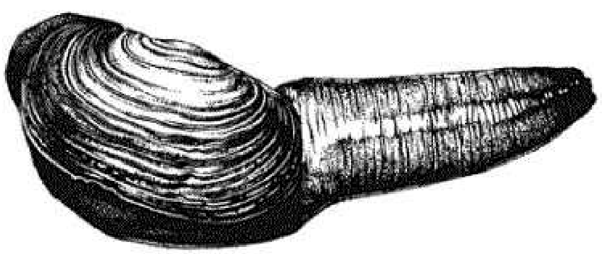
Fisheries and Oceans Canada — Pêches et Océans Canada
Ecosystems and Oceans Science — Sciences des écosystèmes et des océans

Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2017/037

UPDATE TO ESTIMATION METHODS FOR GEODUCK (*PANOPEA GENEROSA*) STOCK INDEX



Geoduck clam, Panopea generosa

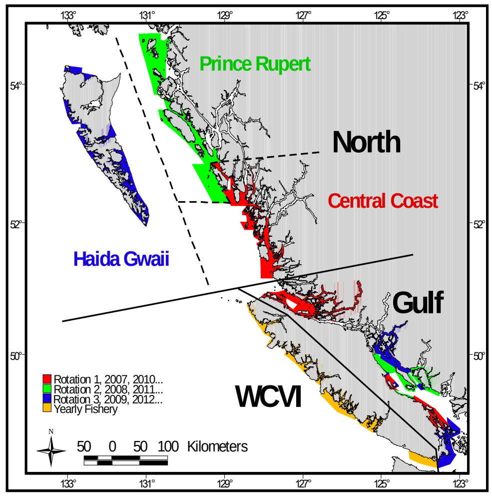


Figure 1. Map of British Columbia showing the location of the five geographical regions (Haida Gwaii, Prince Rupert, Central Coast, Gulf and WCVI) for the Geoduck fishery.

Context:

The British Columbia Geoduck fishery is managed at the by-sub-bed spatial scale. The limit reference point (LRP) is defined as current biomass being equal to 40% of estimated unfished biomass. The stock index, defined as the ratio of current biomass to unfished biomass, is calculated for each bed and beds with a stock index below 0.4 are closed to harvest (Bureau et al. 2012).

Few Geoduck beds have been surveyed prior to first harvest. Therefore, unfished biomass has been estimated as current biomass on a bed plus commercial fishery removals from the bed, with the assumption that recruitment and natural mortality are equal, or in other words, that there is no surplus production.

If surplus production occurs, the current method of estimating unfished biomass in the Geoduck stock assessment framework (Bureau et al. 2012) can lead to biased estimates of stock index and all harvested Geoduck beds possibly reaching the LRP, irrespective of actual stock status. This may be an artefact of the method currently used to estimate unfished biomass and not be reflective of true stock status.

Fisheries and Oceans Canada (DFO) Fisheries and Aquaculture Management Branch requested that Science Branch provide a review of methods currently used to estimate Geoduck unfished biomass and provide alternative Geoduck unfished biomass estimation methods. Advice in this report will be used to update Geoduck unfished biomass and stock index estimation methods to remove the identified biases.

This Science Advisory Report is from the March 15-16, 2017 regional peer review on the Update to estimation methods for Geoduck (Panopea generosa) stock index. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

SUMMARY

- For each Geoduck sub-bed, virgin biomass (B_0) is now defined as the theoretical long-term equilibrium exploitable biomass in the absence of fishing. Because B_0 cannot be estimated using the current methods when harvest has occurred before the first survey, estimated unfished exploitable biomass (*B*') will be used as a proxy for B_0.
- Current methods for estimating *B'* on surveyed and un-surveyed beds were reviewed.
- Simulations showed that the current model produces biased estimates of *B*' and stock index if the assumption of "no surplus production" in the existing model is not met.
- Based on available data, literature review and fisheries stock assessment and population growth theory, the assumption of "no surplus production" in the current model is unlikely to be met, i.e., surplus production is likely occurring on BC Geoduck beds.
- Alternative options for estimating *B'* for surveyed and un-surveyed beds were presented, along with their assumptions, advantages and disadvantages.
- For surveyed Geoduck beds, "Option 3B – Unfished biomass equals biomass from first survey plus landings before 1989" was recommended for estimating unfished biomass (*B'*).
- For un-surveyed Geoduck beds, "Option 2 – Use regional estimates of unfished density to estimate unfished biomass (*B'*)" was recommended.
- It is recommended that unfished biomass (*B*') is re-estimated when estimates of Geoduck current biomass are updated, so that the most up to date data inputs (bed area, mean Geoduck weight and density) are used.
- Methods were presented for estimating stock index on a by-Geoduck-sub-bed spatial scale, for surveyed and un-surveyed Geoduck beds. These methods take advantage of increased spatial accuracy of landings data that has been available since 2006. It was recommended to calculate stock index on a by-sub-bed spatial scale, instead of by-bed.
- It was recommended to explore the use of probabilistic methods, which could incorporate uncertainties in the estimated biomass, rather than the current deterministic methods, to determine the probability that the stock index is above 0.4.
- Because of the influence of Geoduck mean weight on the estimation of *B*', further analysis of Geoduck mean weight data and how mean weight is estimated for use in *B*' estimation was recommended.
- Further research is recommended in anticipation of future modifications to the Geoduck stock assessment framework that may be necessary due to expansion in the range of Sea Otters on the BC coast.

INTRODUCTION

The Pacific Geoduck Clam (*Panopea generosa*) commercial fishery began in British Columbia (BC) in 1976 and has since grown to be one of the highest valued fisheries in BC at CAD $44.7 million for the 2016-17 fishing season (J. Austin, pers. comm.). The BC Geoduck fishery is managed at the level of the individual Geoduck sub-bed. There are 2,859 beds, made up of 5,214 sub-beds, ranging in size from 0.03 to 573.3 Ha on the BC coast. Geoduck current biomass (B_c) is estimated for each bed as the product of bed area, Geoduck current density on the bed, and mean Geoduck weight for the bed. For surveyed beds, the latest survey is used in

B_c estimations while for un-surveyed beds, current density data from nearby surveyed beds are used to extrapolate B_c. Current biomass estimates are updated yearly to incorporate the latest data (e.g. density estimates for newly surveyed beds) in the estimates. Harvest options are based on regional annual exploitation rates of 1.2 – 1.8 % applied to the estimated current biomass for each bed (Bureau et al. 2012).

The Limit Reference Point (LRP) for the BC Geoduck fishery was defined as current biomass being equal to 40% of estimated virgin biomass (Zhang and Hand 2007). Virgin biomass (B_0) is generally defined as a theoretical equilibrium biomass in the absence of fishing and is not a measured value, but typically inferred from models (NOAA Fisheries Glossary). To date, in the BC Geoduck assessments frameworks (Hand and Bureau 2012, Bureau et al. 2012), estimated unfished exploitable biomass was referred to as virgin biomass (B_0). A distinction is made in the working paper between theoretical B_0 and estimated unfished exploitable biomass, now referred to as *B*'. From here on, *B'* will be used to refer to estimated unfished (before commercial harvest began) exploitable Geoduck biomass.

Under the current model, unfished exploitable Geoduck biomass (*B'*) is estimated as the sum of current biomass (B_c) and historical landings on a bed (L_t).

$$B' = B_c + L_t$$

The stock index, defined as the ratio of mean estimated current biomass (B_c, mean estimate) to estimated unfished biomass (*B*'), is estimated on a by-bed basis (Bureau et al. 2012). Beds with a stock index below 0.4 are closed to commercial harvest.

The current method of estimating Geoduck unfished biomass assumes:

1. That Geoduck populations were in equilibrium at the start of the fishery, which implies that virgin biomass on a bed is the stable carrying capacity on that bed.
2. That recruitment and natural mortality are in balance, i.e., that no surplus production is taking place after the start of harvest on a bed. This further implies that there is no recovery from fishing when abundance decreases below the carrying capacity because of harvest, contrary to many population growth (logistic or Schafer models) and fishery stock assessment models (e.g. Beverton-Holt or Ricker models).

If surplus production occurs, unfished biomass estimates will increase with subsequent surveys resulting in biased (low) stock indices. This bias in the estimated stock index will eventually cause all Geoduck beds to reach the LRP and result in premature fishery closures on both surveyed and un-surveyed beds, irrespective of the actual stock status.

ASSESSMENT

Simulations were conducted to illustrate how the current *B*' estimation method behaves when the assumption of “no surplus production” is met and when it is not (Figures 2 and 3). The simulations demonstrated that the current model is adequate when there is no surplus production (Figures 2A and 3A) but that bias is introduced in *B'* and stock index estimates when surplus production is occurring (Figures 2B and 3B). As more Geoduck beds get re-surveyed over time, the impacts of the bias illustrated in the simulations increase, if surplus production is occurring. Since beds selected for re-survey are often considered to be commercially important beds for the fishery, the estimation bias may disproportionately impact these “important” beds. A new method to estimate *B'* free of the bias described above is therefore desired, if surplus production is occurring.

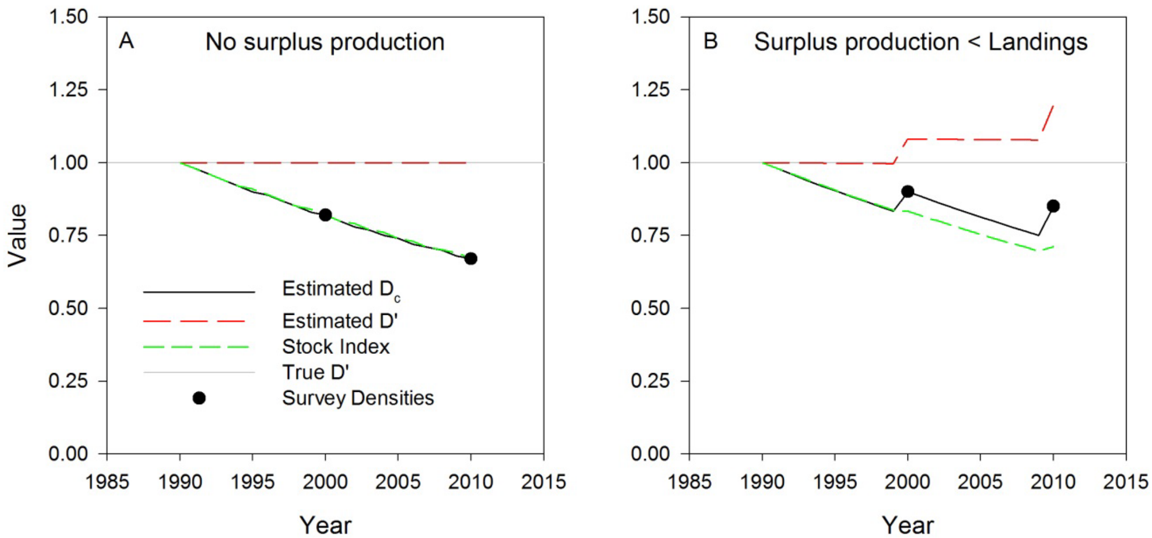


Figure 2.Simulations of estimated geoduck current density (Dc), unfished density (D') and stock index, (A) under the assumption of no surplus production and (B) with surplus production, over a 20 year period using the current method of estimating D'. True stock index values are the same as estimated Dc (black line).

Whether the current Geoduck unfished biomass estimation method is adequate depends on whether or not the assumption of no surplus production is valid. Survey density and landings data for beds that have been surveyed more than once were reviewed to determine if there is evidence for surplus production on commercially harvested Geoduck beds in BC. Average surplus production rates between surveys were estimated and found to be significantly greater than zero in all regions except for the Central Coast; despite the high degree of uncertainty associated with Geoduck density estimates (due to factors including different transect locations surveyed between subsequent surveys, timing of surveys, show factors of Geoduck, and uneven distribution of Geoduck within and across beds). Post-fishing recovery has also been demonstrated for Geoducks in Washington (Goodwin and Bradbury, 2000; Orensanz et al., 2004). Additionally, population growth and fishery assessment models typically predict that surplus production occurs after a stock begins to be harvested. The assumption of "no surplus production" in the current model is thus unlikely to be met and alternative methods for estimation of *B*' are desirable.

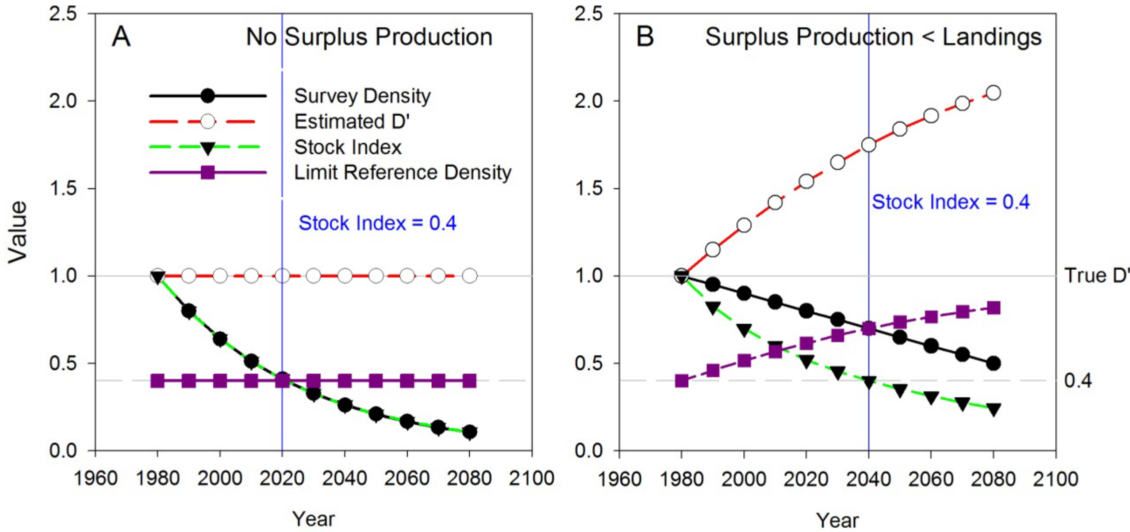


Figure 3. Long range simulations of estimated geoduck current density (Dc), unfished density (D') and stock index, (A) under the assumption of no surplus production and (B) with surplus production. True stock index values are the same as the black lines for survey density.

A variety of options were considered as alternative methods to estimate *B'* on surveyed beds. These options were evaluated based on the number and validity of the assumptions, applicability and the feasibility of implementation. The proposed options all improve on the current method by using the first survey biomass to stabilize *B'*, rather than the current practice of using the latest survey.

The options presented for surveyed beds were:

1. Option 1: B' equals the biomass from the first survey plus the landings before the first survey.
2. Options 2A - 2D introduce estimates of surplus production in the estimation of B'. Surplus production rates can be fixed (using a precautionary value from literature [2A]), estimated from survey data (individual bed values [2B], or average regional values [2C]), or determined from the age-frequency distributions (2D) as in Hand and Dovey (1999).
3. Option 3A: B' equals the biomass from the first survey and assumes that surplus production before the first survey is equal to the fishery removals before the first survey.
4. Option 3B: B' equals the biomass from the first survey plus landings before 1989. This option can be considered an intermediate between options 1 and 3A as only a portion of the landings before the first survey are added to the biomass estimate from the first survey. This assumes that there was no surplus production before 1989 and that surplus production was equal to landings before the first survey after 1989.
5. Option 4 uses a hybrid approach depending on the available data, which results in different methods being used for beds with a single survey and beds with more than one survey.

For un-surveyed beds, two options were presented:

1. Option 1 was not to change the methods used to calculate *B'*. Current biomass would be extrapolated from nearby surveyed beds and cumulative landings added.

2. Option 2 uses regional estimates of unfished density on surveyed beds to estimate *B’* on un-surveyed beds. Assumptions behind this method will depend on the method chosen to estimate *B’* for surveyed beds.

When the most recent Geoduck assessment framework was implemented in 2008 (Bureau et al. 2012), the finest spatial scale at which it was possible to estimate the stock index was by-bed. Since 2006, the Geoduck fishery has been managed at the by-sub-bed spatial scale thereby increasing the spatial accuracy of landings data. Methods were presented to estimate Geoduck stock index at the by-sub-bed spatial scale for surveyed and un-surveyed beds to take advantage of the increased spatial accuracy in landings data since 2006. The methods proposed to estimate the stock index at the by-sub-bed spatial scale for surveyed beds also imply that current biomass (B_c) should be estimated at the by-sub-bed spatial scale.

Results

Option 3B was recommended to estimate B’ for surveyed beds. Because of high landings in the early years of the fishery, option 3A assumes that surplus production was correspondingly high during those years. This assumption may not be realistic for years with high landings and therefore, excluding some of the early years of the fishery where high landings occurred may be justifiable. Option 3B makes no assumptions about surplus production after the first survey. Option 3B is applicable to all surveyed beds and can easily be implemented. Option 3B was chosen over option 3A because the assumption of “surplus production equals landings” under option 3A was considered unrealistic for the fishery years prior to 1989.

Option 2 was recommended for un-surveyed beds because it uses estimated unfished density on surveyed beds to extrapolate B’ on un-surveyed beds. This method therefore relies on both the methods for estimating B’ for surveyed beds and the assumption that estimated unfished density on nearby surveyed beds are representative of unfished density on un-surveyed beds.

A recommendation was made to change from calculating the Geoduck stock index on a by-bed to a by-sub-bed spatial scale. Increased spatial accuracy of landings data since 2006 will allow for more precision in stock index estimates in the future if calculations are done at the by-sub-bed spatial scale.

Ecosystem Considerations

Sea Otters are predators of Geoducks. As the abundance and range of Sea Otters increases in BC, their impact on commercially harvested Geoduck stocks is likely to increase. Sea Otter predation may cause a phase-shift in equilibrium Geoduck population levels. After Sea Otters become established in an area, it may be justifiable to update the estimated Geoduck *B’* to reflect an altered abundance regime. Further research is recommended to support future modifications to the Geoduck Stock Assessment Framework that may be necessary to assess Geoduck stocks in response to the expansion of Sea Otters on the BC coast.

The potential impacts of climate change and other associated changes (ocean acidification, etc.) on Geoduck stocks are poorly understood and a source of uncertainty in the Geoduck fishery. Warmer sea surface temperatures have been associated with faster growth of Geoducks (Black et al. 2009). However, shellfish hatcheries in Washington State have experienced low survival in recent years and ocean acidification is suspected to be the cause. The overall impact that climate change may have on Geoduck stocks in BC is therefore unknown.

Sources of Uncertainty

Trends in Geoduck mean weight over time have not been investigated. The entire time-series of available data is used to estimate mean weights used in *B'* calculations. If mean weight has changed over time, this could result in increased uncertainty in the biomass estimates.

Only 228 Geoduck beds have been surveyed more than once. Beds chosen for re-survey are sometimes beds that are considered to be productive or commercially important and therefore, re-surveyed beds are not a random sample of beds on the coast. Re-surveyed beds thus may not be representative of all Geoduck beds within a region. Further, dive survey density estimates generally have poor precision. Because of the uncertainty in density estimates and possible bias towards re-surveying productive beds, caution should be exercised in interpretation and use of surplus production estimates derived from density values.

Some uncertainty exists in Geoduck landings data, especially in the years before 1989 because of poor geo-referencing and under-reporting of landings prior to implementation of dock-side validation of all landings in 1989.

Future Work

Future work is recommended to explore the use of probabilistic methods to incorporate uncertainty in biomass estimation inputs (using the recommended *B'* and stock index estimation methods) to be carried through to the probability of the stock index being above 0.4. This approach would improve the Geoduck fishery's compliance with DFO's Sustainable Fisheries Framework incorporating the Precautionary Approach.

It was suggested that alternative methods to estimate *B'* could be investigated for Geoducks, i.e., Bayesian surplus production models or delay-difference models as alternatives to the current deterministic methods.

Future work is recommended to analyze trends in Geoduck mean weight over time because potential changes in mean weights could affect B' estimates.

Future work was recommended to investigate impacts of sea otters and look at other possible environmental effects. This could involve long term monitoring on select sites where some data has already been collected in the South Coast and could be expanded to the North Coast, or the use of index sites to monitor the combined effects of recruitment and natural mortality. Analysis of recent Geoduck biological sample data was recommended to investigate recent trends in Geoduck recruitment on the BC coast.

CONCLUSIONS AND ADVICE

The discussions, conclusions and recommendations arising from this regional peer review are summarized as follows:

- For each Geoduck sub-bed, B_0 is now defined as the theoretical long-term equilibrium exploitable biomass in the absence of fishing. Because B_0 cannot be estimated using the current methods where harvest has occurred before the first survey, estimated unfished exploitable biomass (*B'*) will be used as a proxy for B_0.
- Simulations showed that the current *B'* estimation model produces biased estimates of *B'* and stock index if the assumption of "no surplus production" in the existing model is not met.

- Based on available data, literature review and fisheries stock assessment and population growth theory, the assumption of “no surplus production” in the current model is unlikely to be met, i.e., surplus production is likely occurring.
- For surveyed Geoduck beds, estimate unfished biomass (*B’*) using “Option 3B – Unfished biomass equals biomass from first survey plus landings before 1989”.
- For un-surveyed Geoduck beds, estimate unfished biomass (*B’*) using “Option 2 – Use regional estimates of unfished density to estimate unfished biomass”.
- Update estimates of Geoduck unfished biomass (*B*’) when estimates of Geoduck current biomass are updated so that the most up to date data inputs (bed area, mean Geoduck weight and density) are used.
- For un-surveyed Geoduck beds, estimate stock index on a by-sub-bed spatial scale.
- For surveyed Geoduck beds, estimate stock index on a by-sub-bed spatial scale, which implies estimating current biomass (B_c) at the by-sub-bed spatial scale also.
- It was recommended to explore the use of probabilistic models, rather than the deterministic methods currently used, to carry through uncertainty in biomass calculation inputs (density, mean weight, bed area) to the probability that the stock index is above 0.4.
- Because of the influence of Geoduck mean weight on the estimation of *B*’, further analysis of Geoduck mean weight data and how mean weight is estimated for use in *B*’ estimation was recommended.
- Further research is recommended to support future modifications to the Geoduck stock assessment framework that may be necessary due to expansion in the range of Sea Otters on the BC coast.

SOURCES OF INFORMATION

This Science Advisory Report is from the March 15-16, 2017 regional peer review on the Update to estimation methods for Geoduck (*Panopea generosa*) stock index. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Black, B.A., Copenheaver, C.A., Frank, D.C., Stuckey, M.J. and Kormanyos, R.E. 2009. Multi-proxy reconstructions of northeastern Pacific sea surface temperature data from trees and Pacific Geoduck. Palaeogeography, palaeoclimatology, palaeoecology. 278: 40-27.

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: v + 79p.

Goodwin, L., and Bradbury, A. 2000. The time between successive crops (recovery time) of subtidal Geoducks (*Panopea abrupta*) in Puget Sound, Washington. Appendix 2 *In:* Palazzi,

Hand, C.M., and Bureau, D. 2012. Stock assessment framework for the British Columbia Geoduck fishery, 2002. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/120: vi + 33p.

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. Manuscr. Rep. Fish. Aquat. Sci. 2479: 33p.

Orensanz, L.M., Hand, C.M., Parma, A.M., Valero, J., and Hilborn, R. 2004. Precaution in the harvest of Methuselah's clams – the difficulty of getting timely feedback from slow-paced dynamics. Can. J. Fish. Aquat. Res. 61: 1355-1372.

Zhang, Z. and Hand, C. 2007. Determination of geoduck harvest rates using age-structured projection modeling. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/064: 49p.

THIS REPORT IS AVAILABLE FROM THE:

Centre for Science Advice
Pacific Region
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

Telephone: (250) 756-7208
E-Mail: csap@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2017. Update to estimation methods for Geoduck (*Panopea generosa*) stock index. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/037.

Aussi disponible en français :

MPO. 2017. Mise à jour des méthodes d'estimation de l'indice de la taille du stock de panope (Panopea generosa). Secr. can. de consult. sci. du MPO, Avis sci. 2017/037.