

# **Geoduck (*Panope generosa*) Density and Biomass Estimates in Pacific Fishery Management Area 23**

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FISHERY MANAGEMENT AREA 23

by

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**ABSTRACT**

Bureau, D. 2017. Geoduck (*Panope generosa*) density and biomass estimates in Pacific Fishery Management Area 23. Can. Manuscr. Rep. Fish. Aquat. Sci. 3111: vi + 17p.

In Barkley Sound, Pacific Fishery Management Area 23, eight Geoduck density dive surveys were conducted between 2000 and 2014 to estimate Geoduck density on a portion of the beds open to commercial harvest. Three large long-term closures to commercial Geoduck harvest are located within Area 23: the Broken Group Islands and West Coast Trail portions of the Pacific Rim National Park Reserve, and the Bamfield Marine Sciences Centre research closure. Between 2012 and 2014, substrate mapping surveys were conducted to identify potential Geoduck habitat within the three long-term closures. Subsequently, four density dive surveys were conducted on potential identified habitat within the closures between 2012 and 2014.

Average current Geoduck density on surveyed beds open to commercial harvest was 0.83 Geoducks/m<sup>2</sup>. Average Geoduck density on surveyed beds within the closures was more than double, i.e., 1.87 and 1.89 Geoducks/m<sup>2</sup> for the Bamfield Marine Sciences Centre and the Broken Group Islands closures respectively. The total (closures + open areas) Geoduck bed area in Area 23 was estimated at 1,281.3 Ha, with 805.4 Ha (62.9%) within the long-term closures and the remaining 475.9 Ha (37.1%) in the areas open to commercial harvest. The total (closures + open areas) mean current Geoduck biomass in Area 23 was estimated at 20,621.4 metric tons (t), with 16,782.5 t (81.4%) within the long term closures and the remaining 3,839.0 t (18.6%) in the open areas.

## RÉSUMÉ

Bureau, D. 2017. Estimations de la densité et de la biomasse des panopes (*Panope generosa*) dans le secteur de gestion des pêches du Pacifique 23. Rapp. manus. can. sci. halieut. aquat. 3111 : vi + 17 p.

Dans la baie Barkley, secteur de gestion des pêches du Pacifique 23, huit relevés en plongée ont été effectués, entre 2000 et 2014, dans le but d'estimer la densité des panopes dans une portion des bancs ouverts à la pêche commerciale. Trois importantes fermetures de la pêche commerciale au panope se trouvent dans le secteur 23 : l'archipel Broken Group et des portions de la piste de la côte Ouest de la réserve du parc national du Canada Pacific Rim, ainsi que la fermeture du Bamfield Marine Sciences Centre. Entre 2012 et 2014, des relevés cartographiques des substrats ont été effectués dans le but de trouver des habitats potentiels de panopes dans les trois fermetures à long terme. Par la suite, entre 2012 et 2014, quatre relevés en plongée visant à estimer la densité ont été effectués sur des habitats potentiels, au sein de ces fermetures.

La densité moyenne actuelle de panopes dans les bancs ouverts à la pêche commerciale faisant l'objet de relevés était de 0,83 panope/m<sup>2</sup>. La densité moyenne de panopes dans les bancs faisant l'objet de relevés au sein des fermetures était plus de deux fois plus élevée, c'est-à-dire 1,87 et 1,89 panope/m<sup>2</sup> pour le Bamfield Marine Sciences Centre et l'archipel Broken Group respectivement. L'aire totale (fermetures et secteurs ouverts) des bancs de panopes dans le secteur 23 a été estimée à 1 281,3 hectares, dont 805,4 hectares (62,9 %) au sein des fermetures à long terme, et 475,9 hectares (37,1 %) dans les secteurs ouverts à la pêche commerciale. Le total (fermetures et secteurs ouverts) moyen actuel de biomasse de panopes dans le secteur 23 a été estimé à 20 621,4 tonnes métriques (t), dont 16 782,5 t (81,4 %) au sein des fermetures à long terme, et 3 839 t (18,6 %) dans les secteurs ouverts.



## INTRODUCTION

In British Columbia (BC), the Pacific Geoduck (*Panopea generosa*) has been commercially harvested in Barkley Sound, within Pacific Fishery Management Area (PFMA) 23, later referred to as Area 23 since 1979. Area 23 is unique along the BC coast because large portions of it are closed to commercial Geoduck harvest. There are three large, long-term closures to commercial Geoduck harvesting in Area 23 (Figure 1). Two closures, the Broken Group Islands and West Coast Trail, are portions of the Pacific Rim National Park Reserve (established in 1970), while the Bamfield Marine Sciences Centre research closure encompasses a large portion of the Deer Group Islands (established before 1987, exact date unknown). These large reserves may play a role in Geoduck population dynamics and productivity in Area 23, which prompted interest to survey Geoduck populations within the closures.

Geoducks are subject to predation by Sea Otters (*Enhydra lutris*). Along the west coast of Vancouver Island, the Sea Otter population range extends down to Clayoquot Sound (north of Barkley Sound) (Nichol et al. 2015). Individual Sea Otters have been sighted within Barkley Sound and the population range is expected to expand into the area (Nichol pers. comm.). With the expected Sea Otter range expansion into Area 23, documenting Geoduck densities inside and outside of Geoduck harvest closures, before Sea Otter impact, may help determine how Geoduck populations respond to predation by Sea Otters in the future.

Eight SCUBA dive surveys to assess the density of commercially harvested Geoducks have been conducted in Area 23 since 2000. Between 2012 and 2014 remote-sensing hydro-acoustic substrate mapping surveys were conducted in the Broken Group Islands, West Coast Trail and Bamfield Marine Sciences Centre closures to identify locations of potential Geoduck habitat and estimate their area. Density dive surveys were then conducted on portions of the identified areas to determine Geoduck density within closures in Area 23. This report presents estimates of Geoduck bed area, density, and biomass, for Area 23, inside and outside areas closed to commercial Geoduck harvest.

## METHODS

### GEODUCK BED AREA ESTIMATES

The area of commercially harvested Geoduck beds is estimated using several sources of information as detailed in Bureau et al. (2012). The location of Geoduck harvest events, as reported on harvesters' logbooks, is the first source of data used in estimating Geoduck bed area. Estimates of area can then be refined using one or more of the following: substrate mapping

surveys, density dive surveys, comments from on-grounds fishery monitors and comments from harvesters. Geoduck density dive surveys have historically focused on already identified commercially harvested Geoduck beds.

The locations of potential Geoduck beds within the closures in Area 23 were unknown. Areas of potential interest were first identified by looking at marine charts of the region. In 2012 and 2013, areas of interest within the Broken Group Islands, Bamfield Marine Sciences Centre and West Coast Trail closures were substrate-mapped using remote-sensing technology (QTC View) which uses hydro-acoustics backscatter analysis and classification to determine the sediment composition of the top layer of the seabed (Murfitt and Hand 2004). In 2014, further substrate mapping surveys were conducted in the Broken Group Islands using Nobeltec TimeZero Catch software with PBG module and compatible Furuno depth sounder (<http://www.nobeltec.com/>). A portion of the areas identified by the substrate mapping surveys as potential Geoduck habitat were then selected for density dive surveys.

## **DENSITY DIVE SURVEYS**

Eight Geoduck density dive surveys were conducted on portions of the commercially harvested beds in Area 23 in 2000, 2002, 2005, 2010, 2011, 2012, 2013 and 2014. After identifying areas of potential Geoduck habitat in the closures, through substrate mapping, density dive surveys were conducted in the Broken Group Islands in 2012, 2013 and 2014, and in the Bamfield Marine Sciences Centre closure in 2013.

Geoduck density dive surveys followed the methods described in Bureau et al. (2012), Babuin et al. (2006), Hand and Dovey (1999, 2000) and Campbell et al. (1998). In summary, transect locations are randomly chosen along a Geoduck bed with a ratio of one transect for every 150 m of bed length. Transects are laid perpendicular to shore from 3 m chart datum to 18 m chart datum depth. Transect lines are marked every 5 m and divers count Geoducks in 1 X 5 m quadrats along the line. Divers also record the number of horse clams encountered, depth, the three dominant substrate types and the dominant algae species found in each quadrat.

## **DATA ANALYSES**

### **Density Estimates**

Geoduck dive survey data for both commercially harvested beds and beds in closures were analyzed using the Geoduck Analysis Program which was created in-house at the Pacific Biological Station and interfaces directly with the Geoduck Biological database (Bureau et al. 2012).

Details of density calculation procedures were described in Bureau et al. (2012). In summary, transects within a survey are grouped into “survey sites” and the program estimates Geoduck density for each survey site. Confidence bounds are estimated through bootstrapping.

Overall average Geoduck survey densities were calculated for each closure as the average of survey site densities; and for beds open to commercial harvest as the average of all surveyed bed densities. For commercially harvested beds that were surveyed more than once, only the most recent survey estimate was used.

Since the surveys of beds in open areas were conducted over a 15 year period, estimates of current density on the surveyed beds were calculated by subtracting estimated density removed by harvest after a survey from survey density estimates, as detailed in Bureau et al. (2012). Density removed from a Geoduck bed since a survey was estimated by dividing commercial landings on the bed after the survey by the estimated mean Geoduck weight and bed area.

### **Mean Weight Estimates**

For beds in the open portions of Area 23, mean Geoduck weight was estimated from commercial fishery data as described in Bureau et al. (2012). Logbook data from 1997 to 2014 was used for estimating mean weight on commercially exploited beds (1997 was the first year when “piece counts” were included on logbooks allowing for estimation of mean Geoduck weight). If a bed had less than 10 fishing events during that period, the mean weight for the Geoduck Management Area (GMA) or Sub-Area (if GMA had less than 10 fishing events during that period) was used.

For surveys conducted in the Broken Group Islands, the average Geoduck weight from logbook data for PFMA 23-8 was used ( $1208.5 \pm 37.9$  g, based on 1997-2014 landings). For newly discovered beds in the Bamfield Marine Sciences Centre closure, the average Geoduck weight from logbook data for the Bamfield Marine Sciences Centre closure GMA was used ( $1079.7 \pm 16.7$  g, based on commercial harvest that mistakenly occurred on three beds in the closure in 2001 and 2002). For the three beds that had logbook data, the bed-specific average weight from logbook data was used. For beds in the West Coast Trail closure the mean weight for Area 23 was used ( $997.9 \pm 54.4$  g, based on 1997-2014 landings) as insufficient data was available to calculate a Sub-Area mean weight.

### **Biomass Estimation**

Geoduck biomass was calculated on a bed-by-bed basis as the product of Geoduck bed area, Geoduck density and Geoduck mean weight (Bureau et al. 2012). Estimation methods varied slightly depending if a bed has been surveyed or not and if it is in a closure or not, as detailed below.

### Current Biomass on Surveyed Commercial Beds

Geoduck density dive surveys took place in Barkley Sound over a 15 year period (2000 – 2014) during which harvest occurred on open beds. In order to make results comparable between surveys and to provide the most up-to-date estimates, biomass was reported in terms of “current” biomass where landings since the latest survey on a bed were subtracted from the survey biomass estimate. Recruitment and natural mortality were assumed to be equal.

Biomass on surveyed beds was estimated following the methods described in Bureau et al. (2012). Survey biomass was estimated by multiplying Geoduck mean weight, survey density and bed area; landings post-survey were then subtracted from the survey biomass estimate to yield current biomass. Only transects located within Geoduck habitat were included in analyses for surveyed beds.

### Current Biomass on Un-Surveyed Commercial Beds

For un-surveyed commercially harvested beds, biomass was estimated using discretization methods described in Bureau et al. (2012). All Area 23 current density estimates from surveyed harvested beds were used in the discretization process to extrapolate current biomass to un-surveyed beds. For extrapolation of biomass to un-surveyed beds, density was calculated using all transects surveyed, which may include transects that were located outside of Geoduck beds (Bureau et al. 2012). Using all transects surveyed may provide more precautionary estimates of Geoduck density if some transects fell off beds and is justifiable when extrapolating to un-surveyed beds where uncertainty is greater.

### Biomass on Surveyed Beds Located in Closures

Biomass on surveyed beds within the closures was estimated following the methods described in Bureau et al. (2012). In summary, survey biomass was estimated by multiplying Geoduck mean weight, survey density and bed area. Since there was no harvest in the closures, there was no need to correct survey biomass to current biomass. It was assumed that biomass in the closed areas did not change since 2012 (year of the first survey in a closed area). Only transects located on Geoduck habitat were included in analyses for surveyed beds.

### Biomass on Un-Surveyed Beds Located in Closures

Substrate mapping in the closures identified more bed area than was feasible to dive survey. For un-surveyed beds within closures, biomass was estimated using discretization methods described

in Bureau et al. (2012). All density estimates from surveyed beds within Area 23 closures were used in the discretization process to extrapolate biomass to un-surveyed beds within closures.

### Overall Biomass Estimates

Current biomass estimates from surveyed and un-surveyed commercially harvested Geoduck beds were summed to provide the estimate of biomass available to the commercial fishery. For the closures, survey biomass estimates from surveyed beds and extrapolated biomass on un-surveyed beds were summed to provide estimates of biomass for each closure. Overall biomass for Area 23 was estimated as the sum of biomass in commercially harvested beds and closures.

## **RESULTS**

### **GEODUCK BED AREA**

Geoduck bed area in the portions of Area 23 open to commercial harvest is estimated at 475.9 Ha on 76 beds (Table 1). Of this, 5.3 Ha (1.1%) is closed to harvest due to lack of testing for paralytic shellfish poisoning (PSP) in Sub-Area 23-11 leaving 470.6 Ha open to commercial harvest.

Results of substrate mapping surveys conducted between 2012 and 2014 identified 580.7 Ha of Geoduck bed area on 155 beds in the Broken Group Islands portion of the Pacific Rim National Park Reserve (296.3 Ha dive surveyed), 200.0 Ha of Geoduck bed area on 34 beds in the Bamfield Marine Sciences Centre closure (151.0 Ha dive surveyed) and 24.7 Ha of Geoduck bed area on 2 beds in the West Coast Trail closure (none dive surveyed); for a total of 805.4 Ha on 191 Geoduck beds in long-term closures within Area 23 (Table 1).

Total Geoduck bed area in Area 23 (inside and outside Geoduck harvest closures) is estimated at 1281.3 Ha. Therefore, 37.1% of the Geoduck bed area in Area 23 is located in areas open to commercial harvest while the remaining 62.9 % is located in permanent closures (Table 1).

### **DENSITY**

Density dive surveys were conducted on thirty-eight out of 76 (50.0%) commercially harvested Geoduck beds in Area 23 between 2000 and 2014 (Table 1). In terms of bed area, 376.2 Ha out of 470.6 Ha (79.9%) of Geoduck bed area open to the commercial fishery were dive-surveyed

(excluding closed beds in Sub-Area 23-11). Estimates of mean current density on surveyed beds ranged from 0.28 to 1.86 Geoducks/m<sup>2</sup> (Table 2) with an average of 0.83 Geoducks/m<sup>2</sup>.

A total of 447.3 Ha were dive surveyed in the Area 23 closures (Table 1), representing 55.5% of the bed area identified in the closures (805.4 Ha). Estimates of survey density on Geoduck beds located within the Broken Group Islands and Bamfield Marine Sciences Centre closures ranged from 0.35 to 4.06 Geoducks/m<sup>2</sup> with an average of 1.89 Geoducks/m<sup>2</sup> in the Broken Group Islands closure and 1.87 Geoducks/m<sup>2</sup> in the Bamfield Marine Sciences Centre closure (Table 3).

## **HARVEST HISTORY ON BEDS OPEN TO HARVEST**

Estimated density removed from all commercially harvested beds, between 1979 (beginning of the fishery in Area 23) and 2014, range from 0.00 to 2.13 Geoducks/m<sup>2</sup> with an average of 0.48 Geoducks/m<sup>2</sup> (Table 4). The average number of years during which harvest took place on commercially harvested beds within Area 23 was seven (range 0 to 24 years, Table 4).

Estimates of density removed from surveyed commercial beds in Area 23 range from 0.03 to 2.13 Geoducks/m<sup>2</sup> with an average of 0.69 Geoducks/m<sup>2</sup>. Surveyed commercial beds were harvested on average eleven years between 1979 and 2014 (range 1 to 24 years). Surveys have thus concentrated on more heavily and/or more frequently harvested Geoduck beds.

Total Geoduck harvest in Area 23 since the start of the fishery is estimated at 2,962.2 metric tons.

## **BIOMASS**

Biomass is discussed in terms of overall biomass inside and outside of closures within Area 23. Mean estimates of Geoduck current biomass were 3,210.4 metric tons (t) for surveyed commercially open beds (Table 2) and 628.6 t for un-surveyed open beds (Table 5) for a total of 3,839.0 t for all beds open to commercial harvest in Area 23 (Table 1). Therefore, 83.6% of the Geoduck biomass in open portions of Area 23 has been surveyed. Biomass on the three closed beds in Sub-Area 23-11 was estimated at 35.0 t (0.9% of the biomass in open areas).

Total estimated mean Geoduck biomass on surveyed beds within Area 23 closures was 9,555.6 t (Table 1 and Table 6), 6,294.9 t in the Broken Group Islands and 3,260.6 t in the Bamfield Marine Sciences Centre closure (Table 1). For un-surveyed beds within Area 23 closures, total estimated mean Geoduck biomass was 7,226.9 t (Table 1 and Table 7), 5,891.6 t in the Broken Group Islands, 910.3 t in the Bamfield Marine Sciences Centre closure and 425.0 t in the West Coast Trail closure.

The total of surveyed and un-surveyed biomass estimates for Area 23 closures was 16,782.5 t (Table 1), 12,186.5 t in the Broken Group Islands, 4,170.9 t in the Bamfield Marine Sciences Centre closure and 425.0 t in the West Coast Trail closure. Within the closures, 56.9% of estimated biomass was surveyed.

Total mean Geoduck biomass in Area 23 (in and out of closures) was estimated at 20,621.4 t (Table 1). Therefore 18.6% of the current estimated biomass is located in portions of Area 23 open to commercial harvest while the remaining 81.4% is located in closures. If biomass on only the surveyed beds within the closures is considered and biomass on un-surveyed beds in the closures is ignored, then 71.3% of the biomass in Area 23 is located within closures.

## **UNCERTAINTIES**

Some assumptions had to be made in analysis of the data. Bureau et al. (2012) provided details of uncertainties associated with biomass calculations for surveyed and un-surveyed Geoduck beds open to commercial fishing.

For Geoduck beds located within closures in Area 23, some additional assumptions were made. Surveys in the Broken Group Islands took place in 2012, 2013 and 2014, it was assumed that density and biomass on the surveyed beds in the Broken Group Islands did not change during that period, i.e. recruitment and natural mortality were assumed to be in balance.

No recent data on mean Geoduck weight within the closures was available. There was no data available to calculate a mean weight specific to the Broken Group Islands and West Coast Trail closures. Mean weight for the Broken Group Islands was thus assumed to be equal to the mean weight of harvested Geoduck beds within Sub-Area 23-8 (same Sub-Area that the Broken Group Islands are in). Mean weight for the West Coast Trail closure was assumed to be equal to mean weight of Geoducks harvested in Area 23 (insufficient data for Sub-Area specific mean weight). Mean weight for beds in the Bamfield Marine Sciences Centre closure were based on harvest that took place on three beds within the closure in 2001 and 2002.

Importantly, the presence of Geoducks on the un-surveyed beds within the closures has not been confirmed but is expected. Most of the Geoduck habitat in the closures (identified through substrate mapping) that was dive surveyed had Geoducks present. At the very least, some of the un-surveyed beds within the closures can thus be expected to have Geoducks.

## **DISCUSSION**

Area 23 is a unique area on the BC coast, with regards to the Geoduck fishery, because of large permanent commercial Geoduck harvest closures. It was estimated that 62.9% of Geoduck bed

area and 81.4% of Geoduck biomass in Area 23 are located within permanent commercial Geoduck harvest closures. The Broken Group Islands closure alone was estimated to contain 45.3% of the Geoduck bed area and 59.1% of the Geoduck biomass in Area 23. Additional undocumented Geoduck populations may be found in other harvest refugia such as beds where Geoducks cannot be extracted from the substrate, portions of Geoduck populations found shallower than 3m depth or deeper than survey and harvest depth limits (typically 20 m depth) (Bureau et al. 2012).

If un-surveyed bed area that was identified through substrate mapping within the closures was ignored and assumed to have no Geoducks, 48.5% of the Geoduck bed area and 71.3% of the Geoduck biomass in Area 23 would fall within permanent closures.

The total Geoduck harvest in Area 23 since the start of the fishery is estimated at 2,962.2 t, or 14.4% of the Area 23 total mean current biomass estimate of 20,621.4 t.

Geoduck density on surveyed beds within the closures was estimated at 1.87 Geoducks/m<sup>2</sup> in the Bamfield Marine Sciences Centre closure and 1.89 Geoducks/m<sup>2</sup> in the Broken Group Islands closure, more than double the estimated mean current density on surveyed beds in open areas (0.83 Geoducks/m<sup>2</sup>). Average density removed from surveyed beds open to commercial harvest was 0.69 Geoducks/m<sup>2</sup>. If natural mortality and recruitment are assumed to be equal on commercially harvested beds, the estimated virgin density on surveyed commercial beds would be 1.52 Geoducks/m<sup>2</sup>, lower than the density estimated for beds in the closures.

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## REFERENCES

- Babuin, J., Dovey, G., Hand, C.M., Bureau, D., Hajas, W., and Murfitt, I. 2006. A survey of Geoduck abundance at the Moore Islands, Central Coast, British Columbia, 1998. Can. Manusc. Rep. Fish. Aquat. Sci. 2739: 29p.
- Bureau, D., Hand, C.M., and Hajas, W. 2012. Stock Assessment Framework for the British Columbia Geoduck Fishery, 2008. DFO Can. Sci. Advis. Sec. Res. Doc.2011/121. viii + 79p.
- Campbell, A., Hand, C.M., Paltiel, C., Rajwani, K.N., and Schwartz, C.J. 1998. Evaluation of some survey methods for Geoducks. pp. 5-42. *In*: Gillespie, G.E. and L.C. Walthers [eds.]. Invertebrate Working papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221: 340p.
- Hand, C.M., and Dovey, G. 1999. A survey of Geoduck populations in the Elbow Bank and Yellow Bank area of Clayoquot Sound, West Vancouver Island, in 1994 and 1995. Can. Manusc. Rep. Fish. Aquat. Sci. 2479: 33p.
- Hand, C.M., and Dovey, G. 2000. A survey of Geoduck populations in the Griffith Harbour area, North Banks Island, in August 1995. Can. Manusc. Rep. Fish. Aquat. Sci. 2541: 20p.
- Murfitt, I., and Hand, C.M. 2004. Acoustical substrate classification for the improved estimation of Geoduck clam abundance and distribution. pp. 289-300. *In*: Nishida, T., P.J. Kailola and C.E. Hollingworth [Eds.]. GIS/Spatial analyses in fishery and aquatic sciences (Vol. 2). Fishery-Aquatic GIS Research Group, Saitama, Japan. 735p.
- Nichol, L.M., Watson, J.C., Abernethy, R., Rechsteiner, E., and Towers, J. 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 + 31p.

Table 1: Summary of Area 23 Geoduck bed area and biomass (in metric tons) in permanent closures and areas open to commercial harvest, for surveyed beds, un-surveyed beds and all beds. BMSC = Bamfield Marine Sciences Centre.

	Surveyed				Un-Surveyed				Total				
	Number	Bed	Biomass		Number	Bed	Biomass		Number	Bed Area		Biomass	
	of Beds	Area (Ha)	Mean (MT)	% Area 23	of Beds	Area (Ha)	Mean (MT)	% Area 23	of Beds	Hectares	% Area 23	Mean (MT)	% Area 23
BMSC Closure	13	151.0	3,260.6	15.8	21	49.0	910.3	4.4	34	200.0	15.6	4,170.9	20.2
Broken Group Islands	36	296.3	6,294.9	30.5	119	284.4	5,891.6	28.6	155	580.7	45.3	12,186.5	59.1
West Coast Trail	0	0.0	0.0	0.0	2	24.7	425.0	2.1	2	24.7	1.9	425.0	2.1
Closures Sub-Total	49	447.3	9,555.6	46.3	142	358.1	7,226.9	35.0	191	805.4	62.9	16,782.5	81.4
Open Beds	38	376.2	3,210.4	15.6	38	99.7	628.6	3.0	76	475.9	37.1	3,839.0	18.6
Total	87	823.5	12,766.0	61.9	180	457.8	7,855.4	38.1	267	1,281.3	100.0	20,621.4	100.0

Table 2: Estimated Geoduck current density and current biomass (in metric tons) on Area 23 surveyed beds open to commercial harvest.

Survey Year	Stat Area	Sub Area	Bed	Current Density (geoducks/m <sup>2</sup> )			Current Biomass (MT)		
				Low 95	Mean	High 95	Low 95	Mean	High 95
2013	23	5	1	0.21	0.37	0.48	5.8	10.2	13.3
2005	23	5	4	0.66	1.23	1.70	46.1	88.1	121.4
2002	23	5	6	0.19	0.47	0.63	37.4	94.4	127.5
2013	23	5	7	0.21	0.37	0.48	8.8	15.5	20.3
2002	23	5	8	1.12	1.81	2.69	42.9	72.1	107.3
2013	23	5	9	0.56	1.37	2.69	17.4	44.1	86.6
2013	23	5	11	0.29	0.65	0.78	16.8	38.7	46.5
2013	23	5	12	0.81	1.55	2.24	32.9	64.6	93.9
2013	23	5	18	0.56	1.37	2.69	2.5	6.2	12.2
2014	23	6	1	0.27	0.41	0.65	66.8	104.5	166.3
2014	23	6	2	0.49	0.83	1.57	67.8	117.3	221.9
2014	23	6	4	0.24	0.64	1.36	10.2	28.3	59.9
2014	23	6	5	0.43	1.25	3.35	24.8	74.2	198.1
2011	23	6	10	1.08	1.54	1.94	133.4	195.5	248.0
2013	23	6	11	0.84	1.23	1.58	79.9	120.2	154.8
2013	23	6	12	0.71	1.23	1.84	26.7	47.0	70.5
2014	23	6	13	0.19	0.76	1.09	7.4	31.0	44.6
2013	23	7	1	0.49	1.86	2.37	36.0	141.5	180.5
2014	23	8	1	0.84	1.17	1.39	71.2	101.5	122.2
2014	23	8	2	0.47	0.79	1.34	23.6	41.3	69.8
2005	23	9	1	0.59	0.84	1.00	79.4	116.6	138.9
2014	23	9	4	0.57	0.73	0.94	86.0	114.5	146.4
2014	23	9	5	0.51	0.67	0.84	78.2	106.6	135.2
2014	23	9	6	0.54	1.10	1.44	62.7	129.2	170.0
2014	23	9	7	0.53	1.09	1.43	8.4	17.4	23.0
2012	23	10	1	0.77	0.98	1.20	662.8	863.7	1060.5
2010	23	10	2	0.40	0.69	1.02	57.7	102.8	152.0
2011	23	10	3	0.25	0.61	0.89	19.3	48.5	70.6
2011	23	10	4	0.28	0.61	1.25	10.8	24.1	49.5
2000	23	10	8	0.02	0.29	0.48	0.7	10.1	16.7
2000	23	10	10	0.01	0.28	0.47	0.1	7.3	12.4
2000	23	10	13	0.53	0.91	1.27	88.0	155.0	216.9
2000	23	10	14	0.13	0.32	0.54	6.9	18.4	30.7
2000	23	10	15	0.11	0.30	0.52	3.6	10.8	18.4
2000	23	10	16	0.25	0.42	0.67	8.5	14.8	23.3
2000	23	10	17	0.02	0.29	0.48	0.4	6.0	9.9
2005	23	10	20	0.03	0.30	0.67	1.6	15.9	35.0
2005	23	10	21	0.06	0.33	0.70	2.4	12.2	25.5
Average				0.43	0.83	1.28			
Sum							1,936.0	3,210.4	4,500.2

Table 3: Geoduck survey density on survey sites located within Area 23 permanent closures.

Year	Survey	Survey Site #	Survey Density (Geoducks/m <sup>2</sup> )		
			Low 95	Mean	High 95
2013	Bamfield	1	1.48	2.34	2.69
2013	Bamfield	2	1.25	2.15	2.53
2013	Bamfield	3	1.08	2.21	3.45
2013	Bamfield	5	0.22	0.65	1.54
2013	Bamfield	6	2.18	2.83	3.67
2013	Bamfield	7	0.90	1.11	1.26
2013	Bamfield	8	1.13	1.82	2.69
2012	Broken Group	1	2.68	2.96	3.17
2012	Broken Group	2	1.58	2.20	2.85
2012	Broken Group	3	1.53	1.90	2.38
2013	Broken Group	4	1.79	2.98	3.88
2013	Broken Group	5	0.23	1.27	1.79
2013	Broken Group	6	2.12	2.88	3.97
2013	Broken Group	7	0.36	0.77	1.23
2013	Broken Group	8	0.32	1.24	1.78
2013	Broken Group	9	0.95	1.90	2.96
2013	Broken Group	10	1.25	4.06	5.11
2014	Broken Group	11	0.99	2.38	3.64
2014	Broken Group	12	0.33	0.83	1.49
2014	Broken Group	13	0.40	1.43	3.05
2014	Broken Group	14	0.36	0.56	0.80
2014	Broken Group	15	0.13	0.35	0.56
2014	Broken Group	16	1.57	1.92	2.40
2014	Broken Group	17	1.71	2.57	3.16
	<b>Bamfield</b>		<b>1.18</b>	<b>1.87</b>	<b>2.55</b>
	<b>Broken Group</b>		<b>1.08</b>	<b>1.89</b>	<b>2.60</b>

Table 4: Harvest history for Geoduck beds open to commercial harvest in Area 23, by Sub-Area.

Area	Sub-Area	Number of Beds	Number of Years Beds Harvested	Total Historical Landings (MT)	Density Removed (Geoducks/m <sup>2</sup> )
23	4	5	1 to 7	24.1	0.05 to 0.32
23	5	13	1 to 19	549.9	0.04 to 2.13
23	6	18	0 to 21	564.6	0.00 to 1.70
23	7	2	0 to 4	9.9	0.00 to 0.13
23	8	7	1 to 11	140.6	0.06 to 0.87
23	9	9	1 to 19	480.5	0.02 to 0.98
23	10	19	1 to 24	1,181.4	0.02 to 1.99
23	11	3	0 to 2	11.3	0.00 to 0.28
		Total Average	7	2,962.2	0.48

Table 5: Estimated current biomass for un-surveyed Geoduck beds open to commercial harvest in Area 23.

Area	Sub Area	Bed Code	Current Biomass (MT)			Status
			Low 95	Mean	High 95	
23	4	1	7.1	22.3	55.5	
23	4	5	3.7	11.6	28.9	
23	4	6	8.2	25.8	64.1	
23	4	10	1.4	4.3	10.6	
23	4	11	1.0	3.0	7.2	
23	5	3	2.2	6.9	16.9	
23	5	5	6.3	19.8	49.6	
23	5	10	13.9	42.7	104.6	
23	5	21	1.3	4.0	9.7	
23	6	7	6.4	19.8	48.4	
23	6	8	3.2	10.0	24.4	
23	6	9	2.5	7.8	19.2	
23	6	14	6.4	19.7	48.3	
23	6	15	6.6	20.3	49.8	
23	6	16	3.7	11.3	27.7	
23	6	17	7.3	22.6	55.4	
23	6	18	1.6	5.0	12.3	
23	6	19	0.1	0.2	0.6	
23	6	20	1.0	3.2	7.9	
23	7	4	1.8	5.4	13.3	
23	8	3	3.0	9.2	22.7	
23	8	4	3.6	11.3	27.7	
23	8	5	3.9	12.2	30.0	
23	8	9	4.1	12.6	30.9	
23	8	10	5.7	17.4	42.6	
23	9	2	16.1	49.5	121.2	
23	9	3	3.5	10.8	26.4	
23	9	8	5.3	16.2	39.6	
23	9	10	1.2	3.7	9.1	
23	10	5	3.4	10.5	25.6	
23	10	7	9.6	29.6	72.5	
23	10	9	38.4	118.2	289.1	
23	10	11	2.9	8.8	21.6	
23	10	18	2.2	6.6	16.3	
23	10	19	3.6	11.2	27.3	
23	11	2	7.0	21.7	53.0	Closed, no PSP testing
23	11	3	3.1	9.5	23.1	Closed, no PSP testing
23	11	4	1.3	3.9	9.6	Closed, no PSP testing
Total			203.6	628.6	1,542.7	

Table 6: Estimated Geoduck biomass on surveyed beds within Area 23 permanent closures.

Year	Survey	Sub			Density (Geoducks/m <sup>2</sup> )	Biomass (MT)		
		Area	Area	Bed		Low 95	Mean	High 95
2013	Bamfield	23	4	659	1.11	96.4	122.5	140.6
2013	Bamfield	23	4	663	1.11	3.8	4.8	5.5
2013	Bamfield	23	5	655	1.82	103.5	170.5	252.8
2013	Bamfield	23	5	657	1.82	27.2	44.6	66.0
2013	Bamfield	23	5	660	1.82	16.9	27.7	41.0
2013	Bamfield	23	5	691	2.15	125.0	219.4	259.3
2013	Bamfield	23	5	692	2.34	11.3	18.4	21.2
2013	Bamfield	23	5	693	2.34	32.0	52.3	60.6
2013	Bamfield	23	7	667	2.83	126.3	169.0	218.9
2013	Bamfield	23	7	668	2.83	603.7	807.9	1,046.0
2013	Bamfield	23	7	670	0.65	52.7	162.3	384.7
2013	Bamfield	23	7	676	2.83	87.3	116.8	151.3
2013	Bamfield	23	7	680	2.21	642.1	1,344.4	2,098.2
2013	Broken Group	23	8	501	0.77	149.6	326.8	522.6
2013	Broken Group	23	8	502	0.77	31.5	68.8	110.0
2013	Broken Group	23	8	503	0.77	4.5	9.8	15.6
2013	Broken Group	23	8	504	0.77	44.9	98.1	156.9
2014	Broken Group	23	8	514	2.38	63.7	158.1	242.5
2014	Broken Group	23	8	515	0.83	109.5	283.6	506.7
2014	Broken Group	23	8	519	0.56	5.4	8.5	12.2
2014	Broken Group	23	8	520	0.56	43.8	69.4	99.3
2014	Broken Group	23	8	523	1.43	49.1	182.6	390.3
2014	Broken Group	23	8	530	0.35	0.8	2.1	3.3
2014	Broken Group	23	8	531	1.92	60.1	76.9	96.7
2014	Broken Group	23	8	532	0.35	3.0	8.1	12.9
2014	Broken Group	23	8	533	1.92	18.7	23.9	30.1
2014	Broken Group	23	8	534	1.92	13.8	17.6	22.2
2014	Broken Group	23	8	541	1.92	11.5	14.7	18.5
2014	Broken Group	23	8	551	1.92	13.3	17.1	21.5
2014	Broken Group	23	8	552	0.35	1.5	4.1	6.6
2014	Broken Group	23	8	553	0.35	3.7	9.8	15.6
2014	Broken Group	23	8	554	0.35	0.6	1.7	2.7
2014	Broken Group	23	8	573	2.57	113.9	176.6	218.7
2013	Broken Group	23	8	588	1.24	63.3	250.5	361.8
2013	Broken Group	23	8	589	1.24	27.8	109.9	158.8
2013	Broken Group	23	8	603	2.88	576.2	810.4	1,120.8
2013	Broken Group	23	8	611	1.90	76.7	157.4	246.3
2013	Broken Group	23	8	614	1.90	84.2	172.9	270.6
2013	Broken Group	23	8	615	1.90	85.7	175.9	275.4
2013	Broken Group	23	8	616	1.90	50.6	103.8	162.5
2013	Broken Group	23	8	619	2.98	227.6	389.9	510.8
2013	Broken Group	23	8	620	2.98	152.9	261.9	343.2
2013	Broken Group	23	8	635	4.06	39.4	132.2	167.5
2013	Broken Group	23	8	637	4.06	108.9	365.4	463.0
2013	Broken Group	23	8	647	1.27	17.9	105.1	148.6
2014	Broken Group	23	8	686	2.57	70.0	108.6	134.5
2012	Broken Group	23	8	687	1.90	113.3	147.2	185.0
2012	Broken Group	23	8	688	2.96	436.6	514.8	563.2
2012	Broken Group	23	8	690	2.20	645.6	930.8	1,212.8
Total						5,447.7	9,555.6	13,575.8

Table 7: Estimated current biomass on un-surveyed Geoduck beds within Area 23 closures, by Sub-Area. BMSC = Bamfield Marine Sciences Centre.

Closure	Area	Sub Area	Number of Beds	Biomass (MT)		
				Low 95	Mean	High 95
BMSC	23	4	5	7.5	42.1	90.5
BMSC	23	5	6	52.6	294.0	631.8
BMSC	23	7	10	102.8	574.2	1,233.8
Broken Group Islands	23	6	1	0.6	3.4	7.3
Broken Group Islands	23	7	1	2.7	14.9	32.1
Broken Group Islands	23	8	117	1,050.6	5,873.2	12,621.4
West Coast Trail	23	7	2	76.1	425.0	913.4
Total				1,292.9	7,226.9	15,530.4



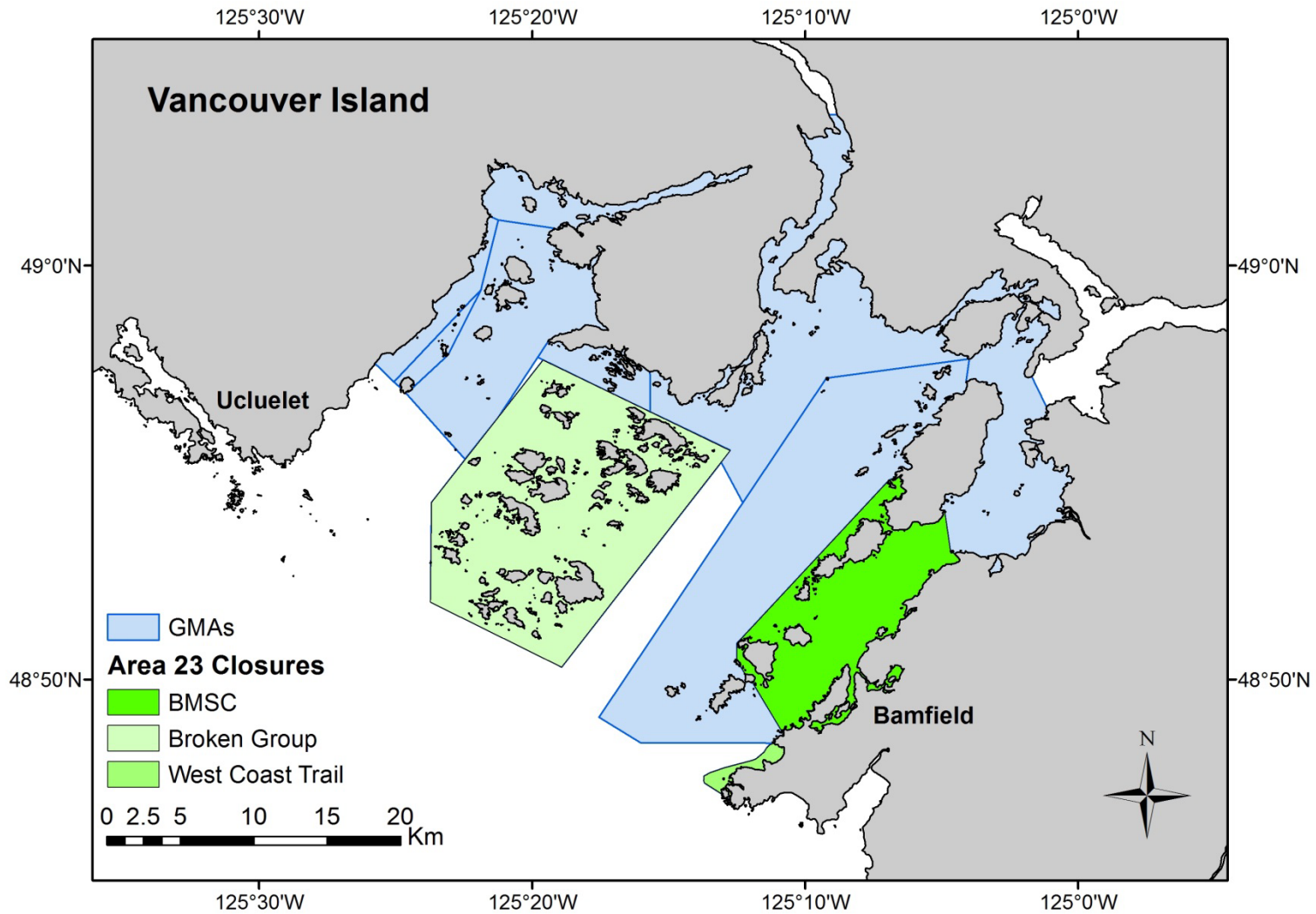


Figure 1: Map of Barkley Sound (Area 23) showing Geoduck Management Areas (GMAs) open to commercial Geoduck harvest and the long term closures to commercial Geoduck harvest (BMSC = Bamfield Marine Sciences Centre). Only the portion of the West Coast Trail closure located within Area 23 is shown, the closure extends further south.