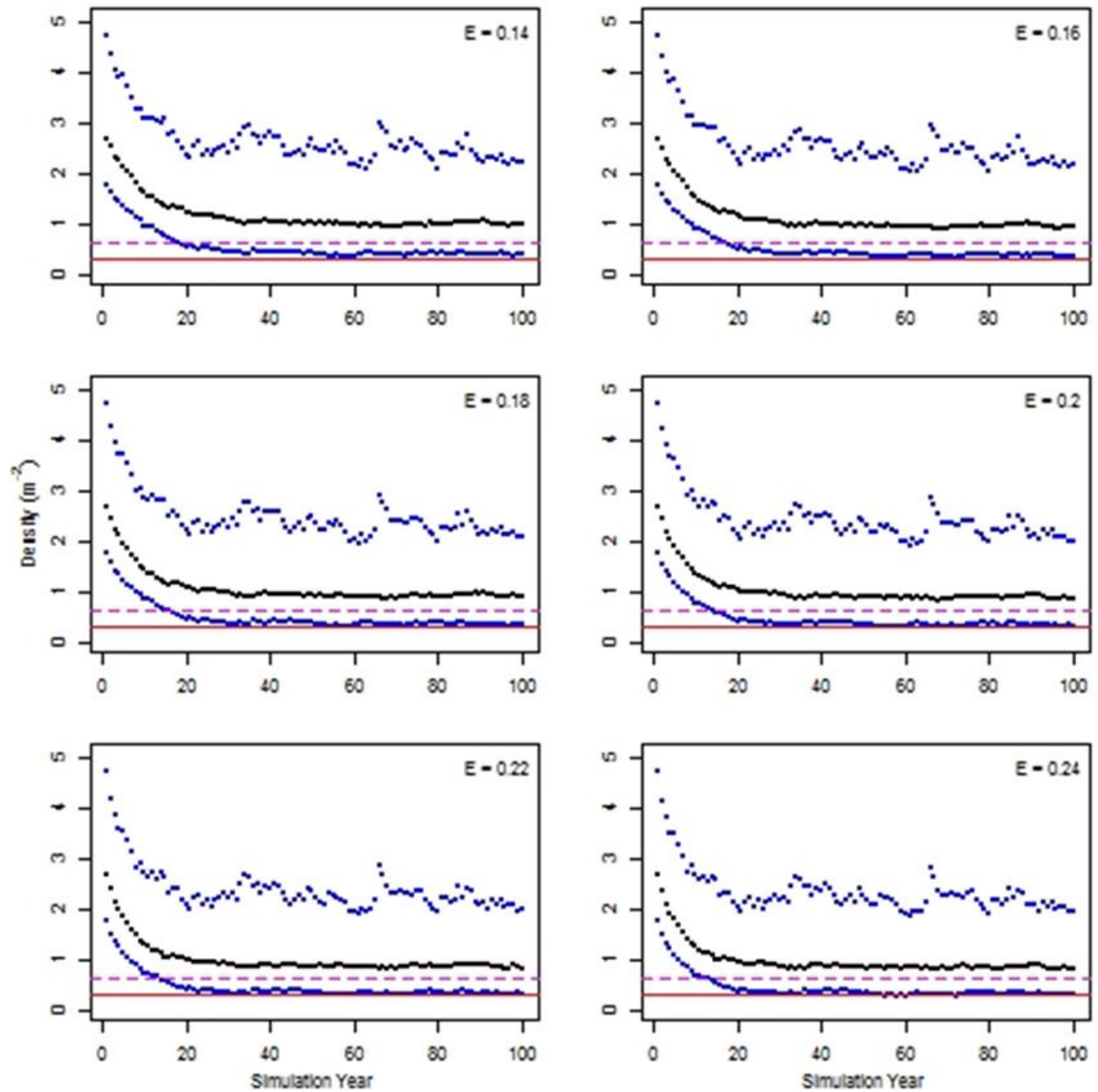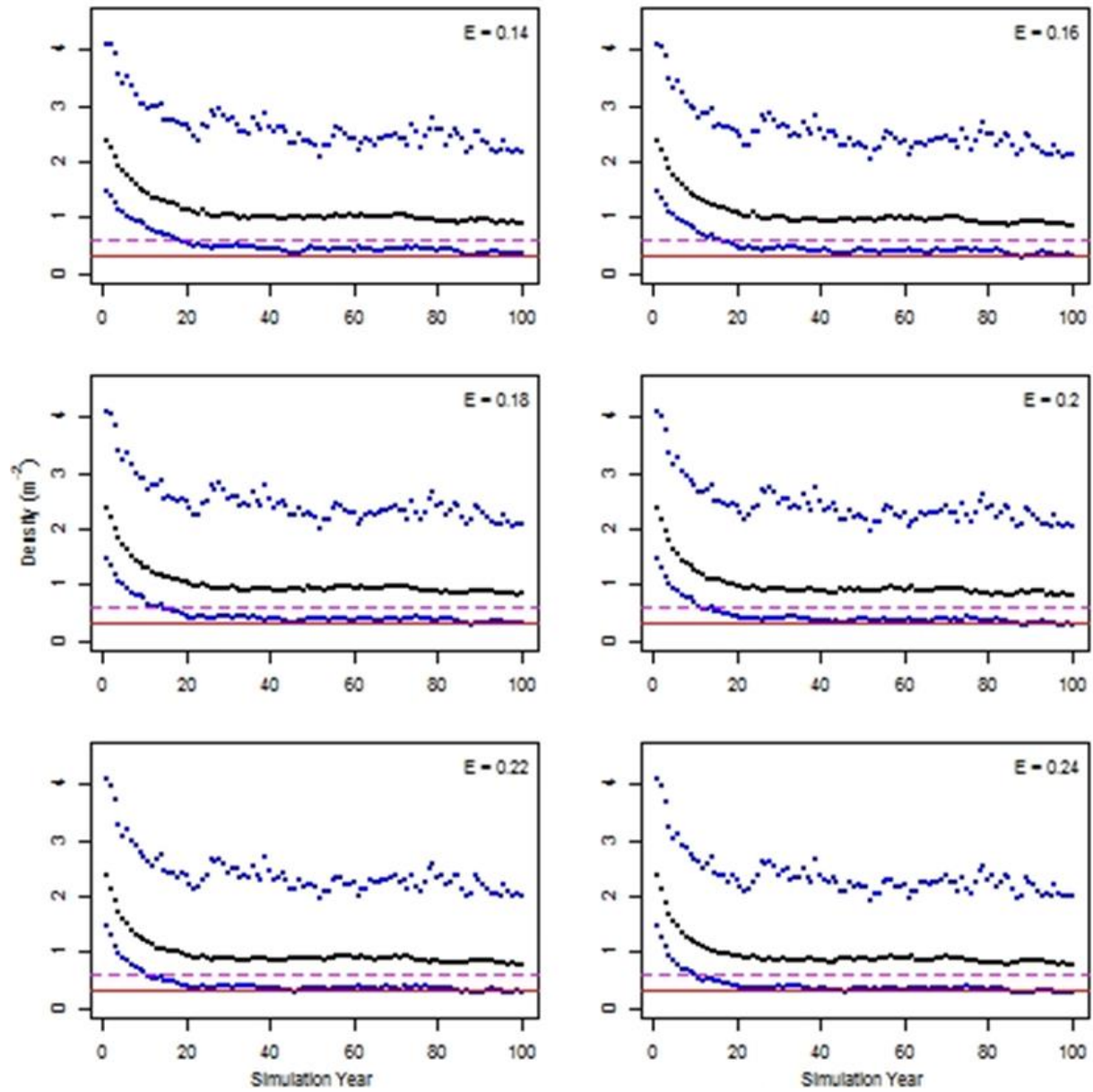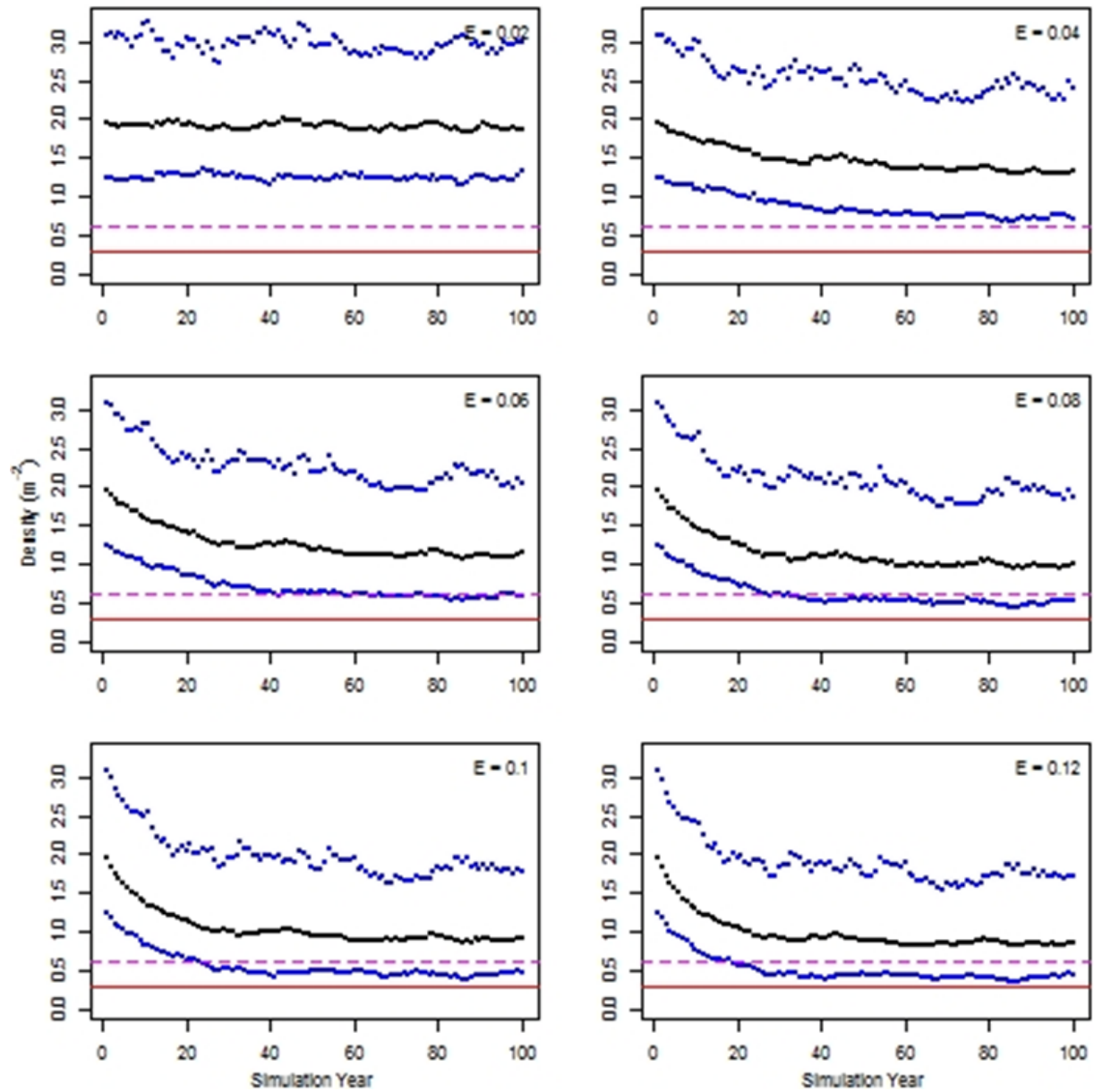
Figure 5 (continued). Median spatial densities of mature Red Sea Urchin (RSU/m^2: black lines) together with 95% confidence intervals (blue lines)under alternative harvest rates (E) over the simulation years for Haida Gwaii, using Tanaka Growth model. The broken and solid red lines denote the Upper Stock Reference Point and Limit Reference Point, respectively.
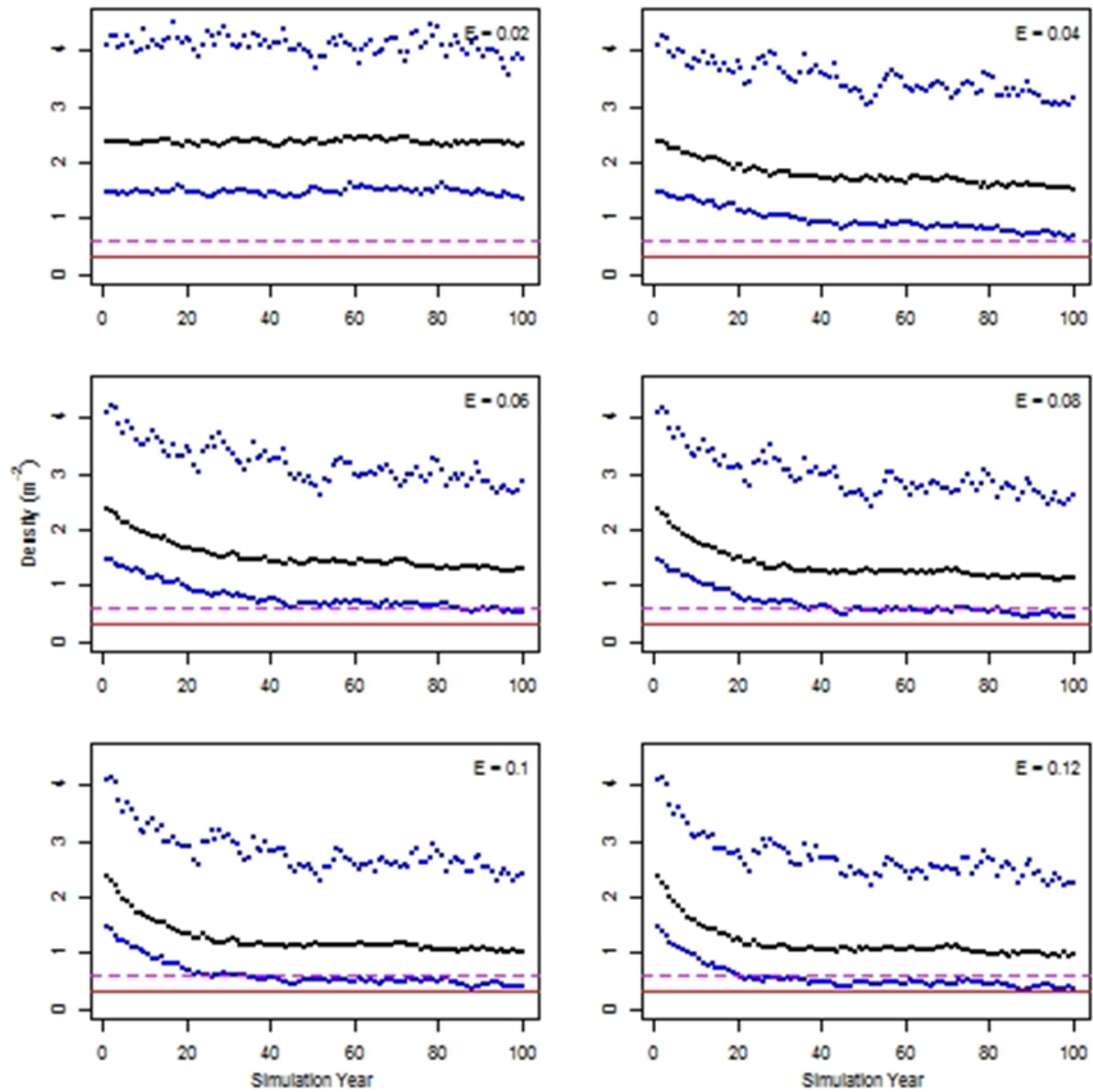
Figure 6. Median spatial densities of mature Red Sea Urchin (RSU/m²: black lines) together with 95% confidence intervals (blue lines)under alternative harvest rates (E) over the simulation years for Haida Gwaii, using Logistic Growth model. The broken and solid red lines denote the Upper Stock Reference Point and Limit Reference Point, respectively (continued on next page).
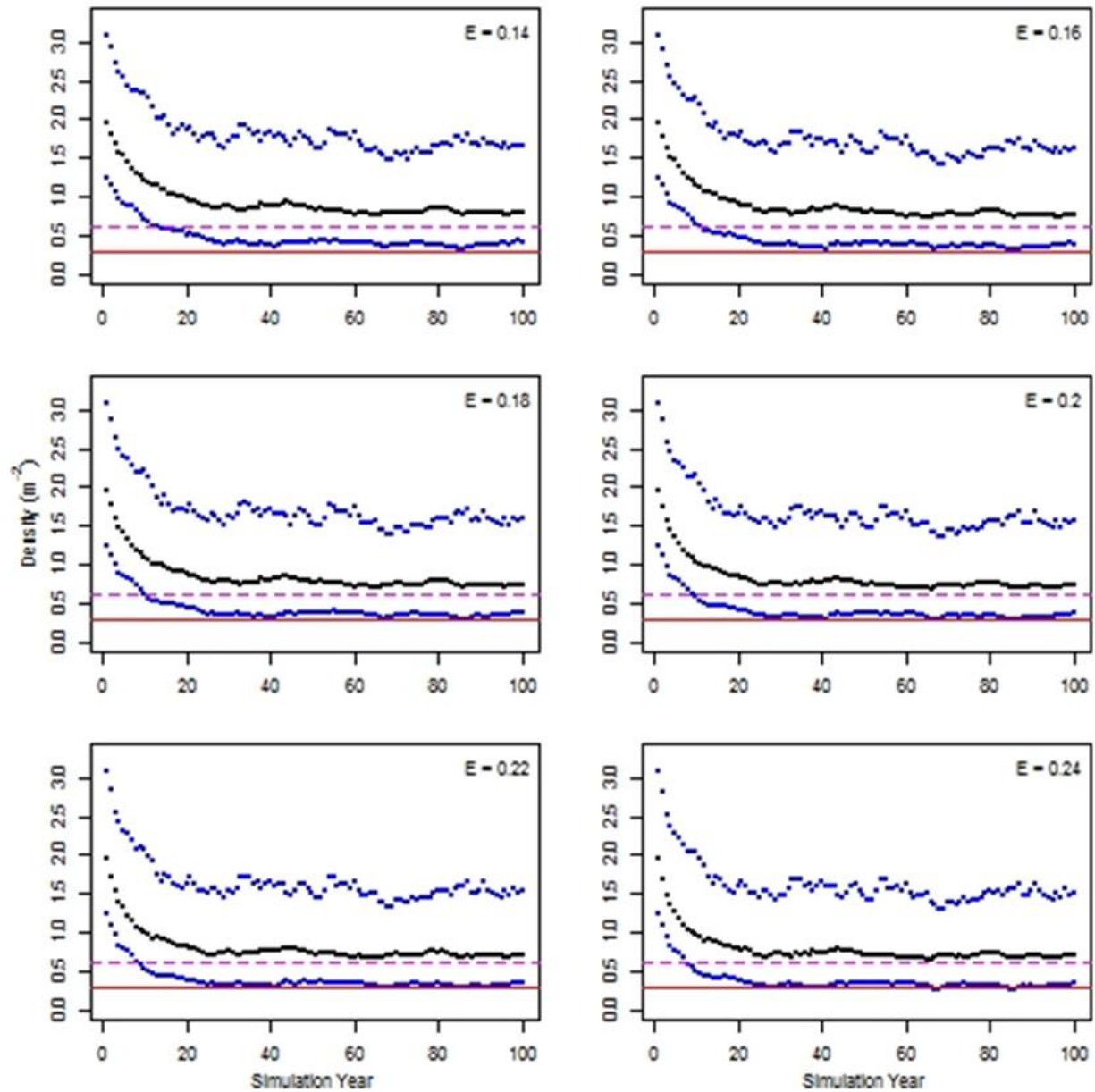
Figure 6 (continued). Median spatial densities of mature Red Sea Urchin (RSU/m²: black lines) together with 95% confidence intervals (blue lines)under alternative harvest rates (E) over the simulation years for Haida Gwaii, using Logistic Growth model. The broken and solid red lines denote the Upper Stock Reference Point and Limit Reference Point, respectively.

Figure 7. Median spatial densities of mature Red Sea Urchin (RSU/m²: black lines) together with 95% confidence intervals (blue lines) under alternative harvest rates (E) over the simulation years for Mainland North Coast, using Tanaka Growth model. The broken and solid red lines denote the Upper Stock Reference Point and Limit Reference Point, respectively (continued on next page).
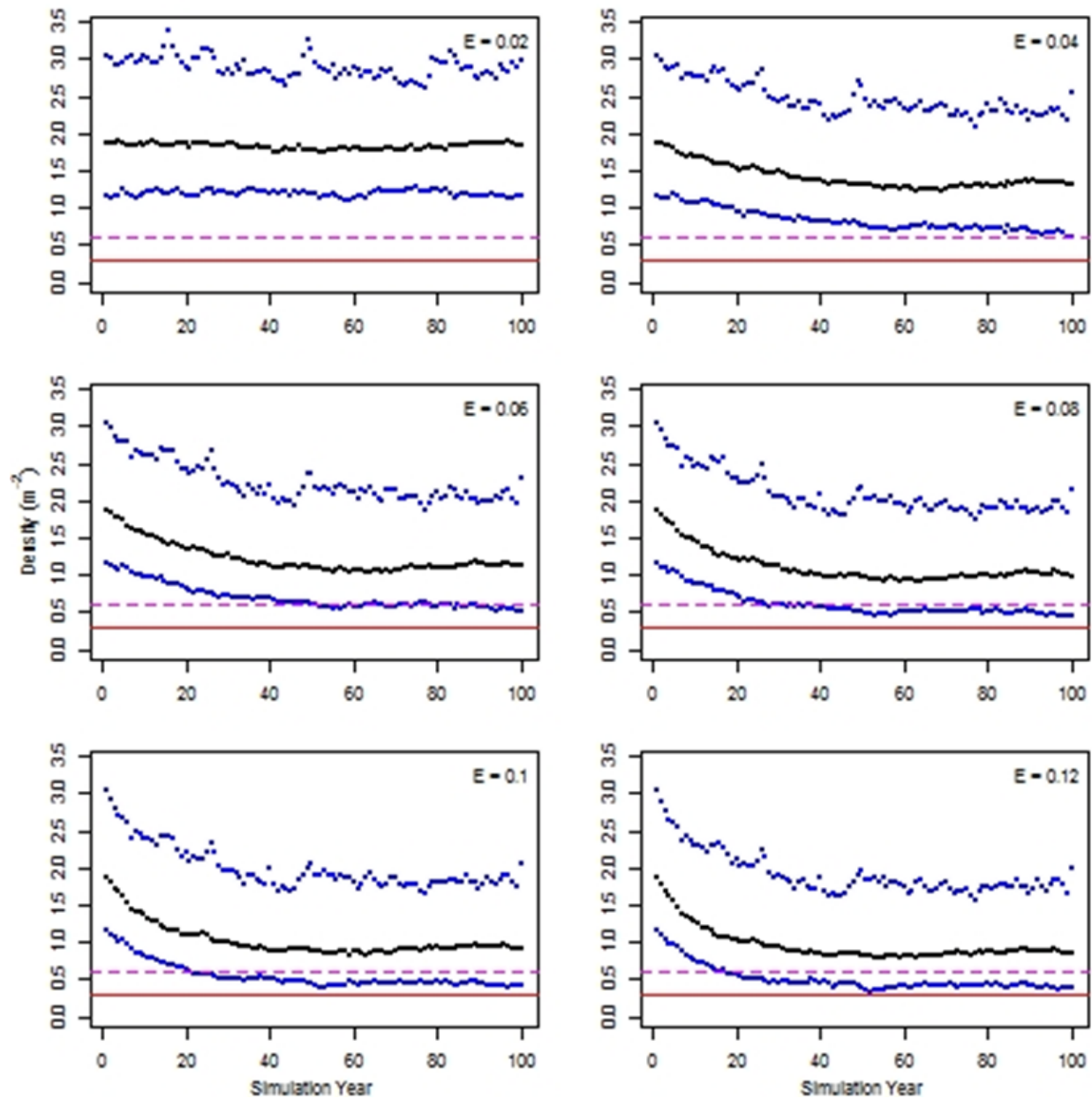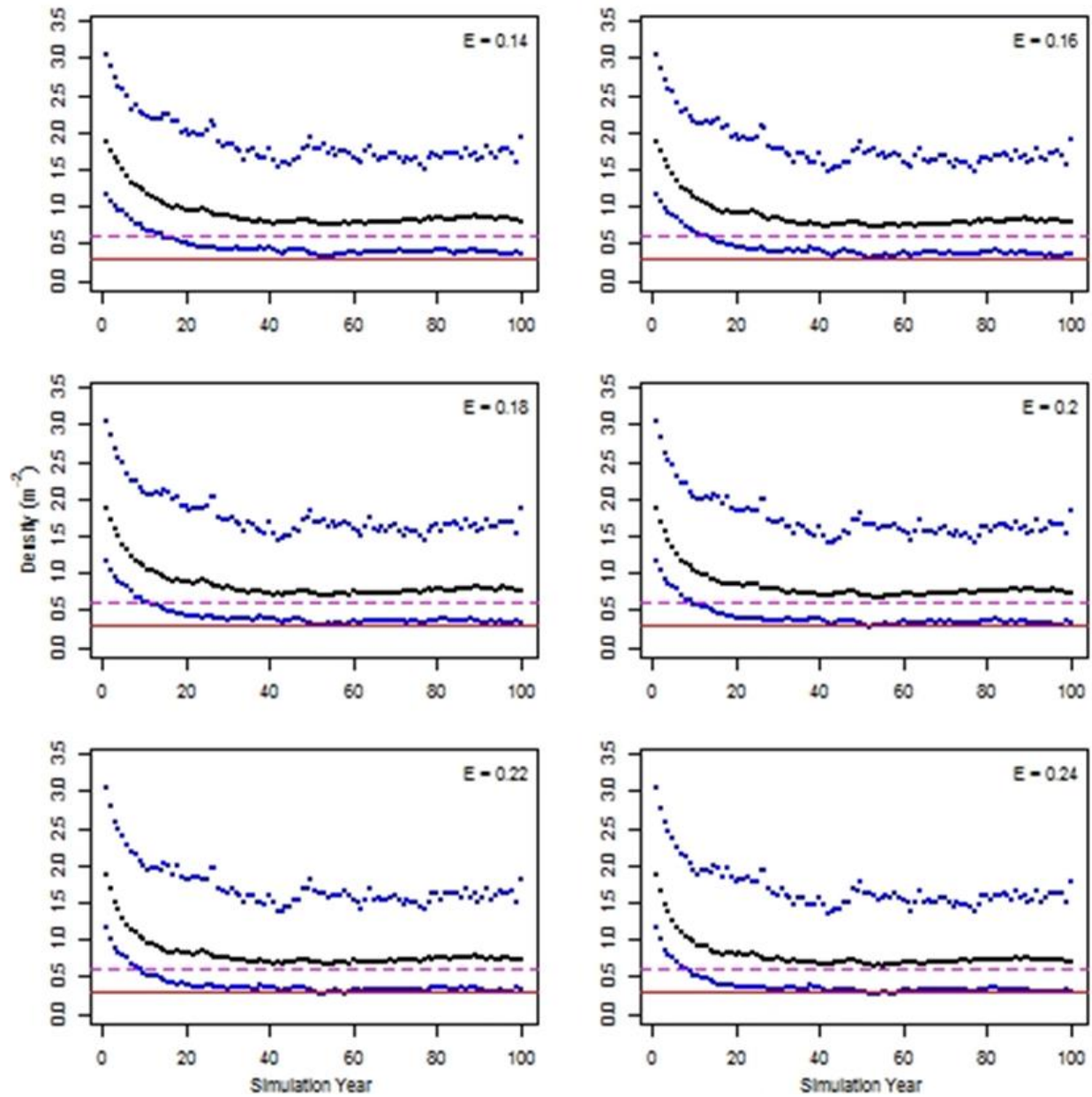
Figure 7 (continued). Median spatial densities of mature Red Sea Urchin (RSU/m²: black lines) together with 95% confidence intervals (blue lines) under alternative harvest rates (E) over the simulation years for Mainland North Coast, using Tanaka Growth model. The broken and solid red lines denote the Upper Stock Reference Point and Limit Reference Point, respectively.

Figure 8. Median spatial densities of mature Red Sea Urchin (RSU/m^2: black lines) together with 95% confidence intervals (blue lines) under alternative harvest rates (E) over the simulation years for Mainland North Coast, using Logistic Growth model. The broken and solid red lines denote the Upper Stock Reference Point and Limit Reference Point, respectively (continued on next page).
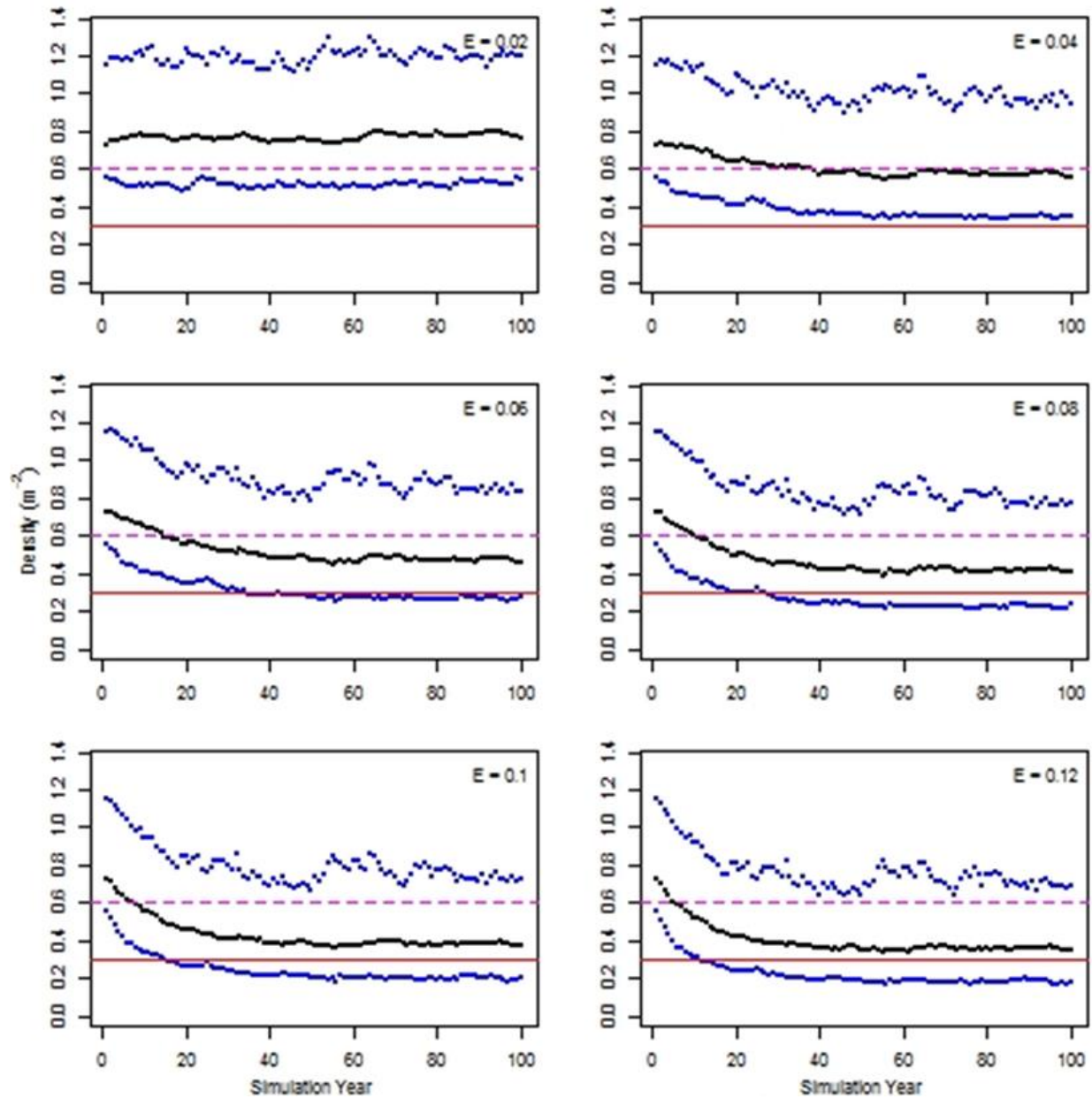
Figure 8 (continued). Median spatial densities of mature Red Sea Urchin (RSU/m²: black lines) together with 95% confidence intervals (blue lines) under alternative harvest rates (E) over the simulation years for Mainland North Coast, using Logistic Growth model. The broken and solid red lines denote the Upper Stock Reference Point and Limit Reference Point, respectively.

Figure 9. Median spatial densities of mature Red Sea Urchin (RSU/m^2: black lines) together with 95% confidence intervals (blue lines) under alternative harvest rates (E) over the simulation years for South Coast Inside Waters, using Tanaka Growth model. The broken and solid red lines denote the Upper Stock Reference Point and Limit Reference Point, respectively (continued on next page).
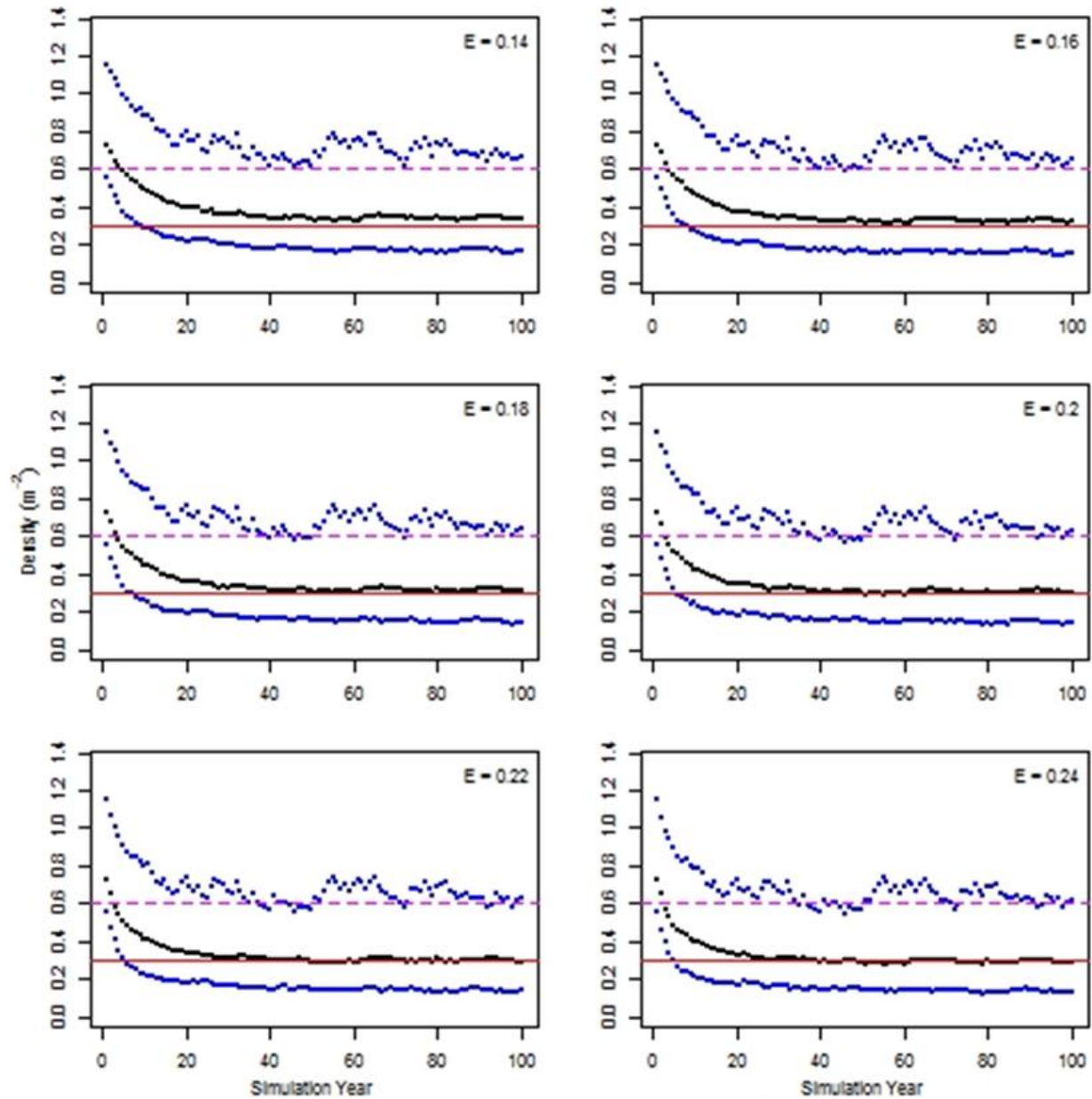
Figure 9 (continued). Median spatial densities of mature Red Sea Urchin (RSU/m²: black lines) together with 95% confidence intervals (blue lines) under alternative harvest rates (E) over the simulation years for South Coast Inside Waters, using Tanaka Growth model. The broken and solid red lines denote the Upper Stock Reference Point and Limit Reference Point, respectively.
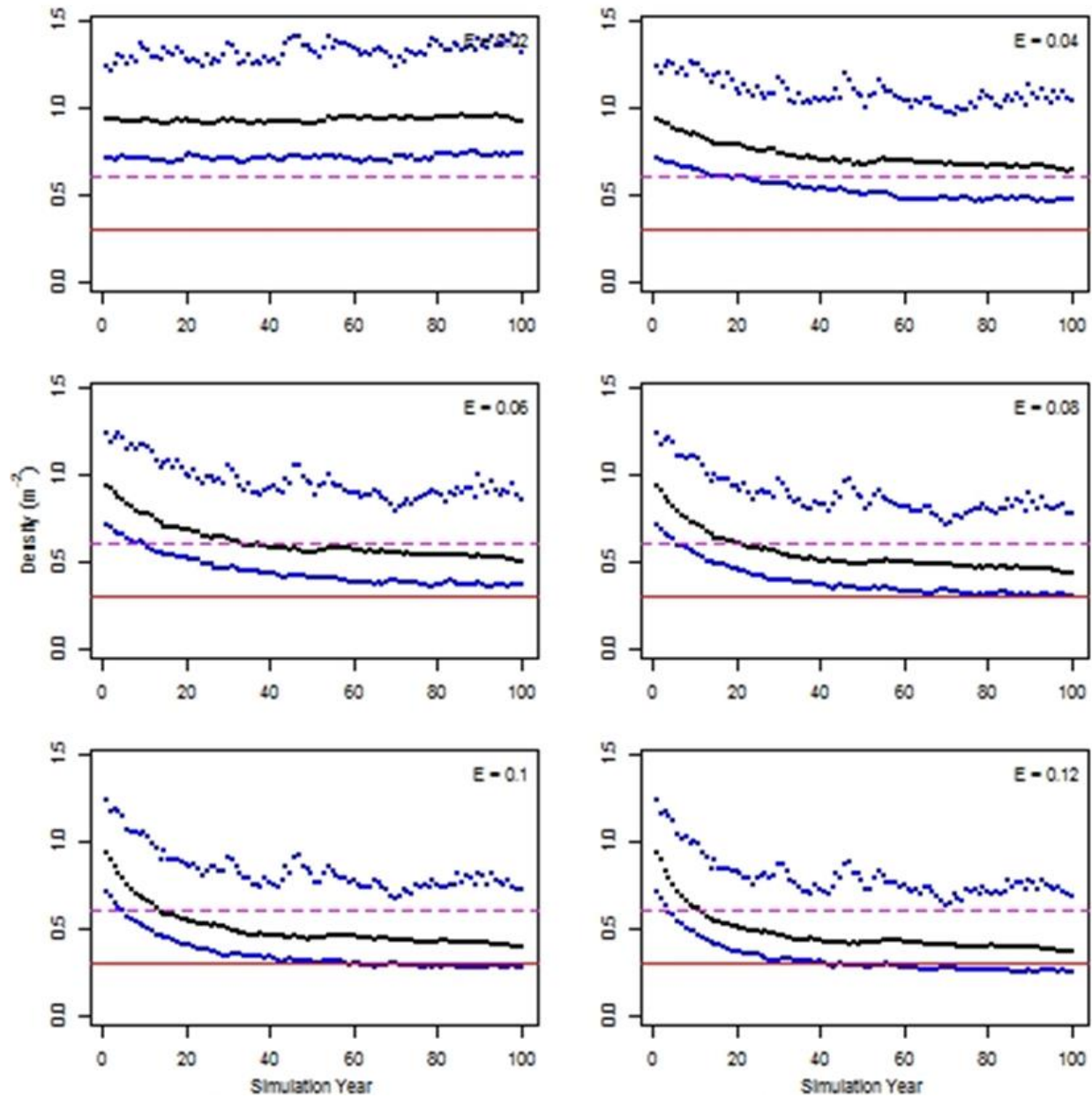
Figure 10. Median spatial densities of mature Red Sea Urchin (RSU/m^2: black lines) together with 95% confidence intervals (blue lines) under alternative harvest rates (E) over the simulation years for South Coast Inside Waters, using Logistic Growth model. The broken and solid red lines denote the Upper Stock Reference Point and Limit Reference Point, respectively (continued on next page).
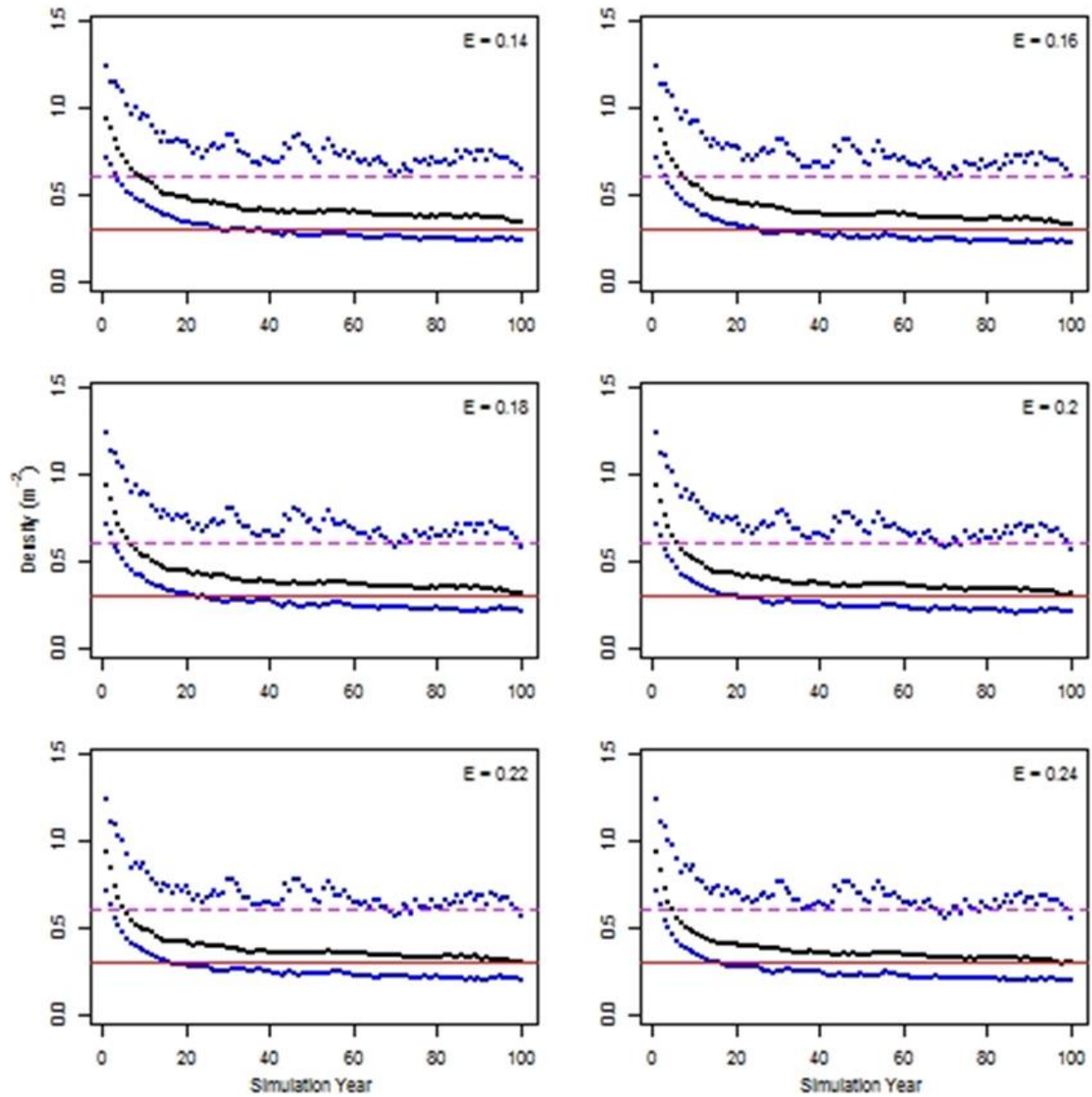
Figure 10 (continued). Median spatial densities of mature Red Sea Urchin (RSU/m^2: black lines) together with 95% confidence intervals (blue lines) under alternative harvest rates (E) over the simulation years for South Coast Inside Waters, using Logistic Growth model. The broken and solid red lines denote the Upper Stock Reference Point and Limit Reference Point, respectively.