Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2016/096

Pacific Region

Update to the assessment framework for Goose Barnacles (Caʔinwa; *Pollicipes polymerus*) incorporating Local Ecological Knowledge and advancements in technology in Clayoquot Sound off the West Coast of Canada

A. Gagne[1], C. Picco[2], D. Rutherford[3], and J. Rogers[4]

[1] T'aaq-wiihak Fisheries
161 First Street
Tofino, BC V0R 2Z0

[2] Nuu-chah-nulth Tribal Council, Uu-a-thluk
161 First Street
Tofino, BC V0R 2Z0

[3] Pacific Biological Station
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

[4] Pacific Biological Station
Fisheries and Oceans Canada
3225 Stephenson Point Road
Nanaimo, BC V9T 1K3

November 2016

Canada

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.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Gagne, A., Picco, C., Rutherford, D., and Rogers, J. 2016. Update to the assessment framework for Goose Barnacles (Caʔinwa; *Pollicipes polymerus*) incorporating Local Ecological Knowledge and advancements in technology in Clayoquot Sound off the West Coast of Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/096. viii + 34 p.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This Goose Barnacle Framework updates a general framework for Goose Barnacles (CaʔinwaA;[1]*Pollicipes polymerus*) in waters off the West Coast of Canada developed by Lauzier in 1999. The update incorporates a revised survey methodology and analytical procedures for estimating goose barnacle bed area and biomass with the inclusion of Local Ecological Knowledge (LEK). Bed area can now be mapped and estimated using advances in Global Positioning System (GPS) technology and Google Earth Mapping Software. New analytical procedures using bootstrapping methodology and LEK are proposed for quantitatively estimating Goose Barnacle biomass. This paper explores the concept of using harvest area closures as an alternative to a biologically-based provisional Limit Reference Point (LRP) and an Upper Stock Reference (USR). The new methodologies are documented and results of recent surveys using the new methodologies are presented.

Goose Barnacle bed area for six rocks in Clayoquot Sound was surveyed using GPS. Replicate surveys were conducted and variability between surveyors averaged 12.3%. Goose Barnacle density data sampled from 19 rocks between 2000 and 2003 were used in the quantitative estimates of biomass for the six rocks with GPS derived bed areas. Densities ranged from 0 to 39 kg/m^2 and averaged 7 kg/m^2. Biomass estimates are presented along with probabilities in a decision table form.

Local Ecological Knowledge is incorporated into several aspects of the assessment framework. LEK is used to estimate the *harvestable* biomass which takes into consideration size range for market, accessibility and availability. LEK *harvestable* biomass was compared to quantitative estimates of total biomass. LEK *harvestable* biomass was found to represent 4.6% of the quantitatively estimated mean biomass for the six rocks surveyed using GPS.

[1] Caʔinwa is the Nuu-chah-nulth word for Goose Barnacles. It translates to *playing with/in the waves.*

Mise à jour du cadre d'évaluation du pouce-pied (CaʔInwa; *Pollicipes polymerus*) afin d'intégrer les connaissances écologiques locales et les avancées technologiques dans la baie Clayoquot au large de la côte Ouest du Canada

RÉSUMÉ

Le présent cadre d'évaluation du pouce-pied est une mise à jour du cadre général d'évaluation du pouce-pied (CaʔInwa; [2]*Pollicipes polymerus*) dans les eaux au large de la côte Ouest du Canada élaboré par Lauzier en 1999. Cette mise à jour intègre une méthode de relevé révisée et des procédures analytiques permettant d'estimer la zone du gisement et la biomasse du pouce-pied, ainsi que les connaissances écologiques locales (CEL). La zone de gisement peut désormais être cartographiée et estimée à l'aide des avancées de la technologie de GPS et des améliorations apportées au logiciel de cartographie Google Earth. De nouvelles procédures analytiques s'appuyant sur la méthode d'auto-amorçage et les CEL ont été élaborées pour estimer de façon quantitative la biomasse du pouce-pied. Le présent article permet d'examiner le concept d'utilisation des fermetures des zones de récolte à titre de solution de rechange à un point de référence limite provisoire fondé sur la biologie et à un point de référence supérieur du stock. Les nouvelles méthodes sont documentées, et les résultats de relevés récents utilisant les nouvelles méthodes sont présentés.

La zone de gisement du pouce-pied sur six rochers de la baie Clayoquot a fait l'objet de relevés à l'aide d'un GPS. On a effectué des relevés répétés, et la variabilité observée entre les évaluateurs était de 12,3 %. Les données sur la densité du pouce-pied échantillonnées à partir de 19 rochers entre 2000 et 2003 ont été utilisées pour les estimations quantitatives de la biomasse pour les zones de gisement sur six rochers ayant fait l'objet de relevés à l'aide d'un GPS. Les densités variaient de 0 à 39 kg/m^2 et étaient en moyenne de 7 kg/m^2. Les estimations de la biomasse et les probabilités sont présentées sous la forme de tables de décision.

Les CEL sont intégrées dans plusieurs aspects du cadre d'évaluation. Les CEL sont utilisées pour estimer la biomasse *exploitable* qui tient compte de la fourchette des tailles aux fins de mise en marché, d'accessibilité et de disponibilité. La biomasse *exploitable* estimée à partir des CEL a été comparée aux estimations quantitatives de la biomasse totale. Il a été constaté que la biomasse *exploitable* estimée à partir des CEL représentait 4,6 % de la biomasse moyenne estimée de façon quantitative pour les six rochers ayant fait l'objet de relevés à l'aide d'un GPS.

[2] CaʔInwa est le mot Nuu-chah-nulth qui signifie « pouce-pied ». Il signifie *jouer dans/avec les vagues.*

1. INTRODUCTION

A general assessment framework for Goose Barnacles (CaʔinwaÍ¾ Pollicipes polymerus) in waters off the West Coast of Canada was prepared and presented to the Pacific Scientific Advice Review Committee (PSARC) in 1999 (Lauzier 1999a). The framework was developed in response to concerns over a lack of information on Goose Barnacle abundance, distribution, and life history parameters, as well as biologically based management controls, ultimately leading to the closure of the commercial fishery in 1999.

Since the framework was developed in 1999, advances in technology have provided an opportunity to update the survey methodology for estimating Goose Barnacle bed area and biomass on a rock-by-rock basis. New policies implemented by the Department of Fisheries and Oceans Canada such as the Sustainable Fisheries Framework, specifically the Fishery Decision-Making Framework Incorporating the Precautionary Approach (DFO 1999), require additions to the original framework. The inclusion of quantifiable information acquired through Local Ecological Knowledge (LEK) adds considerable value and efficacy to the existing assessment framework. Implementing the existing framework (Lauzier 1999a) is costly and resource intensive so opportunities to increase efficiencies are strongly desired.

Local Ecological Knowledge (LEK) is increasingly utilized supplementary to and in the absence of quantitative scientific information. The benefits of incorporating LEK into management go beyond holistic management decisions and include allowing for increased involvement and empowerment of local fishers. Rivera et al. (2014) outline the benefits of shifting the management of small scale fisheries from top-down to bottom-up. By increasing fisher involvement in the management and scientific assessment of small scale fisheries resource users are empowered, fishing stocks are better managed and the management scale is more localized (Rivera et al. 2014). LEK was an effective source of information in making management decisions for marine birds in the Arctic (Gilchrist et al. 2005). Stephenson et al. (2016) make a strong case that LEK is a valuable source for both fishery observations and experiential knowledge as fishers have a remarkable familiarity with the ecological and social systems they are a part of. Fisher knowledge can be incorporated into traditional forms of assessment, with the appropriate analysis, the explicit recognition of the intended use of the information (Stephenson et al. 2016) and exposure to scientific scrutiny (Gilchrist et al. 2005).

The need to revisit the existing Goose Barnacle Framework was in response to a re-invigoration of interest in the Goose Barnacle fishery off the west coast of Vancouver Island (WCVI) from five First Nation communities. In Ahousaht Indian Band et al. v. Canada and British Columbia (2009), the courts found that five Nuu-chah-nulth First Nations located on the WCVI (Ahousaht, Ehattesaht, Hesquiaht, Mowachaht/Muchalaht, and Tla-o-qui-aht) have “aboriginal rights to fish for any species of fish within their Fishing Territories and to sell that fish, with the exception of geoduck” (DFO 2016). Collectively the five plaintiff Nations took on the name of the T’aaq-wiihak Nations. T’aaq-wiihak means fishing with permission of the Ha’wiih (hereditary Chiefs).

Fisheries and Oceans Canada (DFO) is working with the T’aaq-wiihak Nations to uphold the constitutional right and find the manner in which their rights can be accommodated and exercised without jeopardizing Canada’s legislative objectives and societal interests in regulating the fishery. The five First Nations have taken the lead, in collaboration with DFO, to develop an updated assessment framework that incorporates new technology and LEK into the science and management of the fishery. The updated framework was tested in Clayoquot Sound, located within three of the five First Nations’ fishing territories. The proposed framework could be adapted for application in other areas along the British Columbian coast.

The objectives of this paper are to:

1. Develop a new methodology for estimating Goose Barnacle bed area using Trimble Handheld GPS in conjunction with Google Earth Pro.
2. Develop a revised methodology for estimating Goose Barnacle biomass.
3. Provide:
    a. Quantitative estimates of total biomass for some harvest rocks in Clayoquot Sound, in the form of estimated total biomass decision tables.
    b. An estimated sustainable harvest rate.
    c. LEK estimates of biomass available for harvest (*harvestable* biomass).
    d. Limit reference point(s) at an appropriate scale consistent with the Precautionary Approach policy.
4. Examine and identify sources of uncertainties in the data and methods.
5. Provide recommendations for future monitoring.

This update is specific to Clayoquot Sound in Pacific Fishery Management Area (PFMA) 24 and 124 (Figure 1).

2. BACKGROUND

2.1. DISTRIBUTION AND BIOLOGY

Goose Barnacles range from Sakhalin Island in the northwest Pacific, throughout the Aleutian Islands, and down the west coast of North America as far south as Mexico (Bernard 1988).

Goose Barnacles are generally found on rocky open ocean wave-exposed areas and occur in distinctive rosette-shaped aggregations typically 20 to 40 cm in diameter (Hoffman 1989). The aggregations are normally in tightly formed clusters with the larger older individuals at the centre surrounded by a graduation of smaller, younger individuals at the periphery.

Goose Barnacles are hermaphroditic with eggs and sperm present at the same time, however, self-fertilization does not occur (Hilgard 1960). Cirripedes typically reproduce by pseudo-copulation. Lewis (1975) found that only those sperm that had been deposited into the mantle cavity could successfully fertilize the eggs. According to Lewis and Chia (1981), 60% of closely associated (up to 5 cm apart) adults contained embryo masses and the maximum distance between individuals for potential breeding was 11 cm.

Barnacle larvae most readily attach to the stalks of larger, mature Goose and Acorn Barnacles, before forming peduncular extensions that re-attach to the rocky substrate (Hoffman 1989). Within the first five months of settlement rapid growth of up to 4 to 5 mm is estimated to occur and on average a length of 15 mm is reached after the first year for Goose Barnacles on the WCVI (Bernard 1988).

Dispersal of Goose Barnacle larvae can theoretically range from 185 to 930 km, based on the planktonic period of the naupliar larvae (42 days at 12°C) and an average current speed varying between 0.1 and 0.5 knots (Lewis 1975). However, current velocities measured off the WCVI are considerably lower (Thompson et al. 1989) so larval dispersal may be restricted locally to areas on the WCVI (Lauzier 1999b). A more detailed description of Goose Barnacle biology can be found in Lauzier (1999b).

2.2. THE FISHERY

2.2.1 Harvest Method

Typically Goose Barnacles are found to a height of 4.1 m above chart datum, but most *harvestable* barnacles are found in the intertidal range of 2.1 to 2.9 m on slopes up to 45° (Jamieson et al. 1999). Harvesters remove fist-size clumps of *harvestable* barnacles by hand using a long, flat steel bar (e.g., ground car leaf spring with a welded handle) to pry barnacle clumps from Common Mussel (*Mytilus edulis*) or Acorn Barnacle (*Balanus* spp.) substrates (Jamieson et al. 2001). Goose Barnacles are then carefully removed from the surrounding species to minimize peduncle wounding. Goose Barnacle harvest rates typically range from 9 to 15 kg of marketable product/hour (Jamieson et al. 1999).

Natural environmental conditions (i.e., seasonal tides, weather and intertidal topography) and marketable morphological requirements (i.e., correct size, shape, and colour) limit the amount of Goose Barnacles available for harvest at any given time. Jamieson et al. (2001) identify a *harvestable* sized Goose Barnacle as typically having a rostral-carinal (RC) (Figure 2) length of 15 to 30 mm, peduncle length between 20 to 80 mm, and a volume of 5 to 25 ml. The market for Goose Barnacles is for live barnacles - dead barnacles are discarded, and size preference aligns with the *harvestable* size definition. It is estimated that less than 10% of the entire WCVI stock was available for harvest during the 2003 to 2005 experimental fishery (DFO 2005[3]). At each harvest site, most barnacles (i.e., over 90%) are un-harvestable due to their size, appearance, and/or location. Goose Barnacles are considered *harvestable* when they:

1. Fall within the preferred size range for market (penducle length of 20 to 80 mm);
2. Are accessible and not found in places such as deep within rock fissures or cracks, or in areas that are not accessible due to safety; and
3. Can be removed live. This requires growth to occur on biological substrates such as Acorn Barnacles and mussels as opposed to bare rock where Goose Barnacles will rupture and die during the removal process.

2.2.2 History of Fishery

Goose Barnacles are a traditional food source for the Nuu-chah-nulth First Nations, who have harvested CaʔinwaCaʔinwa (the Nuu-chah-nulth term for Goose Barnacles, which means “playing in the waves”) along the northwest coast of North America for millennia. A modern commercial fishery took place from 1978 to its closure in 1999. This fishery peaked in 1988 with 467 licenses being issued and 49 tonnes of product being landed, the majority harvested from PFMA 23, 24 and 26 (Lauzier 1999b). The fishery was closed in May 1999 due to various concerns, including inconsistencies in harvest tracking, a lack Goose Barnacle population data (i.e., biomass, distribution, and abundance information) and uncertainty around habitat impacts (Lauzier 1999a; 1999b). After the fishery closed in 1999, two experimental fisheries took place between 2000 and 2002 to facilitate the gathering of information and the development of appropriate assessment and management strategies. Landings during these periods were very small: 1.8 tonnes and 1.3 tonnes respectively (DFO 2005).

---

[3] DFO. 2005. West Coast Vancouver Island Goose Barnacle Experimental Fishery Guidelines & Harvest Plan. Fisheries and Oceans Canada and West Coast Vancouver Island Aquatic Management Board. 62 pp.

Fisheries and Oceans Canada authorized another experimental fishery that ran from 2003 to 2005. This fishery was a unique example in British Columbia of cooperation between multiple parties including DFO, Province of B.C., WCVI coastal communities, First Nations, Non-Government Organizations (NGO's), harvesters, processors and buyers. This community-based experimental fishery was promising in terms of data collection necessary to develop assessment and management frameworks and develop markets. However, this fishery ended in 2005 mainly due to an influx of cheaper South American product flooding the European market, and management costs.

In 2010, the T'aaq-wiihak Nations began reviewing the information from the 2003 to 2005 experimental fishery with the intent to develop a sustainable fishery. DFO has supported this process by issuing communal commercial licences to the T'aaq-wiihak Nations so they can further develop a cost effective survey protocol, conduct market tests and provide fishery training opportunities.

A limited commercial Goose Barnacle fishery re-opened harvest rocks in September 2013. This fishery is currently composed of 52 Goose Barnacle rocks in Clayoquot Sound which is located along the south coast of Vancouver Island in PFMA 24 and 124 (Figure 1). The product is currently sold only in North America and is the sole commercial Goose Barnacle fishery occurring in North America.

Goose Barnacles can be harvested under a recreational licence however participation is assumed negligible.

2.3. LOCAL ECOLOGICAL KNOWLEDGE

Through the frequency of harvesting events, time spent on harvest sites and traditional knowledge acquisition, T'aaq-wiihak Goose Barnacle harvesters have developed a robust LEK knowledge base. Nuu-chah-nulth First Nations harvested Goose Barnacles for centuries using traditional harvesting techniques and hand harvest tools of the day. Experience is the foundation for developing and honing visual skills to estimate availability of Goose Barnacles on a rock. Knowledge on how to harvest the Goose Barnacles, in terms of preferred locations, harvesting conditions, harvesting techniques and safety considerations (like wave awareness) is passed on within a family from experienced harvesters to younger or new harvesters. Knowledge is typically rooted in location and founded on experiences in the traditional territory or harvesting sites around a Nation's community (Andrew Jackson, Tla-o-qui-aht Fisheries Manager, Tofino, BC, pers. comm.). The transmission and sharing of traditional harvesting knowledge is typically done orally and through direct experience at harvesting sites. As articulated by Battiste (2002), "Indigenous knowledge thus embodies a web of relationships within a specific ecological context… [and] has established customs with respect to acquiring and sharing knowledge… and implies responsibilities for possessing various kinds of knowledge" (page 14). Protection and maintenance of the integrity of knowledge within harvesting families is of key importance to Goose Barnacle harvesters (Andrew Jackson, Tla-o-qui-aht Fisheries Manager, Tofino, BC, pers. comm.). Given the current paucity of data on Goose Barnacle biomass and how populations respond to removals, the inclusion of LEK is an essential addition to the assessment framework.

3. EXISTING ASSESSMENT FRAMEWORK

The existing assessment framework for Goose Barnacle was developed in 1999 as part of the phased approach for new and developing fisheries. Components of the existing framework, relevant to this document, are provided here for background. For more detail refer to the full document by Lauzier (1999a).

The existing assessment methodology for estimating population size requires two types of surveys:

1. surveys to delineate and measure individual Goose Barnacle beds to estimate total defined area; and
2. surveys to estimate Goose Barnacle density and biomass within a bed.

3.1. BED AREA

Surveys to delineate and measure Goose Barnacle bed area involve a labour intensive process of physically measuring the total length of the bed parallel to the shoreline, and then taking multiple width measurements at specified intervals perpendicular to the length. These measurements are then used as inputs to the bed area calculation (Lauzier 1999a). Given the irregular size and shape of rock topography, converting linear measures of length and width to bed area can be challenging.

3.2. ABUNDANCE AND BIOMASS

The existing assessment framework provides very general approaches for surveying abundance and biomass and is documented as follows in Lauzier (1999a, pages 7-8):

> Because goose barnacles occur in highly aggregated clusters, as well as widely interspersed with mussels, a stratified two-stage random design is recommended. Stratified sampling is used to partition the populations into that the sampling units within a stratum area as similar as possible (Gillespie and Kronlund 1999). For example, prior knowledge suggests that an area of high barnacle density, the highly aggregated clusters of the upper intertidal, should be partitioned into a stratum and separated from the mid to lower intertidal, where goose barnacles occur in lower densities interspersed with the mussels. Other habitat information could also be used to partition the area into strata, such as settlement substrate. Stratification may not be necessary or appropriate for all sites. However, it will likely to be used at most sites, as there are potential benefits of reduced variances and narrower confidence intervals associated with the resulting estimates (Kronlund et al 1998). The delineation of strata will be site-specific after an initial reconnaissance of the sampling area.
>
> Two potential methods for abundance estimates are: (1) individual barnacle enumeration; and (2) cluster enumeration, which would be limited to the upper intertidal where goose barnacles typically occur in tightly humped clusters. which would be limited to the upper intertidal where goose barnacles typically occur in tightly humped clusters. Individual goose barnacle enumeration and resulting density estimates can use the same methodology outlined for mussels by Gillespie (1999). As recommended by Paine (1989) for California mussels, sampling quadrats should likely be limited to 100 cm2 (10 cm x 10 cm), to allow quick recovery. Given the natural densities encountered by Austin (1987) of 2000-5000 barnacles m2, 20-50 animals could be expected in each 100 cm2 quadrat. However, an appropriate quadrat size could be determined with field-testing, and sampling intensity (the number of quadrats over a given area) will also need to be determined.
>
> Sample quadrats are selected using a two-stage design. In the first stage, distances are selected at random along the length axis of the stratum. Assuming the quadrat size is 10 x 10 cm, and the stratum length is 20 m, then there are 200 possible quadrats along the length axis. A quadrat position is selected at random between 0 and 199, 89 for example. The quadrat position is then converted to actual distance along the axis by

dividing by the quadrat size (0.1m) and the first selected distance is 8.9 m along a 20 m axis. At each selected distance along the length axis, the width is measured perpendicular to the length axis. At the second stage of selection, three quadrats are systematically placed along the width measurement line from a random starting point. Assuming a 10 x 10 cm quadrat is used along a 5 m width line, then there are 50 possible quadrats for selection. The next largest sample frame that can be divisible by three (number of quadrats to be selected) is 51, representing three 17-quadrat strings arranged from end to end. A random starting point is selected between 0 and 16, 13 for this example. The remaining quadrat positions are determined systematically (by adding 17 to the initial starting point, 13) to give quadrat positions 30 and 47. These positions are then converted to the actual distances along the width line at 1.3 m, 3.0 m. and 4.7 m. The randomization process is then repeated independently for each width line at the first stage distance along the length axis. The systematic placement of quadrats along the width lines ensures an even sampling effort across potentially strong gradients over tidal heights.

A quadrat frame (recommended 10 x 10 cm) is used to select the animals for sampling. Those that have at least half their body within the quadrat are included. All sampled goose barnacles are carefully pried loose, picked, bagged, labelled and retained for detailed processing. Data required for biomass and abundance estimates are total count and total weight pre quadrat. All samples are retained for future selection for further analysis of more detailed biological information.

Mean densities (biomass or abundance) and associated variance can then be estimated using either the two-stage or stratified two-stage estimators provided by Kronlund et al (1998). Mean estimates are then expanded by the bed area to give estimates of total biomass or total abundance. The variances are expanded by the square of the bed area, and then used to calculate standard 95% confidence intervals (Gillespie 1999).

3.3. GROWTH AND AGE

All growth and age estimates currently used in this framework are from the work conducted by Bernard (1988). Goose Barnacle size (length) is measured as the distance between the rostrum and the carina and is referred to as the capitulum or rostral-carinal (RC) length (Figure 2). The Bernard (1988) length/weight relationship was re-published in Lauzier (1999b) and again in this report (Figure 3). The von Bertalanffy (1938) equation below was used by Bernard (1988) to predict the RC length at age in years (Figure 4).

Equation 1: The von Bertalanffy (1938) equation to predict of the rostral-carinal length at a given age in years.

$$l_t = L_\infty(1 - e^{-K(t-t_o)})$$

where:

l_t = length at time t (years)
K = 0.35 (Brodie growth coefficient)
L_∞ =31.6 (length at zero growth)
t_0 =-0.584
t = time (years)

Based on Bernard's (1988) data, 12 years is likely the maximum age for Goose Barnacles. Maturity is reached at a RC length of 14 to 17 mm (between 1 to 3 years of age) (Lewis and Chia 1981; Lauzier 1999b).

3.4. NATURAL MORTALITY

No direct measures to estimate natural mortality were conducted prior to the drafting of the existing assessment framework. As an interim measure Lauzier (1999a) suggested using the following predictive equation from Hoenig (1983) where constants are derived from meta-analyses of the total mortality rates and corresponding maximum observed ages from 134 stocks from three taxonomic groups (molluscs, fish and cetaceans). The maximum age used for Goose Barnacles was t_{max}=12 years (Bernard 1988), and the estimated natural mortality rate (M) = 0.37.

Equation 2: Hoenig's (1983) equation for predicting natural mortality. Uses estimates from all taxonomic groups to predict a generalized natural mortality estimate for species with limited information.

$$\ln(M) = a + b\ln(t_{\max})$$

where:

a = 1.44
b = -0.982 for all taxonomic groups
M = natural mortality
t_{max} = maximum age of Goose Barnacle (12 years)

3.5. HARVEST RATES

Harvest rate calculations require natural mortality estimates. In this case, the natural mortality estimate is not based on Goose Barnacle natural mortality specifically but calculated using a generalized value for all taxa (Hoenig 1983). For this reason, the calculated harvest rate for Goose Barnacles is considered preliminary. The preliminary natural mortality estimate based on Hoenig (1983) is 0.37. Assuming that 12 is the maximum age and using 0.2 as a scaling factor in Gulland's model (Gulland 1971) shown below, the output is an annual harvest rate of 7.5%.

Equation 3: Gulland's (1971) model for determining a harvest rate based on a predicted natural mortality rate and a scaling factor (0.2).

$$HR = 0.2M$$

where:

HR = Harvest Rate
M = Natural mortality (0.37)

4. UPDATES TO THE GOOSE BARNACLE ASSESSMENT FRAMEWORK

The proposed assessment framework updates outlined below include a new method for estimating bed area, methods for estimating biomass using both quantitative and LEK methods, and potential metrics for incorporation of the Precautionary Approach.

The first step for the quantitative population assessments is to delineate bed area (using the new method) and then apply a density estimate to the area to calculate (using a new method) a Goose Barnacle biomass estimate by rock including a measure of uncertainty. A harvest rate (HR) is then applied to the biomass estimate to guide harvest levels.

The LEK component is proposed for use as a method for estimating Goose Barnacle biomass when it is not feasible to conduct a quantitative assessment prior to harvest.

No new information or data were available to update the previously published information in Lauzier (1999 a,b) on growth, age, natural mortality (M), and corresponding appropriate harvest rate (HR).

The updated assessment framework was piloted on six rocks in Clayoquot Sound on the west coast of Vancouver Island that were surveyed and harvested in previous Goose Barnacle fisheries in the 1990's and 2003 to 2005.

4.1. GPS BED AREA MAPPING METHODOLOGY

A Goose Barnacle bed is delineated as unique or separate if there is greater than a five metre gap between barnacle clusters on a rock and/or if the bed is geographically separated from the neighbouring bed by geomorphological features (such as a rock fissure or crack that cannot be traversed). Each surveyor is provided the Decision Table before mapping bed areas in an effort to normalize surveyor methods (Figure 6). Harvest rocks are usually comprised of multiple beds (Figure 5).

To estimate bed area, a GPS Trimble Juno 5 handheld device is used to map Goose Barnacle beds on some harvest rocks in Clayoquot Sound. The Trimble TerraFlex Software is used to convert polygon data to Keyhole Markup Language (.kml), and Google Earth Pro is used to upload bed area polygons, compare replicates, and determine bed area.

Survey methodology involves using trained technicians to walk the perimeter of each Goose Barnacle bed on a rock-by-rock basis using a Trimble GPS handheld device (Figure 5). Once the total perimeter of the bed is surveyed, a polygon is generated by the Trimble. Ideally each bed is surveyed a minimum of three times by different surveyors to obtain a measure of variability, but this is not always possible.

Once the data, in the form of bed area polygon(s), are collected for a specific harvest rock the following procedure is followed:

1. Polygons are uploaded to the Trimble Insphere website. The Insphere website, using the Trimble TerraFlex Software, converts the polygons to .kml files, which are then opened in Google Earth Pro.
2. Bed area is calculated using the Google Earth Pro polygon calculation tool.
3. Bed area maps are created using Google Earth Pro.

Although Goose Barnacle population estimates are calculated by rock, rather than bed, to facilitate the spatial scale of harvest and management by rock, each bed on a specific rock (including replicate bed estimates) is used in the biomass estimation procedure.

4.2. BIOMASS ESTIMATION- QUADRAT METHOD

The Goose Barnacle density data collected from all 395 quadrats sampled from 19 rocks between 2000 and 2003 were used in the harvest rock biomass estimation for the six rocks in this framework. This is the complete set of density data available and spans rocks from Barkley Sound to Kyuquot on the WCVI. Density estimates were obtained following methods outlined in the document "Draft Protocol for Goose Barnacle Abundance and Biomass Surveys" produced by Lauzier and Day in 2000 [4](Appendix A). This method recommends placing12 0.25 m2 quadrats per transect line, at random locations, with three transect lines per bed. All Goose

[4] Lauzier and Day. 2000. Draft Protocol for Goose Barnacle Abundance and Biomass Surveys, 4p.

Barnacles within a quadrat are counted. Three of the 12 quadrats per transect also have a 400 cm^2 quadrat placed, within where all barnacles are removed and taken back to the lab for weight and length measurements. All density data used for the Goose Barnacle biomass estimation in this document were from the Shellfish_Bio_Other Relational Database Management System (RDBMS), Shellfish Section, Marine Ecosystems and Aquaculture Division, Science Branch, Fisheries and Oceans Canada, Nanaimo, B.C.

Total biomass for a rock known as Rock X (C-005, C-006, C-011, C-17, C-019, or C-20) was estimated using the GPS mapped bed areas and Goose Barnacle density as inputs. A bootstrapping (Efron 1981) procedure was used to estimate biomass as follows:

1. Count the number of beds contained on Rock X, and the number (n) of times a measurement was made on bed size
2. Randomly select a measurement from the n measurements for each bed on Rock X
3. Calculate the total area (A) of Rock X by summing up the randomly selected measurements of bed sizes
4. Randomly select a ROCK from the 19 ROCKs whose density and biomass of Goose Barnacle were measured in past surveys
5. Count the number (N) of quadrats used in the survey on this selected ROCK
6. Randomly select, with replacement, N quadrats (bootstrap quadrats) from the quadrats which were surveyed on this ROCK
7. Calculate the mean weight (W) of Goose Barnacle per unit area using the N bootstrap quadrats
8. Calculate Goose Barnacle biomass for Rock X as: W*A
9. Repeat the steps from 2 to 8, 100,000 times.

Calculations were preformed using “R” software (R Core Team 2013). See Appendix C for the R code for the biomass estimates.

4.3. BIOMASS ESTIMATION- LOCAL ECOLOGICAL KNOWLEDGE METHOD

Goose Barnacle LEK surveys were first implemented in 2003 to inform a variety of knowledge gaps related to the stock and fishery. Survey design involved conducting on-the-rock in-person interviews with experienced harvesters and knowledge holders. The surveys were conducted using experienced harvesters with a history of harvesting in each area. Harvesters were only taken to areas that they had direct experience with; not to rocks they had never visited. Harvesters were initially chosen for their willingness to participate (provided they met the condition of being an experienced goose barnacle harvester with over 2+ years of harvesting experience) and a core group of LEK harvesters was eventually established. Harvesters were remunerated for their time on a per trip basis (amended from Day 2012[5]).

In 2014 the number of questions asked during the survey was reduced and focused on the *harvestable* component of the stock. The current methodology involves independently asking one to three experienced harvesters the following four questions:

1. How many pounds of *harvestable* product do you think are on this rock?

[5] Day, A. 2012. 2003-2005 Experimental Goose Barnacle Fishery Review. 40 p.

2. How many pounds could you harvest in one tide?
3. Under what conditions would you harvest this rock? For example, is this rock easy to access in bad weather or would this rock only be harvested under calm conditions?
4. How long do you estimate it will take for Goose Barnacles to regenerate to a *harvestable* size on this rock after selective harvesting?

To reduce variability in responses associated with tidal height and weather conditions all surveys were conducted during five foot low tides or less and only during daylight hours under suitable weather conditions.

To estimate Goose Barnacle biomass using LEK, question 1 was used as an input as follows:

- Answers to question one were averaged, by rock, to estimate the harvestable product available on a given rock.
- The mean LEK estimations of harvestable biomass by rock were then compared to the quadrat estimated total biomass.
- A proportional relationship between LEK and quadrat biomass estimates was developed.
- Based on the proportional relationship, the LEK estimate can be expanded out to estimate total biomass for rocks with no GPS mapped bed area information.

4.4. PRECAUTIONARY APPROACH

The development of a harvest strategy compliant with the Precautionary Approach (PA) is required for Goose Barnacles. The minimum elements of the harvest strategy component of the DFO PA policy included a removal reference for three stock status zones delineated by the Limit Reference Point (LRP) and an Upper Stock Reference (USR) (DFO 1999).

The suggested default provisional reference points of 40% (LRP) and 80% (USR) of B_{msy} are contained within the PA policy but for Goose Barnacle stocks, there is a lack of biological and time series data. Reference points may also be expressed in terms of virgin biomass, B_0, with the LRP and USR expressed as 20% and 40% of B_0, respectively. A suggested way forward is to use total potential habitat area as a proxy for B_0. Total potential habitat is more akin to B_0 than to B_{msy}.

For Goose Barnacles, total potential habitat area was taken from Howes et al. (2001), who developed a biophysical shore zone mapping system as part of a coastal shoreline inventory program for the coastal zone of British Columbia. A system of bio-bands was developed to characterize the distribution of conspicuous assemblages of species that occur within a unit and are visible in aerial video tapes and slide imagery. These bio-bands are repeatable assemblages of intertidal biota that usually have a unique colour signature and intertidal position. Goose Barnacle potential habitat area was taken from the Intertidal-MUS bio-band which identifies potential habitat dominated by *Mytilus californianus* - *Semibalanus carriosus*, with scattered *Pollicipes* (Howes et al. 2001).

5. RESULTS

5.1. BED AREA

Bed area was estimated for 23 beds over six rocks in Clayoquot Sound using the Trimble GPS device. Each bed was surveyed from one to four times by different surveyors to obtain a measure of variability. Bed sizes ranged from a low of 7 m^2 to a high of 1,976 m^2. Of the 23 beds, two beds had four replicate measurements, eleven had three replicates and eight had only a single estimate resulting in a total of 55 bed area estimates (Table 1).

For beds with replicate measurements, the bed area variations (CV) ranged from a low of 0.0% to a high of 34.6% and averaged 12.3% (Table 1). Smaller beds tend to have a larger variation among surveyors.

5.2. BIOMASS ESTIMATION

5.2.1 Quadrat Method

The 395 Goose Barnacle density estimates obtained during the 2001 to 2003 surveys ranged from 0 to 39 kg/m^2 and averaged 7 kg/m^2 (Figure 7).

Nineteen rocks were surveyed using the quadrat method to estimate Goose Barnacle biomass, six of these were in Clayoquot Sound, seven were in Barkley Sound and six were in Kyuquot. Biomass estimates for the 6 rocks in Clayoquot Sound are presented as probability distributions and take into account the variability observed in Goose Barnacle density estimates and in bed area (Figure 7). The probability distributions (10, 20, 30, 50 and 70%) represent the probability of stock size being smaller than the associated biomass estimate (Table 2). Median (50% probability) estimates of Goose Barnacle biomass by rock ranged from a low of 1,972 kg to a high of 12,571 kg (Table 2).

5.2.2 LEK Method

LEK surveys were conducted on 41 out of 52 harvest rocks to estimate *harvestable* Goose Barnacle biomass. Of these, 37 were surveyed from 2003 to 2005 using the expanded questions and eight rocks were surveyed in 2014 using the reduced number of questions. A total of 11 experienced knowledge holders/harvesters were surveyed in 2003-2005 and in 2014. LEK estimates of *harvestable* biomass over all years ranged from 0 to 2,727 kg (0 to 6,000 lbs) (Appendix B). For the six rocks used in this analysis, six different LEK holders/harvesters were surveyed between 2003 and 2014, yielding 20 surveys. Three outlier surveys were removed from LEK estimates for the six rocks used in this analysis. An estimate was considered an outlier if it was notably different than the other estimates. For rock C-020, one outlier that was 75% to 84% less than the other three estimates was removed. Two out of six LEK estimates on rock C-011 were 70% to 90% higher than other estimates and were removed. LEK estimates for all other rocks, not analysed in this study, had no outliers removed (Appendix B).

Of the 41 rocks surveyed using LEK, six rocks were also surveyed using GPS, have corresponding estimates of total biomass, and are the basis for the results of this framework. Two of these six rocks are part of the 19 rocks surveyed with the quadrat method. LEK estimates of harvestable biomass over the six rocks ranged from 45 to 682 kg (Table 3).

Recall that *harvestable* Goose Barnacle biomass is measuring a different component of the population than estimated total biomass, so another step in methodology is required to go from LEK *harvestable* to a total biomass estimation.

For the six study rocks LEK *harvestable* biomass estimates (LEKHB) represented between 0.8% and 15.1% of the estimated median (50% probability) total biomass (Table 3). On average, over the six study rocks, LEKHB represented 4.6% of the estimated median total biomass. This equates to estimated total rock biomasses for the six study rocks from 1,975 to 11,501 kg (Table 4) calculated using the LEKHB/QETB relationship described in the following equation:

Equation 4: Calculation of the estimated total biomass on a rock (ERB) based on the relationship between the LEK estimate of harvestable biomass (LEKHB) and the quantitatively estimated median total biomass ($P_{50\%}$) (QETB).

$$ERB_X = LEKHB_X * LEK\ ratio$$

Where:

ERB_X=Estimated Goose Barnacle Biomass for Rock X

$LEKHB_X$= Average LEK Estimate of Harvestable Biomass for Rock X

LEK ratio = $^1/_{\text{mean (LEKHB:QETB) over all rocks}}$

Estimates of Goose barnacle biomass (*Equation 4*), for the six rocks, resulted in four of the rock estimates being below the median estimated biomass, two rocks exceeding the median estimate and one (Rock C-020) exceeding the upper limit of the estimated biomass probability distribution (Table 4, Figure 8). Given the current data the LEK ratio = 21.7. This value will likely change as more LEK surveys and bed area mapping is completed.

5.3. PRECAUTIONARY APPROACH

Using the Intertidal-MUS bioband data from Howes et al. (2001), a total of 1,058,870 m^2 of potential Goose Barnacle habitat (potential bed areas) exists within Clayoquot Sound. Using area as a proxy for B_0 the LRP (20% B_0) would be 211,774 m^2 and the USR (40%B_0) 423,548 m^2. To operationalize these reference points, the Goose Barnacle stocks within Clayoquot Sound would be considered in the healthy zone if a minimum of 423,548 m^2 of Goose Barnacle area remained as refugia. The LRP would be breached if refugia area was less than 211,774 m^2. Within Clayoquot Sound 72% (761,125 m^2) of the area is located in park reserves and currently closed to commercial harvest. The current estimate of 72% of Goose Barnacle area being in refugia would place the Clayoquot Sound population in the healthy zone.

There are Goose Barnacle harvest sites both north and south of one major park area, Pacific Rim National Park Reserve, surrounding Vargas Island (Figure 5). Given the wide dispersal and recruitment of Goose Barnacles, the park area is thought to be a significant refugia, and contributor to Goose Barnacle recruitment on harvest rocks.

6. DISCUSSION

Quantitative methods for estimating Goose Barnacle biomass are labour intensive and costly, therefore, efficiencies to the methodology are a research priority for those involved. This paper presents updated and more efficient methods for quantitative estimates of bed area and biomass with the added efficacy of incorporating LEK estimates of *harvestable* biomass to estimate total biomass prior to, or in absence of, a quantitative estimate.

The GPS-based methodology for estimating and mapping bed area takes less time and resources to produce bed area estimates compared to the quadrat/transect method of measuring bed length and width at many different points on the bed. The GPS mapping method can delineate distinct bed areas with greater precision and is flexible enough to easily omit areas with no barnacles. The quadrat/transect method does not conform well to the curvilinear shape of Goose Barnacle beds and could result in an overestimate of bed area.

Some variation in bed area measurements using GPS methodology does occur within and among surveyors and is potentially attributed to the following factors:

1. Weather conditions and tides. In larger swell and higher low tides, less of the lowest portion of the bed is available for survey. Generally surveyors attempt to stretch their arms to reach the lowest perimeter of the bed and survey at tides lower than 4 ft (1.2 m). If the lower perimeter of the bed was not visible or could not be mapped due to weather or ocean conditions the survey was aborted.
2. Surveyor boldness. Some surveyors are more agile on the rocks and willing to get closer to the wave surge or walk on steep slippery areas compared to other surveyors.
3. Subjectivity. Surveyors follow the decision tree (Figure 6) rules when surveying rocks, however, in some areas surveyors make subjective decisions to include or not include small numbers of Goose Barnacles disconnected to a larger bed. It is possible that some surveyors miss small patches of barnacles that others include in their survey.

The quadrat based biomass estimation methodology uses density estimates obtained between 2001 and 2003. Two additional quadrat based surveys were conducted in 2013 to groundtruth the findings from the 2000 to 2003 surveys. The results of the 2 surveys in 2013 were inline with the previous 2000 to 2003 surveys. This paper’s bootstrapping methodology was not applied to the estimates from these two more recent surveys. This is a minor short-coming and more density surveys should be conducted in order to increase the data pool and include more recent data points. However, the data used in the analysis are in the same range as earlier rock densities reported by Bernard (1988). Density estimates used in this analysis averaged 7 kg/m^2 and Bernard’s (1988) averaged between 2.7 and 12.8 kg/m^2.

In the bootstrapping procedure used to estimate Goose Barnacle biomass there is an implicit assumption that densities among different beds on the same rock are similar. Anecdotal observations by LEK holders, biologists and technicians corroborate the assumption that Goose Barnacle bed densities are more similar on the same rock than between rocks. This could be a result of similar wave action and environmental conditions at a given rock.

Goose Barnacle biomass estimates by rock are presented as distributions and reported in a decision-type tabular form to allow managers to choose appropriate risk levels. In the absence of updated information no change is recommend to the existing 7.5% harvest rate on the Goose Barnacle population within Clayoquot Sound. This harvest rate applies to the population as a whole and not to an individual bed or rock.

The approach of using total potential habitat as an interim proxy for B_0 is recommended in the unique case of Goose Barnacle in the Clayoquot Sound area due to the sessile nature of the organism, the data limitations associated with estimating population parameters, the small spatial scale on which it is being applied, and in recognition that the refugia are spatially integrated into the current harvest area meaning that larval connectivity is likely.

The quality of LEK varies by individual and location. It is important to gather a range of LEK from different individuals to determine the level of subjectivity and to identify outliers. The LEK estimate of harvestable barnacles (LEKHB) on the six study rocks vary from 0.8% to 15.1% of the estimated median biomass generated through quantitative estimation methods. For the median biomass ($P_{50\%}$) estimate per rock, the average LEKHB estimate represented 4.6% of the rock’s biomass. LEKHB estimates represent the amount of barnacles that harvesters could harvest from a rock live, that are desirable in the market place. This was previously estimated to represent approximately 10 to 20% of a rock’s population (Day 2012).

The individuals that provide LEK have extensive experience in the *harvestable* component of the total Goose Barnacle biomass on a rock. Their experience may not extend to estimating total biomass and so the relationship between LEK *harvestable* and quantitatively estimated total biomass (QETB) was investigated (Equation 4). The estimated total rock biomass (ERB) fell within the QETB estimate range except for one rock (C-020) where the ERB calculated using the LEKHB estimates was considerably higher than the QETB. LEK estimates for C-020 were made three times by a single harvester on different dates in 2004 and ranged from 1000 to 1500 lbs (454 to 682 kg). A single outlier removed from this rock made by a different harvester indicated a much smaller harvestable amount on the rock. This could be a case of overestimation by the harvester with three estimates or perhaps the population dynamics on this rock have changed over the last decade; Goose Barnacle populations are susceptible to damage during storms if large logs and debris smash up against communities. Anecdotal information suggests that rocks with a large proportion of older individuals can experience extensive die offs, likely to leave space for juveniles to move-in and thrive (Marcel Martin, Tla-o-qui-aht Harvester, Tofino, BC, pers. comm), possibly in some cases juveniles are unable to re-establish a community leading to a decline in biomass. Another possible explanation for this variation is the ability of LEK to capture the natural variation among rocks based on the unique productivity, exposure and conditions of different rocks. Clearly further investigation into the linkage between LEKHB and biomass estimation through bed area mapping is required. It is recommended that a further six rocks be mapped each year and that the continuous updating of LEK information occurs during harvest events.

Estimating Goose Barnacle populations on a rock-by-rock basis is the proponent's preferred assessment method for the re-launch of this New Emerging Fishery. Harvesters and Nation Managers prefer setting harvest limits and evaluating Goose Barnacle populations by rock as management at this scale is considered the most sustainable and accurate method, and aligns with harvester behaviour and Goose Barnacle population dynamics. The proposed assessment framework meets the rock-by-rock objective and should be of value to managers in developing an appropriate spatial scale for management.

Even with efficiencies in data collection and methods, collecting data at this resolution through bed area mapping is time consuming and costly. Utilizing the wealth of knowledge that already exists within a pool of experienced harvesters to supplement, corroborate and strengthen empirical results is pragmatic. This knowledge is part of the "best available information" available for Goose Barnacles and aligns with an "ecosystem-based" and "integrated" management approach (Stephenson et al. 2016). When information of scientific merit is combined with quantifiable LEK acquired over a series of lifetimes, a holistic management and assessment system is possible.

The benefits of using LEK go beyond the acquisition of useful data. Fisher involvement can foster a feeling of ownership and encourage compliance through intellectual contributions to the development of fishery harvest limits. In small-scale, remote fisheries that are resource intensive to survey, fisher involvement in data collection and management decision making has numerous benefits including increased fisher empowerment, acceptance of the management system, sustainability of the resource, and the ability to manage the resource on a more finite scale (rock-by-rock or harvest site specific) (Rivera et al. 2014). Conducting transect and quadrat survey methods at the various harvest sites in Clayoquot Sound is resource intensive and time-consuming. Goose Barnacle harvesters are far more experienced than biologists when it comes to safely working on rocks and visit harvest sites more frequently. When harvesters land their product they report the location of their catch by rock and provide a *harvestable* biomass estimate for the product remaining on that rock. Concurrent harvest and rock biomass estimation allows for constant updating of biomass estimations, as Equation 4 is applied and potentially revised. The ability to capitalize on harvester time spent on the rocks provides a unique, cost effective way to collect data and increases the understanding the influence of harvesting activities on Goose Barnacle populations.

7. CONCLUSION

LEK and the revised methodology for bed area mapping are important additions to the current framework and provide a method for estimating and monitoring Goose Barnacle biomass. The results indicate that LEK harvestable biomass represents 4.6% of empirically estimated total biomass will need additional data and information to strengthen and demonstrate the utility of this relationship. Further bed area mapping and total biomass estimation by rock should continue at a recommended rate of six rocks per year. LEK harvestable biomass estimates will continue opportunistically as harvesters visit rocks for harvest, this could amount to between ten and 20 estimates each year.

7.1. SOURCES OF UNCERTAINTY

In this updated Goose Barnacle Framework there are several sources of uncertainty that are not quantitatively incorporated, these include:

- Available data are limited both spatially and temporally, and although all available density data are used as input into the biomass estimation, delineation of the bed area during GPS surveys is somewhat subjective and influenced by surveyor behavior.
- The Howes et al. (2001) bioband data outline potential habitat. Groundtruthing has not been done to determine the proportion of occupied versus unoccupied potential habitat areas.
- The influence of environmental conditions and tidal height impacts on the proportion of bed possible for surveying. In times of higher low tides with swell large enough to wash over the lower edge of the bed, bed area estimates are smaller than under calmer conditions with lower low tides.
- Inherent subjectivity in the LEK estimates by experienced harvesters.
- Density data estimates are from surveys conducted in 2003-2005 and from a combination of Barkley, Clayoquot and Kyuquot Sounds.

7.2. FUTURE WORK

1. Develop a survey schedule to conduct bed area estimation and quantitative biomass estimates for rocks harvested solely based on LEK estimates.
2. Continue to collect data to update the quantitative relationship between LEK and quadrat based estimates.
3. Undertake research on Goose Barnacle harvest recovery response.
4. Conduct research to groundtruth the density estimates from the 2001-2003 quadrat/transect surveys.
5. Carry out research to groundgruth the Howes et al. (2001) bio-band data and determine the proportion of occupied versus unoccupied potential habitat areas.
6. Conduct preliminary research on more advanced technology, such as drones, for calculating bed area.

8. RECOMMENDATIONS

1. Adopt the GPS methodology for estimating Goose Barnacle bed area.
2. Adopt the quadrat based Goose Barnacle biomass estimation procedure for rocks with bed area estimates.

3. Adopt the LEK method for estimating total Goose Barnacle biomass for rocks with no bed area estimates.
4. Adopt using harvest area closures, or refugia, as a proxy for establishing provisional reference points under the Precautionary Approach until more data on stock dynamics is available.
5. Use the previously determined 7.5% HR until such time as further data collection on population biology and dynamics can provide increased support for the selection of HR specific to Goose Barnacles.

9. ACKNOWLEDGEMENTS

The authors want to acknowledge the field contributions from Daniel O'Farrell, Danielle Francis, Jared Dick and Cole Gomez-Leishman. These individuals were key in the collection of data from the harvest rocks, without their dedication and time in the field this work would not have been possible. We would also like to thank all the harvesters who were involved with the LEK surveys and the fishers who harvest and continue to contribute their knowledge to the fishery. Zane Zhang provided the analytical expertise for the biomass estimation. Marcel Martin, Joe David, Guy Louie, Dr. Don Hall, Bryan Rusch, and Graham Gillespie were also instrumental in the launch of this fishery. The authors also want to acknowledge Tammy Norgard and Andrew Day who provided valuable input through their formal reviews of this document.

10. REFERENCES

Austin, W.C. 1987. A Feasibility Study for the Commercial Harvesting of the Goose Barnacle *Pollicipes polymerus*. Final Report prepared by NOPSA Enterprises Ltd. and Kyoyatan Marine Laboratory for the Department of Fisheries and Oceans.

Battiste, M. 2002. Indigenous Knowledge and Pedagogy in First Nations Education: A Literature Review With Recommendations. Ottawa: Indian and Northern Affairs Canada.

Bernard, F. R. 1988. Potential fishery for the Gooseneck Barnacle *Pollicipes polymerus* (Sowerby, 1833) in British Columbia. Fisheries Research, 6:287-298.

DFO. 2005. West Coast Vancouver Island Goose Barnacle Experimental Fishery Guidelines & Harvest Plan. Fisheries and Oceans Canada and West Coast Vancouver Island Aquatic Management Board. 62 pp.

DFO. 1999. A Fishery Decision-Making Framework Incorporating the Precautionary Approach (Accessed September 15, 2016)

DFO. 2016. Integrated Fisheries Management Plan Summary. Pacific Oyster (*Crassostrea gigas*) Pacific Region 2016/17. (Accessed September 15, 2016)

Efron, B. 1981. Nonparametric estimates of standard error: the jackknife, the bootstrap and other methods. *Biometrika*, *68*(3), 589-599.

Gilchrist, G., M. Mallory, and F. Merkel. 2005. Can local ecological knowledge contribute to wildlife management? Case studies of migratory birds. *Ecology and Society* 10(1):20. (Accessed September 15, 2016)

Gillespie, G.E. 1999. Stock assessment and management frameworks for the proposed fishery for sea mussels (*Mytilus californianus*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 1999/116. 46 p

Gillespie, G.E. and A.R. Kronlund. 1999. A Manual for Intertidal Clam Surveys. Can. Tech. Rep. Fish. Aquat. Sci. 2270: 144p

Gulland, J.A. 1971. Science and fishery mangmement. J. Cons. Int. Explor. Mer. 33:471-477

Hilgard, C.H. 1960. A study on the reproduction in the intertidal barnacle *Mitella polymerus* in Monterey Bay, California. Biol. Bull. 119:169-188.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82:898-903

Hoffman, D.L. 1989. Settlement and recruitment patterns of a pedunculate barnacle. *Pollicipes polymerus* Sowerby, of La Jolla, California. J. Exp. Mar. Biol: 125: 83-98.

Howes, D., J. Harper, and E. Owens. 2001. B.C. Biophysical Shore-Zone Mapping System- A Systematic Approach to Characterize Coastal Habitats in the Pacific Northwest. Technical Report by Coastal and Ocean Resources, Inc., Sidney, BC for the Coastal Task Force of the Resource Inventory Committee (RIC), Victoria, BC: RIC Secretariat.

Jamieson G.S., R. Lauzier, and G.E. Gillespie. 1999. Phase 1 Framework for Undertaking an Ecological Assessment of the Outer Rocky Intertidal Zone. DFO Can. Sci. Advis. Sec. Res. Doc. 1999/209. 33 p.

Jamieson G.S., S. Dixon, and R.B. Lauzier. 2001. Initial evaluation of community structure in goose barnacle (*Pollicipes polymerus*) and sea mussel (*Mytilus californianus*) beds off the west coast of Vancouver Island, British Columbia. DFO Can. Sci. Advis. Sec. Doc. 2001/124. 59 p.

Kronlund, A.R., G.E. Gillespie, and G.D. Heritage. 1998. Survey methodology for intertidal clams. *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. Can. Tech. Rep. Fish. Aquat. Sci. 2214.

Lauzier, R.B. 1999a. Framework for Goose Barnacle (*Pollicipes polymerus* Sowerby, 1833) fishery in waters off the west coast of Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 1999/198. iii + 24 p.

Lauzier, R. B. 1999b. A review of the biology and fisheries of the Goose Barnacle (*Pollicipes polymerus* Sowerby, 1833). DFO Can. Sci. Advis. Sec. Res. Doc. 1999/111. 30 p.

Lewis, C.A. 1975. Development of the Gooseneck barnacle, *Pollicipes polymerus* (Cirripedia:Lepadomorpha): Fertilization through settlement. Mar. Bio. 32:141-153.

Lewis, C.A. and F-S Chia. 1981. Growth, fecundity and reproductive biology in the pedunculate cirripede *Pollicipes polymerus* at San Juan Island, Washington. Can. J. Zool. 59:893-901

Paine, R.T. 1989. On commercial exploitation of the sea mussel, *Mytilus californianus*. Northwest Environ. J. 5(1):89-97

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0 (Accessed September 15, 2016)

Rivera, A., Gelrich, S., Garcia-Florez, L., Alcazar, J.L., and Acuna, J.L. 2014. Co-management in Europe: Insight from the gooseneck barnacle fishery in Asturias Spain. Marine Policy. 50: 300-208.

Stephenson, R.L., S. Paul, M.A. Pastoors, M. Kraan, P. Holm, M. Wiber, S. Mackinson, D.J. Dankel, K. Brooks, and A. Benson. 2016. Integrating fishers' knowledge research science and management. ICES Journal of Marine Science, doi: 10.1093/icesjms/fsw025

von Bertalanffy, L. 1938. A quantitative theory of organic growth. Hum. Biol. 181-213

11. TABLES

Table 1. Replicate Goose Barnacle bed area measurements by rock and coefficient of variation (CV)

		Bed area measurements (m^2)					
Rock ID	Bed ID	Replicate1	Rep. 2	Rep. 3	Rep. 4	MEAN	CV
C-005	A	686	620	644	-	650	5.1
C-005	B	570	548	545	-	554	2.5
C-006	A	1861	1733	1976	-	1857	6.5
C-011	A	575	591	645	-	604	6.1
C-011	B	8	13	7	-	9	34.4
C-011	C	48	48		-	48	0.0
C-011	D	68	69	66	-	68	2.3
C-011	E	247	327	254	-	276	16.1
C-011	F	162	125	121	-	136	16.6
C-017	A	270	-	-	-	-	-
C-017	B	688	-	-	-	-	-
C-017	C	155	-	-	-	-	-
C-017	D	260	-	-	-	-	-
C-017	E	35	-	-	-	-	-
C-017	F	22	-	-	-	-	-
C-019	A	858	889	875	875	874	1.5
C-019	B	12	19	10	-	14	34.6
C-019	C	21	26	-	-	24	15.0
C-019	D	18	33	23	21	24	27.4
C-019	E	20	19	21	-	20	5.0
C-019	F	100	91	89	-	93	6.3
C-020	A	397	-	-	-	-	-
C-020	B	121	-	-	-	-	-

Table 2. Quantitatively Estimated Total Biomass (QETB) probabilities by rock and associated quota based on 7.5% harvest rate.

Rock ID	Probability %[a]	Quantitatively Estimated Total Biomass (QETB) kg	Quota based on 7.5% HR kg
C-005	10	4563	342
	20	5494	412
	30	6297	472
	50	8156	612
	70	10198	765
C-006	10	6979	523
	20	8446	633
	30	9697	727
	50	12571	943
	70	15724	1179
C-011	10	4354	327
	20	5266	395
	30	6042	453
	50	7823	587
	70	9802	735
C-017	10	5438	408
	20	6539	490
	30	7478	561
	50	9715	729
	70	12118	909
C-019	10	3979	298
	20	4773	358
	30	5478	411
	50	7070	530
	70	8824	662
C-020	10	1972	148
	20	2368	178
	30	2710	203
	50	3502	263
	70	4381	329

[a] probability of biomass being lower

Table 3. Local Ecological Knowledge Harvestable Biomass (LEKHB) estimates by rock and year. The average LEKHB estimated by rock is shown proportional to the median quantitatively estimated total biomass (QETB).

Rock ID	Year	LEKHB estimate kg	Average per rock kg	QETB (50% prob.) kg	Proportion LEKHB:QETB (50%) %
C-005	2014	455	455	8156	5.6%
C-006	2003	45	98	12571	0.8%
	2003	114	-	-	-
	2003	136	-	-	-
C-011	2003	136	159	7823	2.0%
	2003	182	-	-	-
	2003	182	-	-	-
	2014	136	-	-	-
C-017	2004	91	91	9715	0.9%
	2004	91	-	-	-
C-019	2003	250	240	7070	3.4%
	2004	164	-	-	-
	2004	318	-	-	-
	2014	227	-	-	-
C-020	2004	455	530	3502	15.1%
	2004	455	-	-	-
	2004	682	-	-	-
AVERAGE					4.6%

Table 4. Comparison of Quantitatively Estimated Total Biomass (QETB) and Local Ecological Knowledge Harvestable Biomass (LEKHB) estimated total biomass, by rock.

	Quantitatively Estimated Total Biomass (QETB)		LEK Havestable Biomass (LEKHB)
Rock ID	Probability (%)[a]	kg	kg
C-005	10	4563	-
	20	5494	-
	30	6297	-
	50	8156	9874
	70	10198	
C-006	10	6979	-
	20	8446	-
	30	9697	-
	50	12571	2127
	70	15724	-
C-011	10	4354	-
	20	5266	-
	30	6042	-
	50	7823	3450
	70	9802	-
C-017	10	5438	-
	20	6539	-
	30	7478	-
	50	9715	1975
	70	12118	
C-019	10	3979	-
	20	4773	-
	30	5478	-
	50	7070	5208
	70	8824	-
C-020	10	1972	-
	20	2368	-
	30	2710	-
	50	3502	11501
	70	4381	-

[a] probability of biomass being lower

12. FIGURES

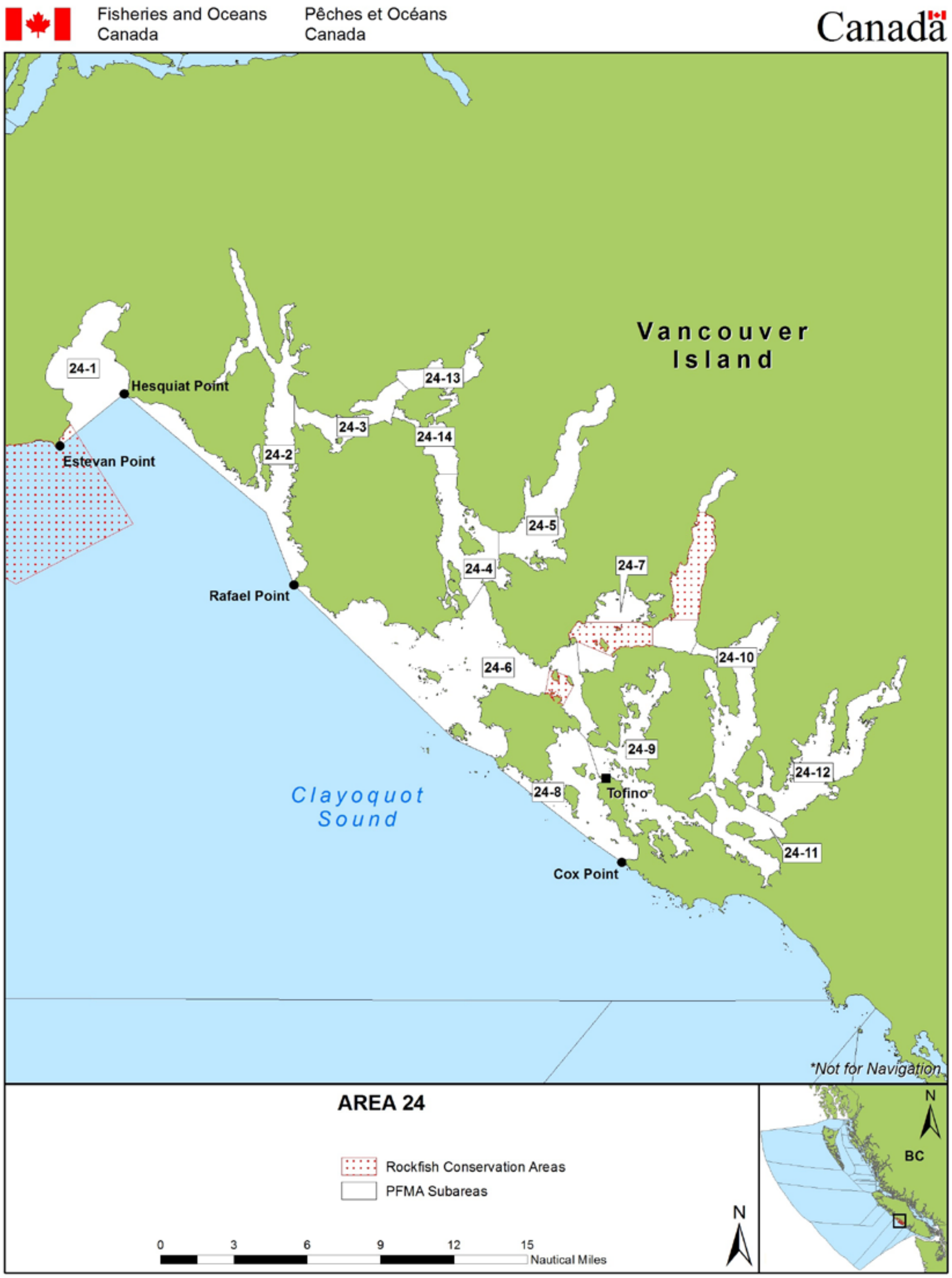

Figure 1. Pacific Fisheries Management Area (PFMA) maps for Clayoquot Sound.

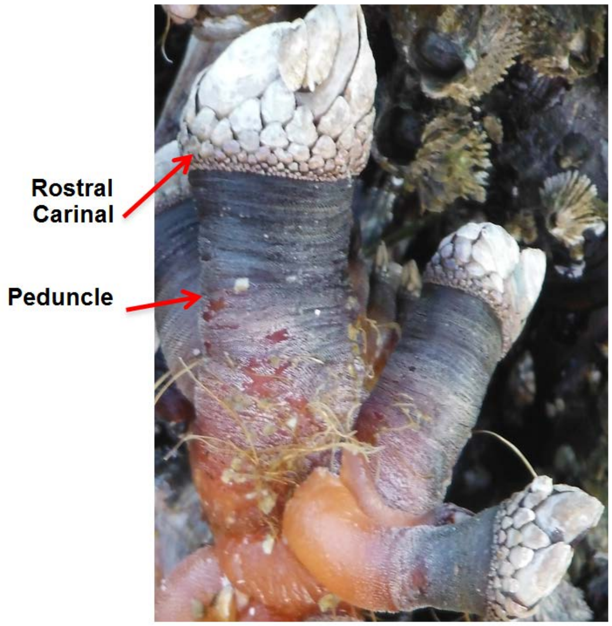

Figure 2. Image of the Goose Barnacle rostral-carinal (RC) and peduncle.

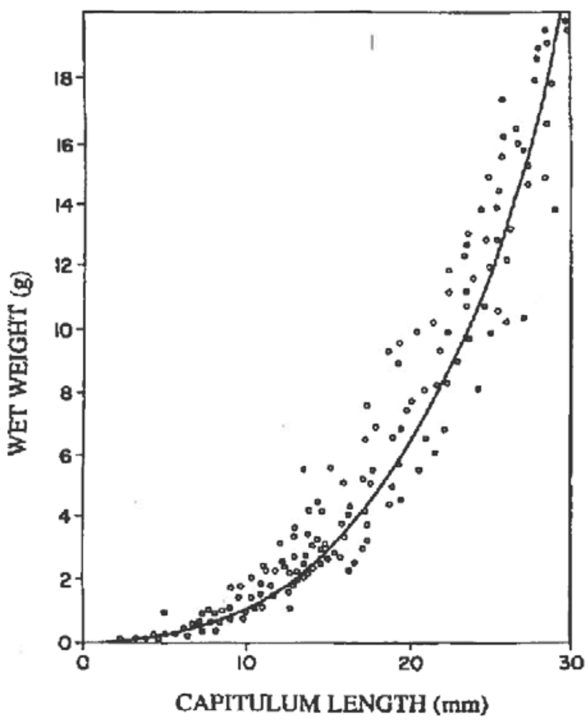

Figure 3. Length weight relationship for Goose Barnacles (from Bernard 1988).

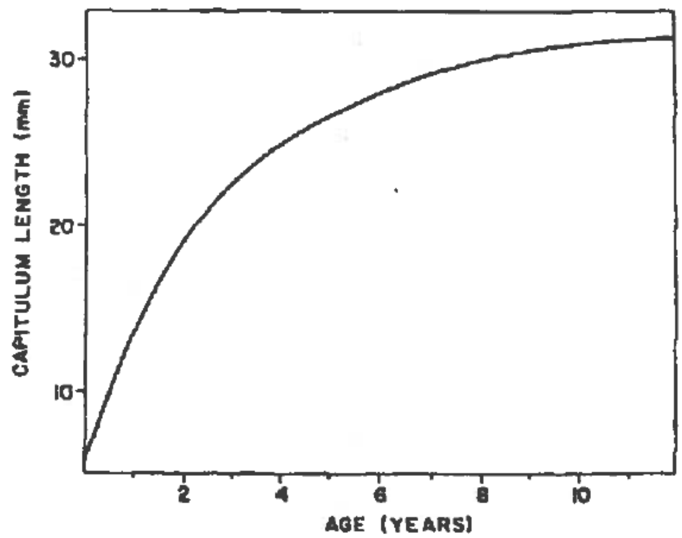

Figure 4. von Bertalanffy growth curve for Goose Barnacles (from Bernard 1988).

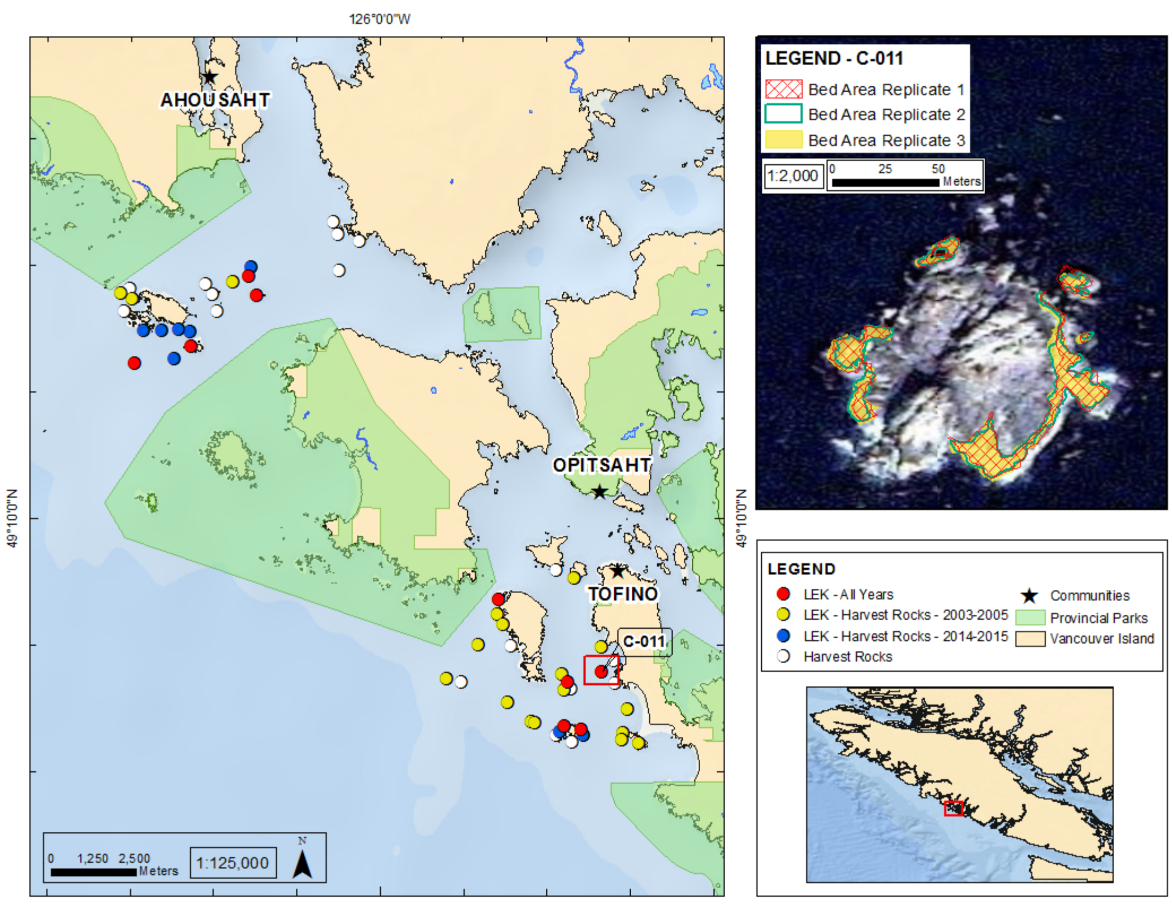

Figure 5. 52 harvest rocks in Clayoquot Sound. The shaded green area represents various Provincial Parks located within Clayoquot Sound. The inset of rock C-011 shows five bed areas mapped with GPS. Each bed area polygon represents a replicate.

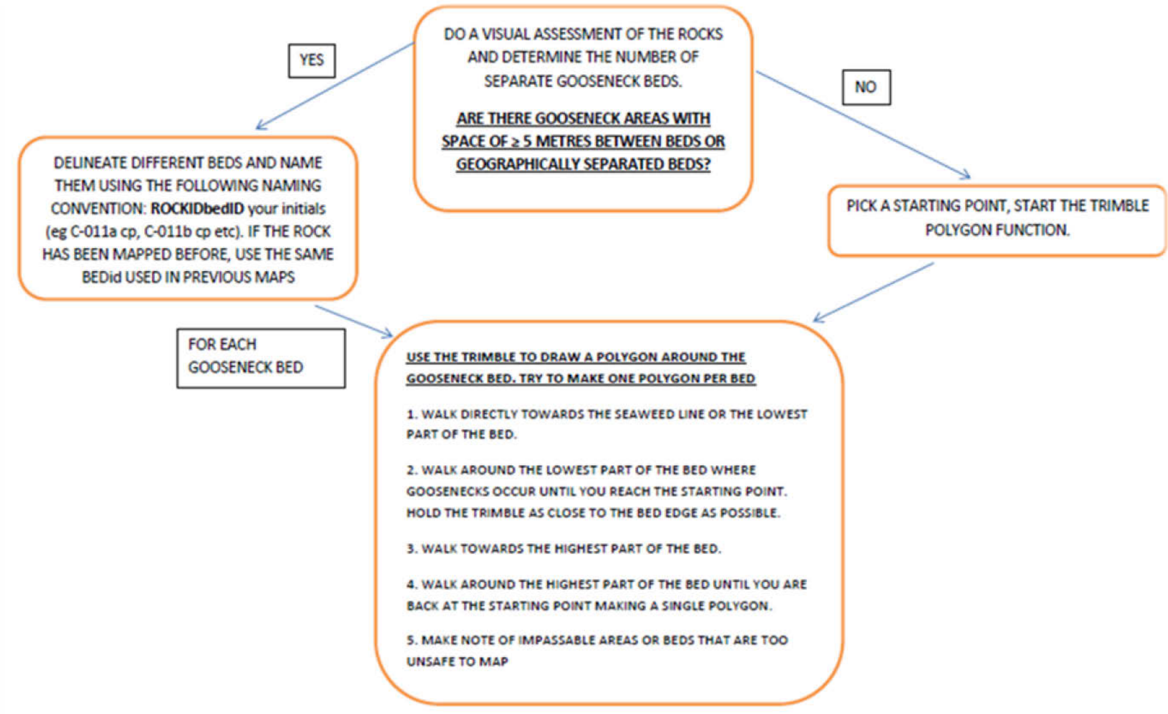

Figure 6. A decision table for surveyors mapping Goose Barnacle bed area.

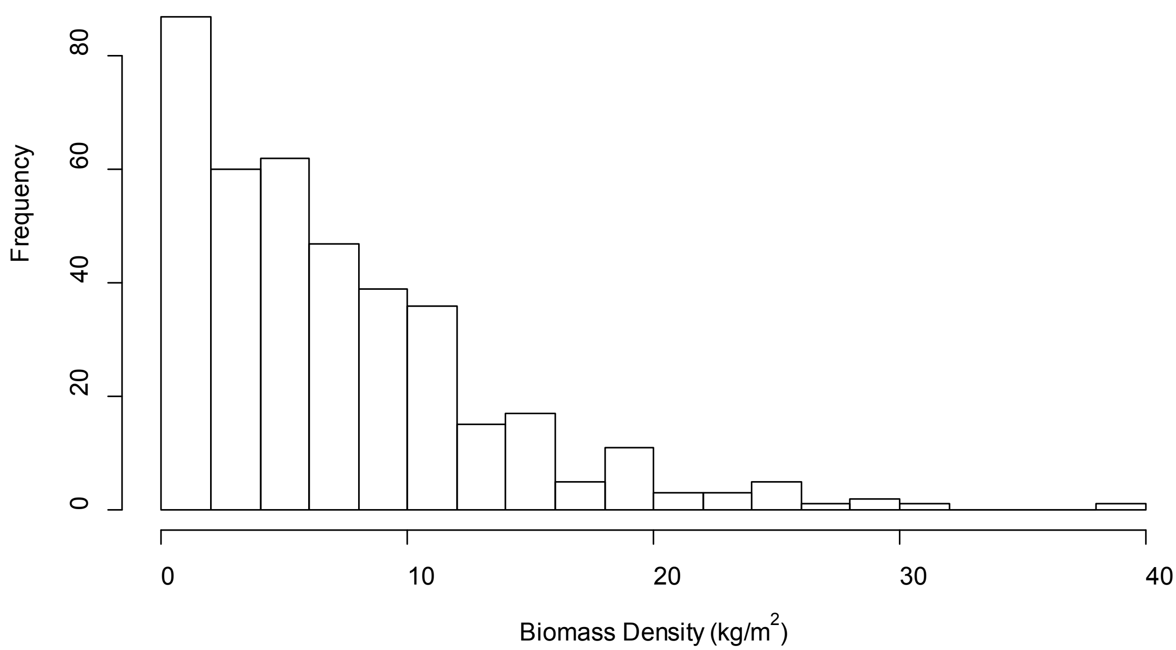

Figure 7. Distribution of Goose Barnacle density estimates from quadrat estimates from 2001-2003 surveys (n=395).

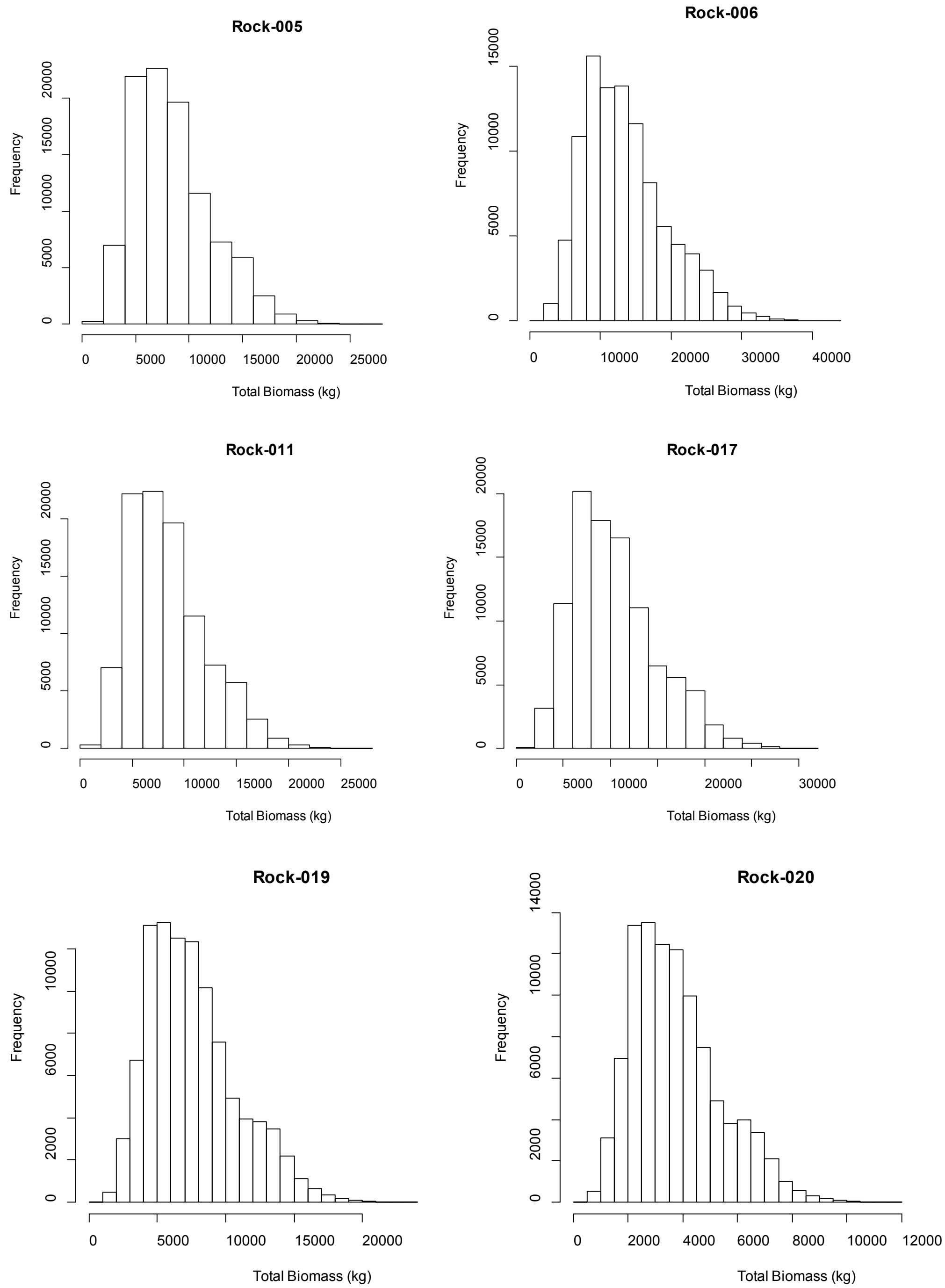

Figure 8. Goose Barnacle Quantitatively Estimated Total Biomass (QETB) distributions, by rock.

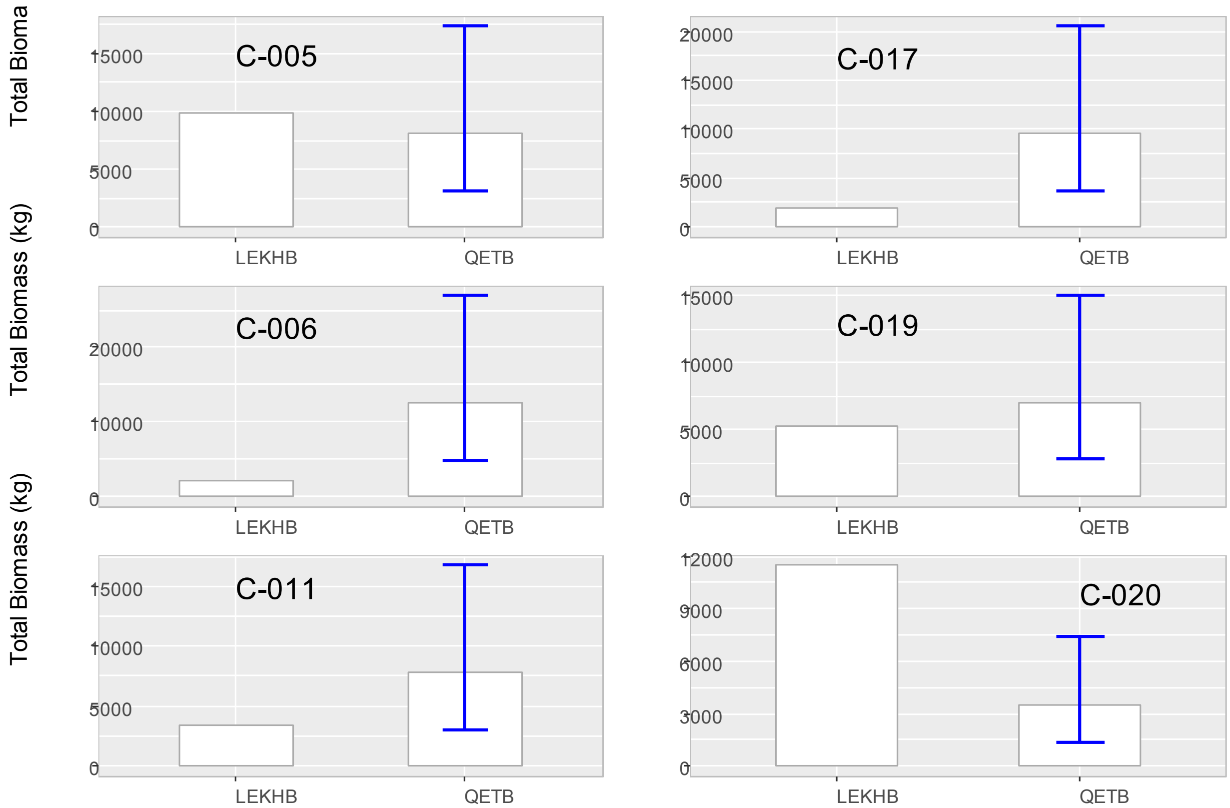

Figure 9. Comparison of Goose Barnacle biomass estimates using Quantitatively Estimated Total Biomass (QETB) and Local Ecological Knowledge Harvestable Biomass (LEKHB).

APPENDIX A

Draft Protocol for Goose Barnacle Abundance and Biomass Surveys

Site selection and survey methodology

Sites should be selected with the advice of harvesters with local experience. Accessibility and safety are key considerations in site selection, and will be dependent on tide and weather conditions. Sites are defined as actual locations, rocks or islets. With the initial surveys, care should be taken that the selected sites are not within the boundaries of parks or marine reserves. Within sites, there maybe one or several beds. A bed is defined as a continuous patch of goose barnacles. Beds should be delineated at each site in order to have manageable assessment units that can be surveyed within the limited time frame of a low tide.

The selection of beds for surveys should be primarily based on safety considerations, and access. Depending on the objectives of the survey, then considerations for bed selection include representativeness as an area index site and/or suitability for experimental harvest.

At each bed to be surveyed, an initial centre line transect is laid out with a surveyor's tape along the longest length axis over the entire length of the bed and in the middle of the delineate..1 bd. In many cases the longest axis of beds will be parallel to the shoreline, but on some exposed rocks, beds may be on fingers extending out towards the sea from a high rock mound or dome. The tape is laid out to follow the contours of the bed surface, which will range from flat surfacs or rolling terrain to steep slopes and gullies. The surveyors tape should not be stretched from end to end. Bed width is measured at selected points perpendiculars to the centre line transect. The frequency of width measurements will depend on the configuration of the bed. A bed shaped like an irregular polygon will require more width measurements than a rectangular bed. The intersection of the width measurements with the centre line transect is noted.

Additional transects are laid on the left (from the origin)(even numbered transects) and right (odd numbered transects) of the centre line and parallel to the centre line transect at a distance of half the narrowest width of the bed. Preliminary surveys show that three transect lines per bed with twelve 0.25-m^2 quadrats per transect will result in estimated error of approximately 50% of the mean.

Along each transect, at least twelve 0.25-m^2 quadrats are randomly placed for enumeration. Quadrat position is determined by selecting two digit random numbers from a random number table and multiplying by the transect length to determine the quadrat location. A coloured bolt or pin is placed at each quadrat location along the transect. Quadrats are placed along the transect with the top left comer on the transect location pin. If a location is selected twice, the second quadrat is placed 1 metre away. Overlapping quadrats are completely counted, regardless of overlap.

All the goose barnacles within the quadrats are counted. If a barnacle is partially witluu the quadrat, it is counted if more than half is within the quadrat frame. Due to the distributional characteristics of goose barnacles, considerable variation in goose barnacle density is expected between quadrats as well as within quadrats. In the preliminary surveys, densities ranged from 0 to > 4,000/m^2 In order to assist in the accurate count of higher density quadrats, partitioning the quadrats is suggested by using rubber bands stretched across the quadrat frame. The 0.25-m^2 quadrat size for enumeration is used as it reduces the variability of using smaller and more numerous quadrats, the quadrat will pick up several small harvestable clumps (which is important for monitoring the effects of harvesting), and it feasible to enumerate within a reasonable time. In addition to the quantitative information provided by counts, providing a short descriptive phrase as to the physical topography of the quadrat should collect useful qualitative information. For example, it should be noted whether the quadrat is on a horizontal flat surface, the top of a rock knob, on a gradual or steep slope, at the top middle or bottom of a vertical wall, or at the bottom of a hole or gully. There was evidence of recent harvesting activities in the preliminary surveys. The actual surface area harvested was difficult to estimate, as recovery by encroaching mussels and emergence of juvenile goose barnacles was well advanced. However, the number of apparent harvest cavities in each quadrat should be noted. The depth of the matrix community should be measured with the aluminium depth gauge developed for these surveys, and the underlying substrate (mussel, acorn barnacle or both) should be recorded. This qualitative information is useful in assessing the factors of variability in densities as well as describing habitat features. Biological samples are enumerated and taken within a 400-cm^2 quadrat that is randomly placed within a 0.25-m^2 quadrat. Six biological samples per transect are taken, but only one 400-cm^2 quadrat selected within a 0.25-m^2 quadrat, to minimize potential adverse impacts of biological samples taken in close proximity. Biological sample quadrat placement should also be stratified to ensure that barnacles, which are attached to bare rock, are excluded, as it virtually impossible to remove intact barnacles from bare rock. All barnacles within the 400-cm^2 quadrat are counted. All barnacles within the quadrat area (surface and subsurface) are then removed with the harvesting tool, bagged and labelled. Care must be taken to obtain the barnacles whole, intact and healthy, without damage to the peduncle. It is not necessary to remove all organisms to the bare rock layer to collect the goose barnacles. The mussel matrix and associated community may exceed 0.3 m in depth, and goose barnacles are only found close to the surface of this matrix, due to their feeding requirements and behavioural characteristics when feeding. Any disturbed co-occurring species such as mussels are replaced in the sample cavity to prevent any further disturbance to the community. While it would preferable to have enumeration quadrats and biomass quadrats the same size, it is not feasible to conduct detailed biological sampling on a 0.25-m^2 quadrat, and the disruption of such a large surface area could be devastating to the subsurface layers and surrounding community. The 400-cm^2 quadrat used in the biological sampling is only slightly larger than the size of the barnacle clumps usually harvested.

The time required to survey a bed depends on the size and topography of the bed, as well as the density of goose barnacles. It was found during the preliminary surveys that an average sized bed could be delineated, measured and surveyed by a 3-person crew in 2 ½ - 3 hours.

Biological samples are processed in the field laboratory as soon as possible after collection. Any fluid in the sample bag is drained (and weighed separately) and all the barnacles are separated from clumps to individuals. Fresh undamaged barnacles ar e measured for rostral-carinal (RC) length, peduncle length, weight, and volume (cc). RC length and peduncle lengths are measured with digital callipers to the nearest mm. Weight is determined with an electronic top-loading balance to 0.1 gm Volume is determined by water displacement in a plastic graduated cylinder to the nearest cc. or ml.

Usually a minimum of 40 barnacles per biological sample has detailed measurements taken. Any remaining barnacles, and/or smaller, damaged barnacles are counted and weighed in aggregate by size category. The average biological sample will take two persons from 45 minutes to an hour to process.

Biological samples are taken to estimate the standing stock biomass by extrapolating goose barnacle counts to estimate goose barnacle biomass. Various growth parameters are measured to determine the configuration of marketable product and the proportion of harvestable biomass to total biomass.

Experimental fisheries

It has been estimated from previous studies and the preliminary biomass methodology study that the harvestable goose barnacle biomass is approximately 10% of the total biomass on any particular rock. Experienced harvesters have shown that a relatively deep matrix is required for harvesting good quality marketable product. Only goose barnacles attached to other organisms, such as acorn barnacles and sea mussels are harvested, as it is relatively easy, with patience, practice and know-how to pry the peduncle foot of goose barnacles from mussels and acorn barnacles without damaging the peduncle. It is virtually impossible to harvest goose barnacles from bare rock with peduncles intact. Experienced harvesters also replace and dislodged or displaced sea mussels into the harvest cavity on the mussel matrix surface.

Evidence was seen of recent harvests in the preliminary biomass survey, likely the result of First Nations harvest for Mother's Day. At most harvest points, the mussel matrix had almost completely closed in over the harvest cavity after 6 or 7 weeks. In other areas, juvenile goose barnacles were emerging through the gaps resulting from harvesting activities. Harvesting demonstrations from experienced harvesters show that the area of harvestable clumps typically varies from 100 to 400 cm^2 .

Due to the unique characteristics of the goose barnacle fishery, experimental fisheries are required in conjunction with traditional assessment techniques to develop a feasible assessment and management plan that ensures sustainability. It is apparent that the harvestable goose barnacle biomass is a relatively small proportion of tbe total biomass, and that the total biomass would likely not be jeopardised by a fishery.

However, there are a number of other issues that need to be addressed, such as what proportion of the harvestable biomass can be harvested annually to ensure sustainability of the harvestable biomass. Anecdotal information from experienced harvesters indicates that this may be very site-specific. Additional concerns that were identified during PSARC meetings include reporting compliance, and potential co-lateral damage to the rocky intertidal community.

An initial assessment for goose barnacles should consist of identification and selection of sites with experienced harvesters, a biomass survey, followed by an experimental fishery, and a subsequent biomass survey to assess the impact of the experimental fishery.

The results of the preliminary survey show that in beds where 3 transects were surveyed, the width of the 95% confidence bounds varied from 0.23 - 0.48 of the resarnpled median. If only 10% of the total biomass in a particular bed or site is suitable for harvesting, then it may be difficult to discern the effects of harvesting by comparing pre- and post-harvesting biomass estimates. Therefore, an observer should monitor experimental fisheries.

Ideally the surveys and experimental fisheries should be undertaken in a relatively short time frame to exclude potential extraneous factors in the assessment of experimental fishery impacts. A variety of sites (in terms of productivity and exposure) were examined in the preliminary study in the Tofino area. However, conditions vary not only within a region, but also between regions. While the total area designated for experimental fisheries should remain small initially, experimental fisheries should be expanded to include other areas of the West Coast of Vancouver Island in order to maximize the number of site-specific conditions as well as to involve as many of the interested experienced harvesters as possible. This will likely require simultaneous surveys in different areas and require more than one assessment crew in order to cover a variety of areas with the remaining summer and fall tides in good weather conditions.

APPENDIX B

Appendix B Table 1. All LEK harvestable biomass estimates (estimated in lbs and converted to kgs) from 2003 to 2014 by rock. 11 experienced Goose Barnacle harvesters were surveyed to provide the LEK estimates.

Rock ID	Knowledge Holder ID	Year	Harvestable Goose Barnacles (kgs)
C-002	3	2003	2727
C-003	7	2003	318
	7	2003	909
C-005	1	2003	68
	8	2014	455
C-006	4	2003	159
	5	2003	68
	1	2003	91
C-008	5	2004	27
	8	2004	91
C-009	4	2003	36
C-010	1	2003	68
	5	2003	68
C-011	1	2003	182
	5	2003	136
	4	2003	182
	8	2014	136
C-012	6	2004	91
	9	2004	91
C-013	5	2003	91
C-014	5	2003	227
	1	2003	318
C-017ind	2	2004	91
	10	2004	91
C-018	5	2003	227
C-019	5	2003	250
	2	2004	164
	8	2004	318
	8	2014	227
C-020ind	8	2004	682
	8	2004	455
	8	2004	455
C-022	5	2003	227
	1	2003	909
C-023	2	2003	682
	1	2003	455
	2	2004	2727
	5	2004	682

Rock ID	Knowledge Holder ID	Year	Harvestable Goose Barnacles (kgs)
C-024	5	2003	364
	1	2003	455
C-047	9	2004	114
	6	2004	136
C-048	6	2004	455
	9	2004	455
C-049	5	2004	455
	8	2004	682
C-051	8	2004	1136
	5	2004	1818
C-053	5	2004	182
	8	2004	182
C-055	10	2014	182
C-057	10	2004	909
	8	2004	909
	2	2004	909
	10	2014	909
C-058	11	2014	455
C-059	8	2004	409
	5	2004	455
	10	2014	455
C-060	10	2014	136
C-061	10	2014	0
C-065	10	2014	0
C-066	10	2014	0
C-068	10	2014	0
C-072	8	2004	182
	5	2004	205
C-073	9	2004	14
	6	2004	23
C-075	4	2003	455
	6	2003	455
C-076pk	4	2003	68
C-078pk	4	2003	455
	6	2003	364
C-080pk	4	2003	682
	6	2003	1364
C-082pk	4	2003	45
C-083pk	4	2003	68
C-087pk	4	2003	136

APPENDIX C

R Code Used To Estimate Goose Barnacle Biomass

```
# Sept. 2015 (Goose Barnacle Biomass Estimation)
ID = "011"       # Rock ID number; to be changed accordingly

NS = 100000                # Number of simulations
GenDensity = function(X) {  # 'X' would, sequently, be an element of a list object
      n = length(X)       # Number of the element
      y = sample(X, size=n*NS, replace=T) # Bootstrap 'NS' times
      z = matrix(y, nrow=NS)
      W <<- apply(z, 1, mean)  # '<<-' enable checking, after function run
      W }

Title = paste("Rock-", ID, sep='')
setwd('c:/Barnacle/')
Measure = read.table("Measurement.txt", header=T) # Measurements from other areas
Rock = read.table(paste("Rock", ID, ".txt", sep=''), header=T)

Total = split(Measure$TotalWt, list(Measure$SiteName)) # Total Weight in grams
LRock = split(Rock$AREA, list(Rock$BED_ID))
N = length(Total)                        # Number of sites with measurement

TotalWt = sapply(Total, GenDensity)
# Could also correctly sample from a single number
Area = sapply(LRock, function(x) x[sample.int(length(x), size=NS, replace=T)])
AreaTotal = apply(Area, 1, sum)               # Total bed size on the rock
Si = sample(1:N, size=NS, replace=T)      # Selected sites
ind = cbind(1:NS, Si)
TotalSWt = TotalWt[ind]*AreaTotal*(25/1000)       # kg/m2

hist(TotalSWt, main=Title, xlab="Total Biomass (kg)")
quantile(TotalSWt, seq(0.1, 0.9, 0.1))
```