# Rocky Mountain Ridged Mussel (*Gonidea angulata*) Index Site Surveys in the Okanagan Basin, British Columbia, 2011-2016

Sean MacConnachie, Lindsay Dealy, Joy Wade, Lora Nield, Linnea Flostrand, and Paul Grant

Science Branch, Pacific Region
Fisheries and Oceans Canada
Pacific Biological Station
Nanaimo, BC
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# ROCKY MOUNTAIN RIDGED MUSSEL (*Gonidea angulata*) INDEX SITE SURVEYS IN THE OKANAGAN BASIN, BRITISH COLUMBIA, 2011–2016

by

Sean MacConnachie, Lindsay Dealy, Joy Wade, Lora Nield, Linnea Flostrand, and Paul Grant

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, British Columbia V9T 6N7

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# ABSTRACT

MacConnachie, S., Dealy, L., Wade, J., Nield, L., Flostrand, L., and Grant, P. 2021. Rocky Mountain Ridged Mussel (*Gonidea angulata*) Index Site Surveys in the Okanagan Basin, British Columbia, 2011–2016. Can. Manuscr. Rep. Fish. Aquat. Sci. 3210: vi + 22 p.

Rocky Mountain Ridged Mussel (*Gonidea angulata*) is one of only a few species of freshwater mussel in British Columbia, restricted in Canada to the Okanagan Basin. In 2005 this species was listed under the *Species at Risk Act* (SARA) as Special Concern, and in 2010 it was reassessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as Endangered. As a continuation of previous work and to inform future assessments and conservation efforts in the Okanagan Basin, index sites that were easily accessible and known to have *G. angulata* were selected to estimate abundance at these areas over time. Mean mussel densities across all index sites from 2011–2016 ranged from 0.11 to 2.82 mussels/$m^2$. Estimates of total abundance at each site ranged between 131 and 3,589 mussels. Mussel density by depth was also examined, and mussels were observed to be in depths between 0.02 and 1.76 m. They were generally found in higher densities in water depths greater than 0.50 m, and typically declined with depths exceeding 1.5 m. We recommend that these surveys be continued annually to provide ongoing estimates of abundance for future assessment work and to inform conservation efforts focused on the survival or recovery of this species.

# RÉSUMÉ

MacConnachie, S., Dealy, L., Wade, J., Nield, L., Flostrand, L., and Grant, P. 2021. Rocky Mountain Ridged Mussel (*Gonidea angulata*) Index Site Surveys in the Okanagan Basin, British Columbia, 2011–2016. Can. Manuscr. Rep. Fish. Aquat. Sci. 3210: vi + 22 p.

Au Canada, la gonidée des Rocheuses (*Gonidea angulata*) est une des rares espèces de moule d'eau douce de la Colombie-Britannique, et elle est limitée au bassin de l'Okanagan. En 2005, cette espèce a été inscrite à la liste des espèces préoccupantes au titre de la *Loi sur les espèces en péril* et, en 2010, elle a été réévaluée par le Comité sur la situation des espèces en péril au Canada (COSEPAC) et inscrite en tant qu'espèce en péril. Dans la continuité des travaux entrepris et pour orienter les futures évaluations et mesures de conservation dans le bassin de l'Okanagan, des sites repères facilement accessibles et reconnus pour leur population de *G. angulata* ont été sélectionnés pour en estimer l'abondance au fil du temps. La densité moyenne de moules parmi tous les sites repères de 2011 à 2016 variait de 0,11 à 2,82 moules/$m^2$. L'abondance totale pour chaque site était estimée à entre 131 et 3 589 moules. La densité de moules en fonction de la profondeur a aussi été étudiée et observée à une profondeur située entre 0,02 et 1,76 mètre. Les moules se trouvaient en plus grande densité à une profondeur de plus de 0,50 mètre; cette densité diminuait en général à une profondeur de plus de 1,5 mètre. Nous recommandons de poursuivre ces relevés chaque année, pour pouvoir fournir en continu des estimations de l'abondance en prévision de futures évaluations et pour orienter les efforts de conservation axés sur la survie ou le rétablissement de cette espèce.

# INTRODUCTION

Rocky Mountain Ridged Mussel, *Gonidea angulata* (Lea, 1838), is a freshwater bivalve in the family Unionidae. It is morphologically and taxonomically unique as the only extant member of the genus *Gonidea* (Graf 2002). *G. angulata* is a large, trapezoidal-shaped mussel, with a shell up to 125 mm long, 65 mm high, 40 mm wide, and shell walls up to 5 mm thick (Clarke 1981). It has a sharp and prominent posterior ridge running from the umbo to the angular basal margin of each valve, hence the common name Rocky Mountain Ridged Mussel (Figure 1). The periostracum, or outer shell, is commonly yellowish brown to blackish brown with obvious concentric growth rests, and the nacre, or inner shell, is centrally white or salmon coloured but pale blue along the outer posterior margin (Clarke 1981). Its hinge teeth are irregular and poorly developed.

*G. angulata* reaches the northern limit of its global range in southern British Columbia (BC). In Canada, live *G. angulata* have only been observed within the Okanagan Basin (COSEWIC 2010; BC Conservation Data Centre 2020). Populations within the Okanagan Basin account for approximately 5% of the current global distribution (COSEWIC 2010). Throughout its North American range, this species is found within both lacustrine and riverine habitat, and within Canada, predominantly in lakes where soft substrate is present with a low slope (0–20%) (COSEWIC 2010; Snook 2018). Riverine habitats require stable banks with low hydraulic variability (i.e., channelized sections), such as the Okanagan River, where this species is found near Oliver (COSEWIC 2010; Snook 2018). Both habitats require sufficient food, suitable water quality, and appropriate substrate sizes, depending on the energy of the site (Snook 2018). While *G. angulata* are typically observed in shallow waters, specimens have been recorded at depths of 10–20 m in Washington and Oregon (COSEWIC 2003). However, few surveys in BC have been conducted at depths greater than 3 m and to date most surveys have focused on shallow shoreline along the littoral zone. Freshwater mussels also have a distinctive life cycle, which includes a parasitic larval stage (glochidia) that requires a fish host to complete their reproductive cycle (Neves et al. 1985). Therefore, host fish must also be available within potential suitable habitat (COSEWIC 2010; Snook 2018).

*G. angulata* was designated Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2003 (COSEWIC 2003). It was subsequently listed under the *Species at Risk Act* (SARA) in 2005. The status of *G. angulata* was re-examined by COSEWIC and assessed as Endangered in 2010 largely due to the potential threat of introduced Zebra (*Dreissenia polymorpha*) and Quagga (*D. bugensis*) mussels (COSEWIC 2010), ongoing foreshore and riparian development, and the potential impact of some Eurasian Watermilfoil (*Myriophyllum spicatum*) control methods. The tendency of freshwater mussels to occupy shallow water may also make them susceptible to emersion (exposure to air) when water levels decline, thermal stress, and increased risk of predation (Vaugh and Taylor 1999; Burlakova and Karatayev 2007).

Very little quantitative information is available for population assessments for *G. angulate* in BC. Stanton et al. (2012) documents much of the efforts undertaken up until 2011 to develop and apply qualitative and quantitative surveys to characterize the presence of *G. angulata* in BC and to estimate density and local abundances in the Okanagan watershed. As a continuation of this previous work and to inform future assessments and conservation efforts, index sites known to have measurable densities of *G. angulata* were established and visited from 2011 to 2016. This document summarizes the findings of surveys undertaken over six years in the Okanagan watershed with the goal of providing mean density and abundance estimates by site in addition to summarizing findings on depth distribution of *G. angulata*.

# METHODS

## INDEX SITES

Aggregations of *G. angulata* have been previously documented in Okanagan Lake, Okanagan River, Skaha Lake, Vaseux Lake, and Osoyoos Lake within the Okanagan Basin (COSEWIC 2010). For this study, sites known to have *G. angulata* present with easily accessible shorelines were selected as index sites including Dog Beach, Kinsmen Park, Oliver, Three Mile Beach, Vaseux Lake, and Vernon (Figure 2; Table 1).

### Dog Beach

Dog Beach, also known as Peach Orchard Dog Park, is located in the town of Summerland, BC and is on the westward side of Okanagan Lake. Two index sites, Dog Beach 1 (DOG-1) and Dog Beach 2 (DOG-2), were surveyed at this municipal park.

DOG-1 receives predominately southern wind/wave action and is sheltered from most northerly wind/wave actions by a point jutting out from the shore. The area is comprised of large cobble mixed with sand. The shoreline has a paved walking trail right above the high water mark, with a paved road above that. Aquatic vegetation is limited here. Riparian vegetation consists mainly of a few large trees with no understory. Note that towards the north end of DOG-1 the waters become more shallow and transect lengths are thus increased.

DOG-2 is located north of the point. It is characterized by being more protected from southerly winds/waves by the point and receives the wind/wave action from the northerly direction. The substrate is primarily sand with occasional cobble. The northern end of the site is defined by a chain link fence that runs from the top of the sandy beach into the water. Aside from the fence, the site is similar to DOG-1 where there are no buildings at or below the high water mark. Aquatic vegetation is limited and riparian consists of a few large trees with no understory.

## Kinsmen Park

Kinsman Park is located approximately 1 km south of the Peach Orchard Dog Park along Lakeshore Drive. The index site KIN is adjacent to a municipal park. North of KIN is Prairie Valley Creek that drains the surrounding hillside. At the south end of this site, a dense bed of mixed vegetation, predominantly *Potamogeton spp*. and Eurasian Watermilfoil, has resulted in shorter transects due to impaired visibility. The substrate is predominantly sand with occasional large boulders. The shoreline has been significantly modified at this site. It has sections that have been built out into the lake and armoured with large boulders. One area that has not been infilled has a wooden retaining wall feature and acts as a bay due to the adjacent infills into Okanagan Lake. Prior to 2015, riparian vegetation at this site was removed by the District of Summerland staff due to the invasive nature of the large trees. The area was replanted with native species in September 2015. Running perpendicular to the shore approximately half way along the baseline is the remnants of an abandoned breakwater comprised of large boulders, wooden pilings and planks. Some mussels can be found amongst these rocks.

## Oliver

The Oliver index site is different from those previously described in that it is a channelized section of the Okanagan River. It is located within the Town of Oliver. The land adjacent to the index site consists of a dike with recreational use and a community park landward of the dike. The Okanagan River at this site is approximately 20 m wide. The edges of the banks have been described as “good *G. angulata* habitat” (DFO 2010) with primarily large cobble boulders that lead to a sandy, gravel river bottom. Vegetative areas are dispersed throughout the edges of the channel. The site is approximately 385 m long, running downstream from a pedestrian bridge to the Visitors Centre.

## Three Mile Beach

Three Mile Beach index site is located on the east side of Okanagan Lake, in northeast Penticton. This site is adjacent to Three Mile Beach, a municipal beach that provides access to the lake for the general public. Like Peach Orchard Dog Park, this site is located on a predominant point out into Okanagan Lake. The site has a direct exposure to southern winds/waves but also has a strong northern exposure at the west end. The substrate is primarily cobble with increasing sand and then vegetation at greater depths. The shoreline at the site is generally unmodified and has some intact riparian vegetation. The site has the most exposure to both northerly and southerly winds.

## Vaseux Lake

Vaseux Lake index site is located in Vaseux Lake Provincial Park accessed via Highway 97. Vaseux Lake is small lake south of both Okanagan and Skaha lakes

between the town of Okanagan Falls and Oliver. The substrate at the index site is a mix of large boulders and sand. The site is sheltered from winds. Fine sediments are found throughout the site covering all of the larger boulders and cobble. The foreshore has a mix of thick riparian growth, small sandy beach, and a grassy area.

Vernon

The Vernon index site is located on the northwest edge of Kin Beach in the city of Vernon. The survey site is perpendicular to the extended edge of the bay but was established to run parallel to the shoreline. The substrate is characterized by cobble for the first 10 m of a transect followed by sand. The foreshore has very little riparian vegetation with the exception of a few large trees and grassy play area.

## SURVEY DESIGN

Surveys involved a two-person snorkel team to place transects, measure water depth, and count mussels by quadrat. An additional observer was located on shore to record data. First a baseline (surveyor's tape) was stretched out along the shoreline at the waters' edge, which ranged from 30 to 60 m depending on the index site. The start and end point of each baseline were recorded with a GPS. Transects perpendicular to the baseline were placed systematically every three metres along the baseline starting at 0 m. Transects varied in length but averaged approximately 30 m and were typically terminated when the substrates were no longer appropriate for surveying (e.g. beyond snorkelling depth, plant material obstructed the view, or an old dock or other large object limited access). Along each transect, mussels were enumerated using a one metre squared (1-$m^2$) quadrat every other metre. Quadrats began at the two metre mark of each transect in 2011. From 2012 to 2016, quadrats were started at the baseline for each transect. Depth was measured with a metre stick at the southwest corner of each quadrat and recorded. When counting mussels, sediment sifting did not occur and individuals were not disturbed or removed from the substrate in order to limit physiological stress.

The above sampling design was used at all index sites except Oliver. Due to the channelled nature of the Okanagan River at the Oliver site, a cumulative count approach was taken whereby snorkelers surveyed replicates of continuous transects down the length of the site (385 m). Two snorkelers, one on either side of the river, walked downstream from the pedestrian bridge in Oliver along the edges of the river bank in water mostly varying in depth from 1.3–1.7 m. For an especially deeper area along the east side of the river (>1.7 m), observations were made while swimming. Using a 1-metre ruler as a guide to measure width and constrain search effort, running tallies of observed *G. angulata* were recorded using a hand held tally counter. After the snorkelers reached the end of the survey length they returned to the starting point, switched sides and repeated the walk to create replicate counts. Surveys at this site

were only conducted in 2015 as flow rates were too high to conduct surveys in other years.

Surveys were conducted during daylight hours (0900–1600) in October of 2011 and in late August in 2012 through 2016 (Table 1).

### DATA ANALYSIS

As all quadrats were 1-$m^2$, the total area of all quadrats combined determined the Area Surveyed at each site for each year (Table 2). The Sample Area for each survey was estimated to be six times the Area Surveyed, as quadrats were placed every second metre along transects which were placed systematically every three metres along the baseline (Table 2). Estimates of Sample Area therefore represent the total potential area which could have been surveyed. Estimates of sample area were validated using ESRI ArcMap version 10.6.1. where polygons encompassing transects produced similar results. Mean density was determined by calculating the density of each transect, then averaging the density (mussels per $m^2$) of all transects in a site. Mean density and abundance estimates were computed using Data Analysis Tools in Microsoft Excel.

For each index site a histogram showing frequency of mussel detections at various depth ranges was created in Microsoft Excel. Mussel density by depth was plotted by index site in R-3.6.0.

## RESULTS

Seven index sites were surveyed between 2011 and 2016. The geographic positions of the index sites and the year(s) they were surveyed are provided in Table 1. Note that the reported GPS coordinates in Table 1 are approximations as the baseline shifted spatially each year due to fluctuating lake water levels.

### MUSSELS BY SITE

The number of *G. angulata* observed per 1-$m^2$ quadrat ranged from zero to 18 over all index sites. The majority of all quadrats contained zero mussels (2,882 of 4,446 quadrats, or 65%).

For each index site, a summary of *G. angulata* count data, mean density, and abundance estimates by sample area are provided in Table 2.

Mean densities ranged from 0.11 ±0.11 mussels/$m^2$ at Vaseux Lake in 2015 to 2.82 ±1.05 mussels/$m^2$ at Three Mile Beach in 2015 (Table 2). Abundance estimates for

index sites ranged from 131 ±102 mussels at Vernon in 2015 to 3,589 ±1,340 mussels at Three Mile Beach in 2015 (Table 2).

Cumulative counts from the Oliver snorkel survey are provided in Table 3.

## MUSSELS BY DEPTH

Survey depths ranged from 0 to 1.78 m over all index sites (Table 4). Observations of *G. angulata* occurred in depths between 0.02 and 1.76 m. Overall, relatively low counts occurred in water less than 0.50 m (n=134 of 3,844 individuals, or 3.5%). For most sites, *G. angulata* were found at higher densities at depths of 0.50–1.00 m and typically declined with greater depths exceeding (>1.5 m) (Table 4, Figure 3). A visual representation of *G. angulata* density by depth for each site is provided (Figure 3).

For each site, the frequency of mussel detections at various depths was examined. A mussel detection is defined as a quadrat in which one or more mussels were observed.

At Dog Beach index site DOG-1, the frequency of mussel detections increased gradually up to a maximum at 1.01–1.10 m (21% of detections) followed by a decline in frequency at depths greater than 1.10 m (Figure 4). Quadrat depths ranged from 0 to 1.78 m; mussels were detected between 0.20 and 1.74 m (Table 4).

At Dog Beach index site DOG-2, most detections (70%) occurred between 0.51 and 1.00 m (Table 4; Figure 5). Quadrat depths ranged from 0 to 1.60 m; mussels were detected between 0.20 and 1.32 m (Table 4).

At Kinsmen Park (index site KIN) the frequency of mussel detections generally increased up to the maximum occurrence at 0.81–0.90 m (17% of detections) followed by a decline in frequency at depths greater than 0.90 m (Figure 6). Quadrat depths ranged from 0 to 1.63 m; mussels were detected between 0.27 and 1.52 m (Table 4).

At Three Mile Beach (index site TMB) the highest percentage of detections (18%) occurred in the 1.01–1.10 m depth range (Figure 7). This site had considerably more detections in deeper waters with 59% of observations occurring at depths greater than 1.00 m (Table 4). Quadrat depths ranged from 0 to 1.76 m; mussels were detected between 0.02 and 1.76 m (Table 4).

At Vaseux Lake (index site VAS) the majority of detections (87%) occurred between 0.51 and 1.00 m (Table 4; Figure 8). This site had no detections in waters >1.00 m. Quadrat depths ranged from 0.20 to 1.20 m; mussels were detected between 0.20 and 0.98 m (Table 4).

At Vernon (index site VER) the majority of detections (96%) occurred between 0.51 and 1.00 m (Table 4; Figure 9). This site had few detections (2%) in waters ≤0.50 m and

>1.00 m. Quadrat depths ranged from 0.00 to 1.18 m; mussels were detected between 0.48 and 1.05 m (Table 4).

## DISCUSSION

Rocky Mountain Ridged Mussel (*G. angulata*) which has been assessed as Endangered, is one of only a few species of freshwater mussel in BC, and is restricted to the Okanagan Basin in Canada. In this watershed *G. angulata* has been impacted by historical loss and degradation of habitat (COSEWIC 2010) and the survival or recovery of this species may continue to be jeopardized by current threats ranging from the potential impacts from the introduction of Zebra (*Dreissenia polymorpha*) and Quagga (*D. bugensis*) mussels, ongoing foreshore and riparian development, and the potential impact of some Eurasian Watermilfoil control methods (DFO, 2010). Although freshwater mussels play an important role in aquatic ecosystems as filter feeders, affecting nutrient dynamics and water chemistry, as components of food webs, and as indicators of freshwater ecosystem health (Grabarkiewicz and Davis 2008), a large number of knowledge gaps remain for *G. angulata* and other freshwater mussel species. Despite the risk of extinction *G. angulata* faces, very little quantitative information is available for population assessments. Therefore, these surveys were conducted to characterize the presence of *G. angulata* in BC and to estimate density at index sites in the Okanagan watershed.

In this study, only visible individuals were enumerated in order to limit physiological stress associated with sediment sifting or removing individuals from the substrate. Therefore, it is likely that some individuals could have been buried in sediment and not enumerated. As such, abundance estimates of *G. angulata* across all index sites from 2011–2016 reflect a minimum number of mussels per index site. *G. angulata* are also mobile animals (COSEWIC 2010), and the extent to which they move daily or seasonally is unknown. The influence of variables, such as water temperature, substrate size and mussel size on mobility are also not fully understood. Therefore, estimates at sites are expected to fluctuate seasonally and annually to some degree. Nevertheless, estimates of density appeared to show fluctuations in trends across sites and years, with the most recent year (2016) showing the lowest abundance across the time series for all sites. As more data is collected trend analysis with appropriate co-variates will be undertaken.

Determination of at-depth distribution was listed as a suggested research activity to address uncertainty in the Recovery Potential Assessment for *G. angulata* (DFO 2011). Although some variation occurred between sites in terms of substrate and habitat, *G. angulata* was generally detected more frequently in water depths greater than 0.50 m, and detections typically declined with greater water depths exceeding >1.5 m. Although detection error could be higher at greater depths, elsewhere *G. angulata* are also typically observed in shallow waters (less than 1.5m) (COSEWIC 2003). While surveys

in BC have generally focused on shallow shoreline along the littoral zone, specimens have been recorded at depths of 10–20 m in Washington and Oregon (COSEWIC 2003). In the Okanagan, specimens have been observed at depths of ~7.5 m in Vaseux Lake and 2.4 m in Okanagan Lake (Stanton et al. 2012). Therefore, *G. angulata* can occur at greater water depths in the Okanagan Basin, but likely in much lower densities.

Conversely, *G. angulata* was also detected in shallow water <0.50 m, including 0.02 m at Three Mile Beach (TMB). The tendency of freshwater mussels to occupy shallow water may also make them susceptible to emersion (exposure to air) when water levels decline, thermal stress, and increased risk of predation (McMahon 1991; Vaugh and Taylor 1999; Burlakova and Karatayev 2007). In 2001, the Canadian Okanagan Basin Technical Working Group (COBTWG) created a fish and water management tool (FWMT) project which utilizes a set of quantitative decision-support models to aid in water management decisions affecting lake levels and river flows (Hyatt 2004; Hyatt and Bull 2007). The aim of the FWMT project is to improve water management practices by satisfying resource management objectives to sustain or increase Sockeye Salmon (*Oncorhynchus nerka*) and kokanee (*O. nerka*) production and meet socioeconomic needs for irrigation and recreational purposes while reducing the risk of droughts or floods (Hyatt 2004; Hyatt and Bull 2007). Information on density at depth of *G. angulata* has been added to the FWMT with a goal of reducing the impact to *G. angulata* from dewatering events.

Future Research Recommendations:

- Refining habitat requirements, linking distribution and survival to substrate type and availability.

- Further study to understand the spatial overlap and potential impact of some Eurasian Watermilfoil control methods.

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# REFERENCES


BC Conservation Data Centre. 2020. BC Species and Ecosystems Explorer. B.C. Minist. of Environ. Victoria, B.C. Available:http://a100.gov.bc.ca/pub/eswp/ (accessed November 20, 2020).

Burlakova, L.E., and Karatayev, A.Y. 2007. The effect of invasive macrophytes and water level fluctuations on unionids in Texas impoundments. Hyrdobiologia 586: 291–302.

Clarke, A.H. 1981. The freshwater molluscs of Canada. National Museum of Natural Sciences: National Museums of Canada, Ottawa, Ont.

COSEWIC. 2003. COSEWIC assessment and status report on the Rocky Mountain Ridged Mussel *Gonidea angulata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 29 pp. http://publications.gc.ca/collections/Collection/CW69-14-370-2004E.pdf

COSEWIC. 2010. Updated COSEWIC status report on Rocky Mountain Ridged Mussel *Gonidea angulata*. Committee on the Status of Endangered Wildlife in Canada. Otawwa. viii + 55 pp. http://publications.gc.ca/collections/collection_2012/ec/CW69-14-614-2011-eng.pdf

DFO. 2010. Management Plan for the Rocky Mountain Ridged Mussel (*Gonidea angulata*) in Canada. [Final]. *Species at Risk Act* Management Plan Series. Fisheries and Oceans Canada, Vancouver. iv + 52 pp.

DFO. 2011. Recovery Potential Assessment for Rocky Mountain Ridged Mussel (*Gonidea angulata*) in British Columbia. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/053.

Grabarkiewicz, J. and W. Davis 2008. An introduction to freshwater mussels as biological indicators. EPA-260-R-08-015. U.S. Environmental Protection Agency, Office of Environmental Information, Washington, D.C. 108 pp.

Graf, D.L. 2002. Molecular phylogenetic analysis of two problematic freshwater mussel genera (*Unio* and *Gonidea*) and a re-evaluation of the classification of nearctic Unionidae Bivalvia: Palaeoheterodonta:Unionida). J. Moll. Stud. 68:65–71.

Hyatt, K.D. 2004. An overview of the Okanagan watershed Fish-and-Water Management Tools (FWMT) project. Canadian Okanagan Basin Technical Working Group website: http://www.obwb.ca/obwrid/docs/159_2004_Overview_OK_Watershed_FWMT.pdf [accessed December 2011].

Hyatt, K.D., and Bull, C. 2007. Fish and Water Management Tool project assessments: Record of management strategy and decisions for 2005. Can. Manuscr. Rep. Fish. Aquat. Sci. 2808: x + 37 p.

McMahon, R.F. 1991. Mollusca: Bivalvia. In Ecology and Classification of North American Freshwater Invertebrates. Edited by J.H. Thorpe and A.P. Covich. Academic Press, San Diego, CA. pp. 315–399.

Neves, R.J., Weaver, L.R., and Zale, A.V. 1985. An Evaluation of host fish suitability for *Villosa vanuxemi* and *V. nebulos* (Pelecypoda: Unionidae). Am. Midl. Nat. 113: 13–19.

Snook, R. 2018. Information in support of the identification of critical habitat for the Rocky Mountain Ridged Mussel (*Gonidea angulata*). DFO Can. Sci. Advis. Sec. Res. Doc. 2018/040. viii + 56 p.

Stanton, L., Lauzier, R., MacConnachie, S., Nield, L., Pollard, S., Heron, J., and Davies, S. 2012. Exploratory surveys and directed studies of Rocky Mountain Ridged Mussel (*Gonidea angulata* Lea, 1839) in British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 3003: viii + 63 p.

Vaughn, C.C., and Taylor, C.M. 1999. Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. Conserv. Biol. 13: 912–920.

**Table 1. Geographic positions of seven index sites surveyed for *Gonidea angulata* in the Okanagan Basin, British Columbia, and survey dates from 2011 to 2016.**

| Site | Index site | Start Latitude | Start Longitude | Survey Dates | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | October 20–21, 2011 | August 29–30, 2012 | August 27–28, 2013 | August 26, 2014 | August 25–26, 2015 | August 27–31, 2016 |
| Dog Beach | DOG-1 | 49.60709 | -119.64971 | X | X | X | X | X | X |
| | DOG-2 | 49.60758 | -119.65009 | X | | X | | X | X |
| Kinsmen Park | KIN | 49.59893 | -119.65078 | X | | X | | X | X |
| Oliver | OLI | 49.18578 | -119.54841 | | | | | X | |
| Three Mile Beach | TMB | 49.53754 | -119.57647 | | | | | X | X |
| Vaseux Lake | VAS | 49.29765 | -119.53076 | | | | | X | |
| Vernon | VER | 50.24958 | -119.35226 | | X | | | X | |

**Table 2. Summary of *Gonidea angulata* count data, mean density, and abundance estimates per sample area for the year(s) that each index site was surveyed between 2011 and 2016.**

| Index Site | Year | # Transects | Area Surveyed ($m^2$) | Total Mussel Count | Mean Density | | Sample Area ($m^2$) | Abundance Estimate | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Mussels/$m^2$ | SD | | # Mussels | SD |
| DOG-1 | 2011 | 19 | 281 | 498 | 1.78 | 0.74 | 1,686 | 3,004 | 1,252 |
| | 2012 | 16 | 304 | 446 | 1.48 | 0.49 | 1,824 | 2,693 | 903 |
| | 2013 | 17 | 273 | 264 | 1.02 | 0.69 | 1,638 | 1,663 | 1,130 |
| | 2014 | 16 | 301 | 181 | 0.64 | 0.33 | 1,806 | 1,150 | 589 |
| | 2015 | 16 | 316 | 347 | 1.12 | 0.30 | 1,896 | 2,119 | 565 |
| | 2016 | 15 | 284 | 117 | 0.46 | 0.26 | 1,704 | 776 | 451 |
| DOG-2 | 2011 | 18 | 270 | 176 | 0.65 | 0.61 | 1,620 | 1,050 | 988 |
| | 2013 | 16 | 220 | 74 | 0.34 | 0.21 | 1,320 | 449 | 271 |
| | 2015 | 16 | 300 | 89 | 0.30 | 0.25 | 1,800 | 540 | 454 |
| | 2016 | 17 | 305 | 52 | 0.17 | 0.12 | 1,830 | 315 | 228 |
| KIN | 2011 | 10 | 91 | 106 | 1.17 | 0.53 | 546 | 637 | 290 |
| | 2013 | 13 | 157 | 264 | 1.72 | 1.27 | 942 | 1,623 | 1,193 |
| | 2015 | 16 | 196 | 264 | 1.17 | 0.90 | 1,176 | 1,380 | 1,062 |
| | 2016 | 16 | 175 | 41 | 0.20 | 0.20 | 1,050 | 207 | 205 |
| TMB | 2015 | 17 | 212 | 606 | 2.82 | 1.05 | 1,272 | 3,589 | 1,340 |
| | 2016 | 15 | 197 | 205 | 1.04 | 0.41 | 1,182 | 1,228 | 487 |
| VAS | 2015 | 16 | 250 | 29 | 0.11 | 0.11 | 1,500 | 169 | 160 |
| VER | 2012 | 20 | 201 | 64 | 0.32 | 0.20 | 1,206 | 383 | 245 |
| | 2015 | 9 | 113 | 21 | 0.19 | 0.15 | 678 | 131 | 102 |

**Table 3. Summary of *Gonidea angulata* observed over a distance of 385 m along the Okanagan River in 2015 at the Oliver index site in Oliver, British Columbia.**

| Index site | Year | Swimmer | Left side | Right side |
|---|---|---|---|---|
| OLI | 2015 | 1 | 123 | 150 |
| | | 2 | 132 | 180 |
| | | **Average count** | 128 | 165 |
| | | **Mean density (*G. angulata* per $m^2$)** | 0.33 | 0.43 |

**Table 4. Summary of *Gonidea angulata* distribution by depth at six index sites. A detection is defined as a quadrat in which one or more mussels were observed.**

| Index site | Total # quadrats | Mussel detections (n) | Detections at depth | | | Survey depth range (m) | Minimum detection depth (m) | Maximum detection depth (m) |
|---|---|---|---|---|---|---|---|---|
| | | | ≤0.5 m (%) | 0.51–1.00 m (%) | >1.00 m (%) | | | |
| DOG-1 | 1,759 | 789 | 2 | 47 | 51 | 0.00–1.78 | 0.20 | 1.74 |
| DOG-2 | 1,095 | 251 | 9 | 70 | 21 | 0.00–1.60 | 0.20 | 1.32 |
| KIN | 619 | 216 | 13 | 62 | 25 | 0.00–1.63 | 0.27 | 1.52 |
| TMB | 409 | 225 | 10 | 31 | 59 | 0.00–1.76 | 0.02 | 1.76 |
| VAS | 250 | 23 | 13 | 87 | 0 | 0.02–1.20 | 0.20 | 0.98 |
| VER | 201 | 47 | 2 | 96 | 2 | 0.00–1.18 | 0.48 | 1.05 |

**Figure 1. Image of an adult Rocky Mountain Ridged Mussel (*Gonidea angulata)* from Okanagan Lake observed in July 2009 at Dog Beach, Summerland, British Columbia. Photograph by L. Stanton.**

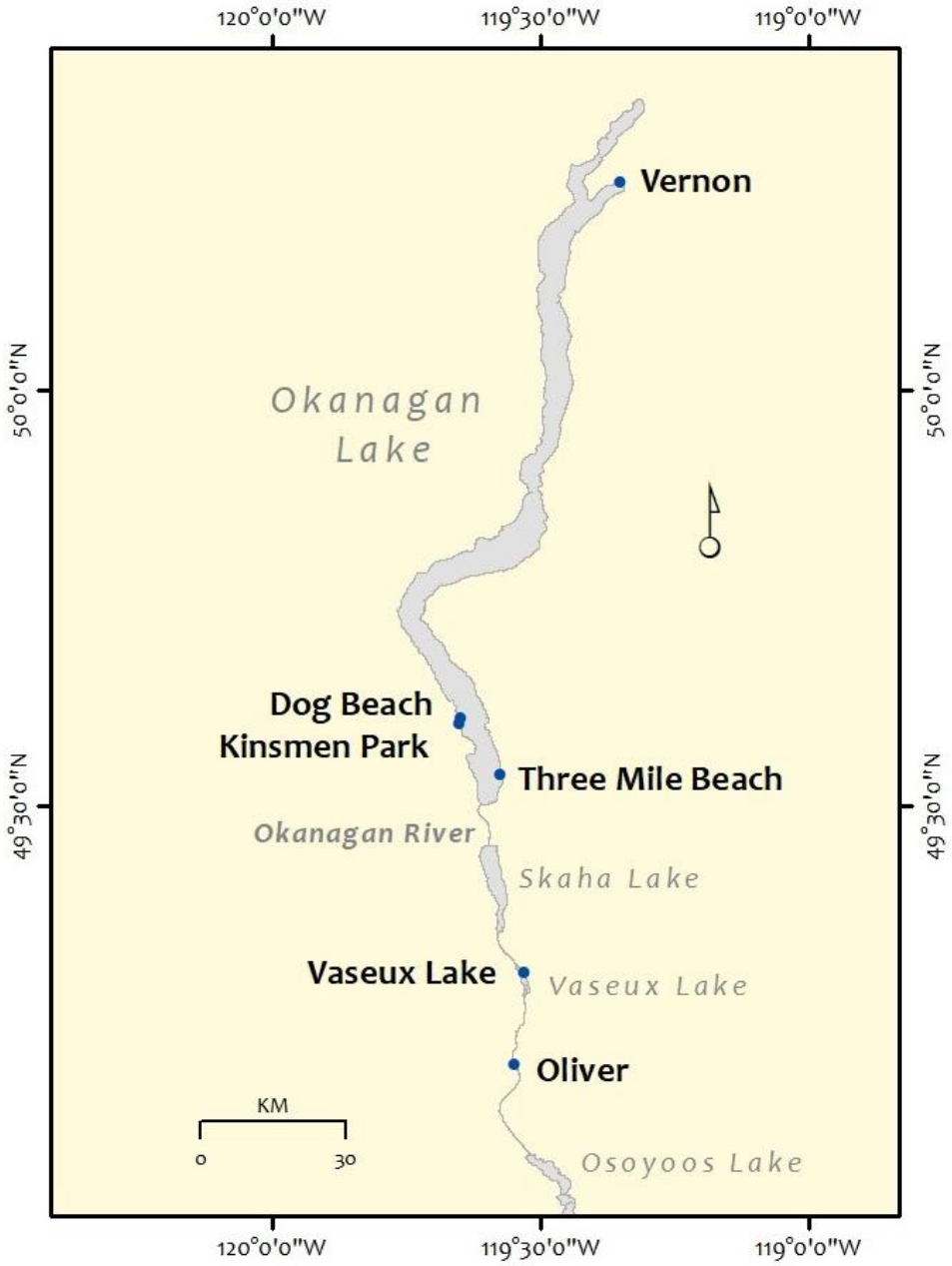


**Figure 2. Sites selected for yearly surveys of Rocky Mountain Ridged Mussels (*Gonidea angulata*) in the Okanagan Basin, British Columbia (2011–2016).**

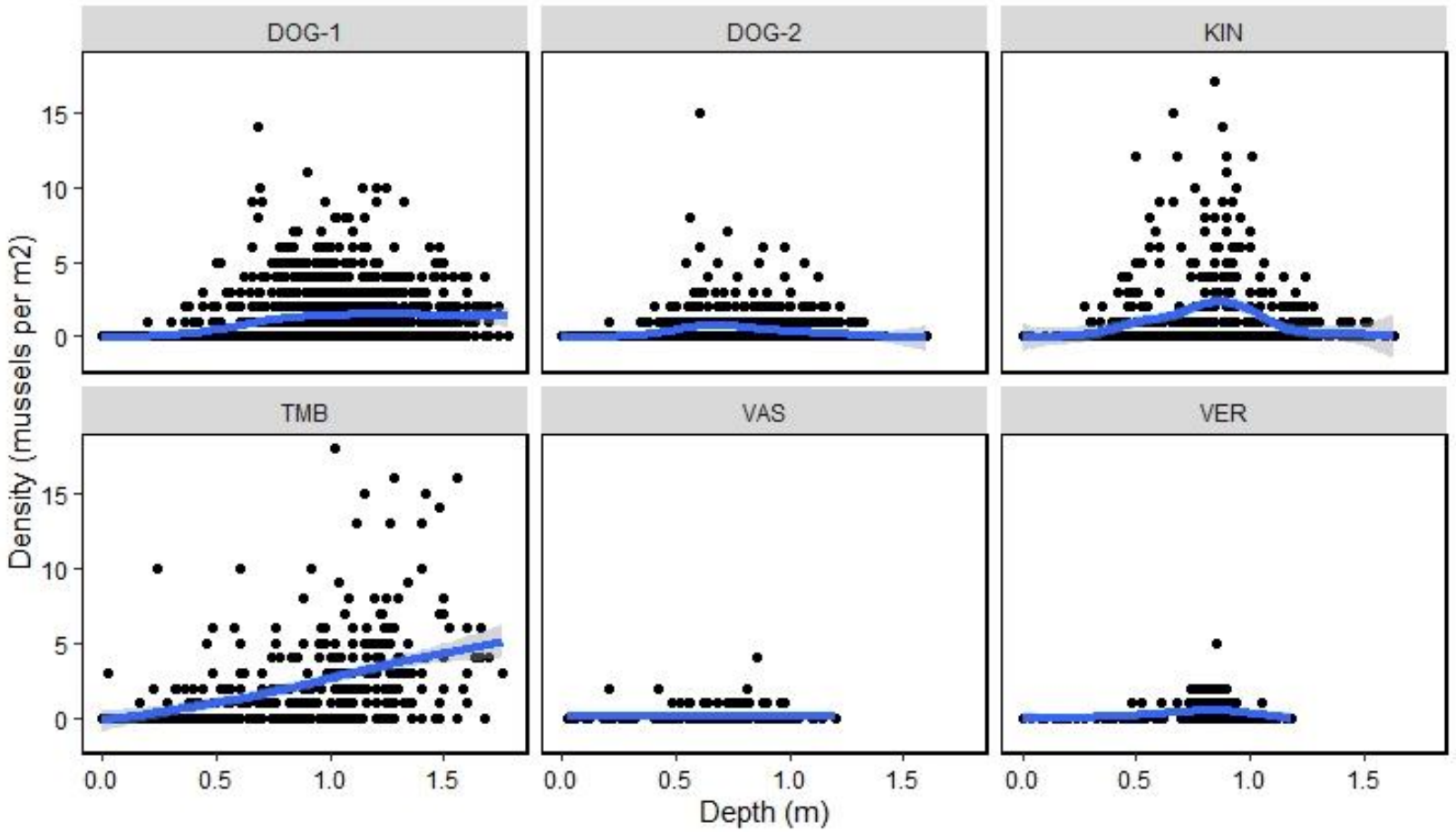


**Figure 3. Scatterplot of *Gonidea angulata* density by depth at Dog Beach index sites (DOG-1 and DOG-2), Kinsmen Park (KIN), Three Mile Beach (TMB), Vaseux (VAS), and Vernon (VER). Lines represent smoothed regression with 95% confidence intervals.**

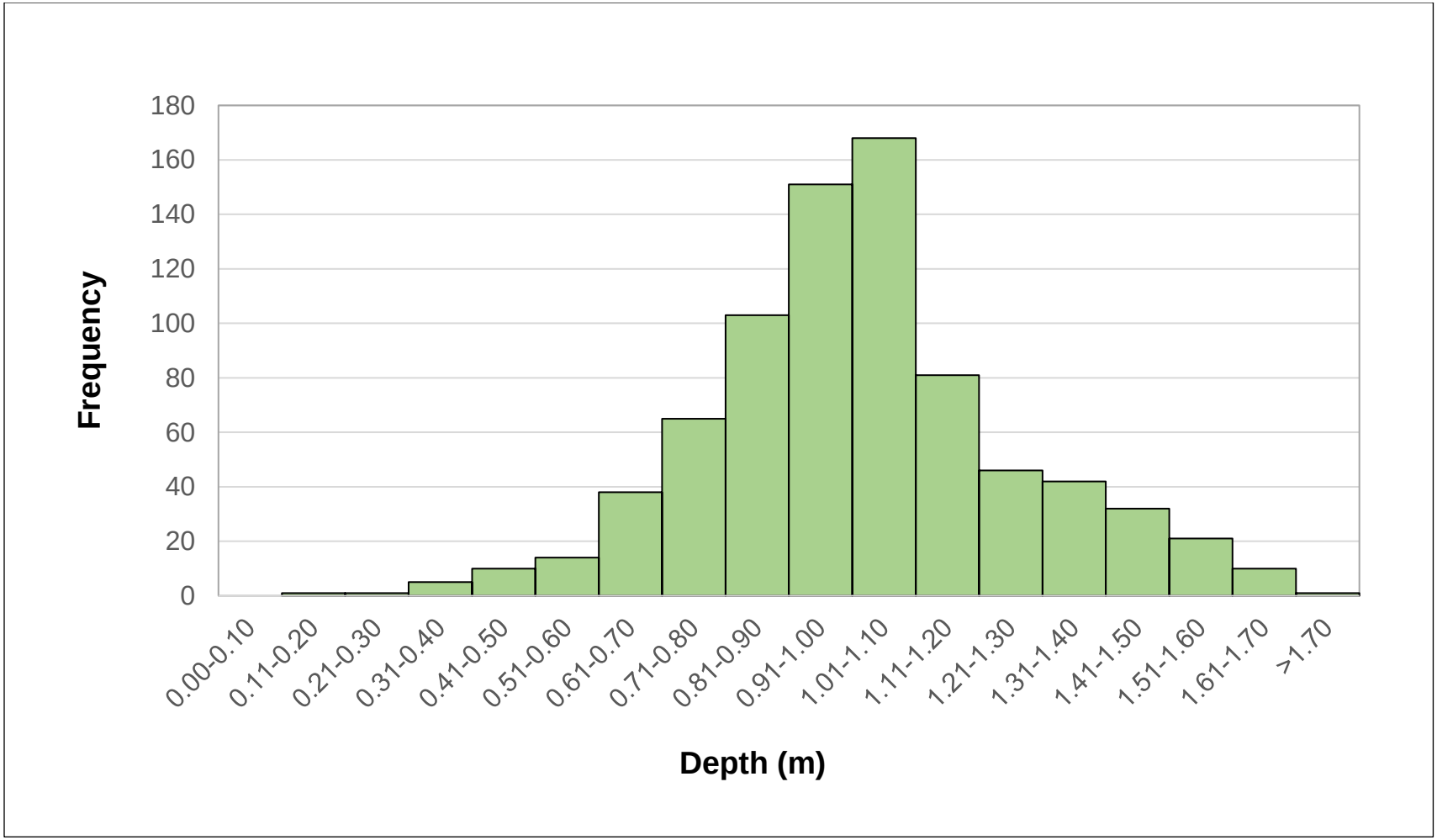


**Figure 4. Frequency of *Gonidea angulata* occupying various depths at Dog Beach index site DOG-1 in Summerland, Okanagan Lake, British Columbia (n=789).**

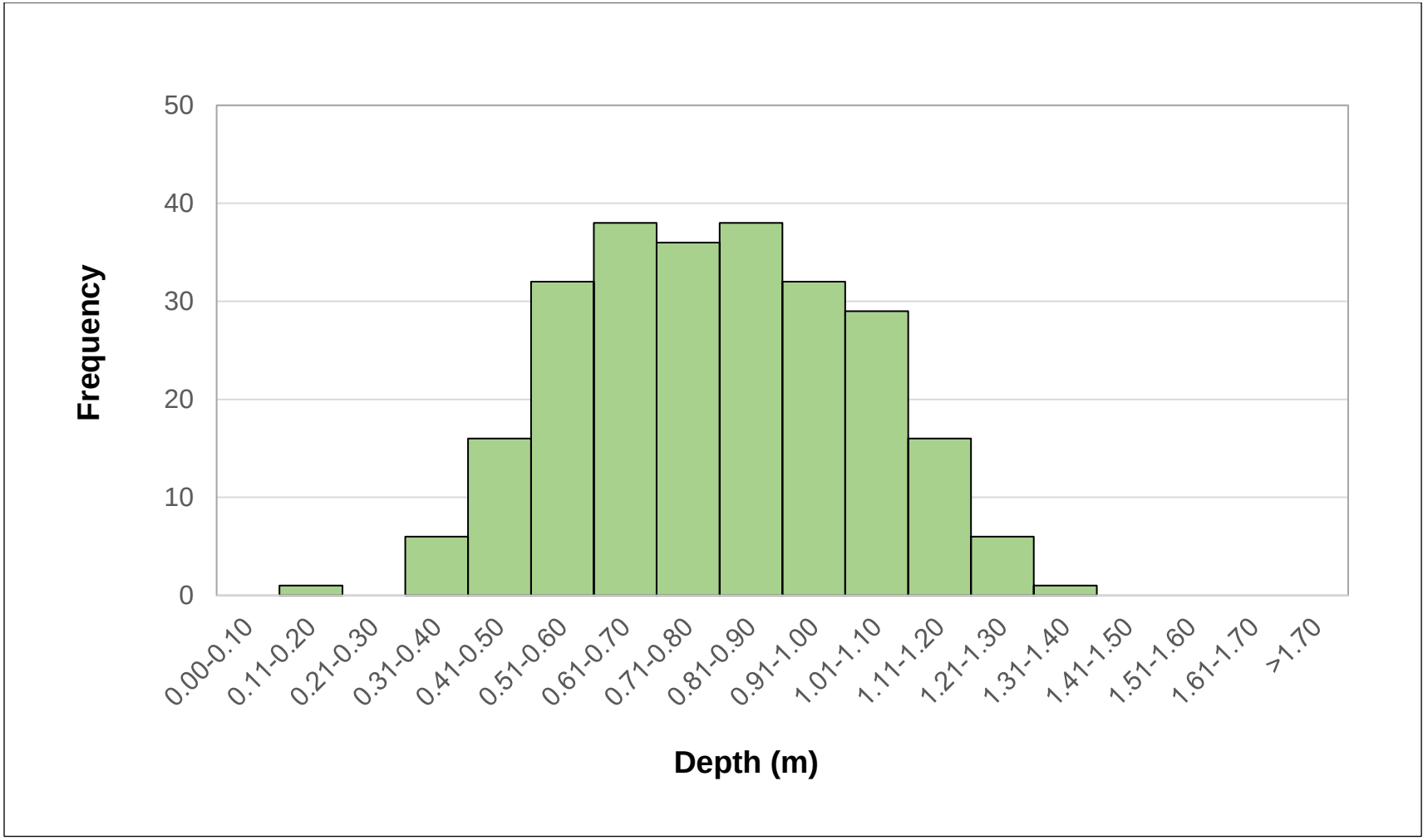


**Figure 5. Frequency of *Gonidea angulata* occupying various depths at Dog Beach index site DOG-2 in Summerland, Okanagan Lake, British Columbia (n=251).**

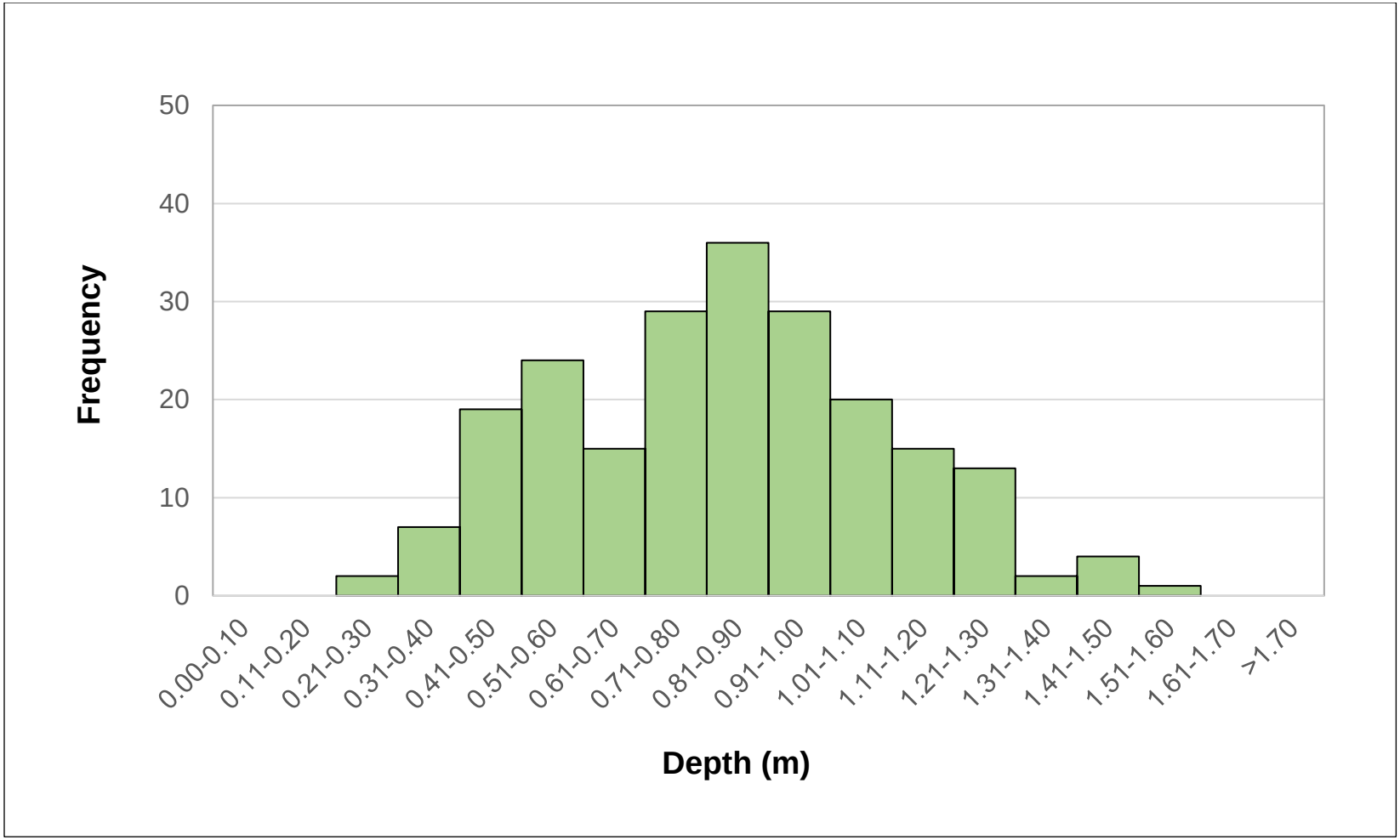


**Figure 6. Frequency of *Gonidea angulata* occupying various depths at Kinsmen Park index site in Peachland, Okanagan Lake, British Columbia (n=216).**

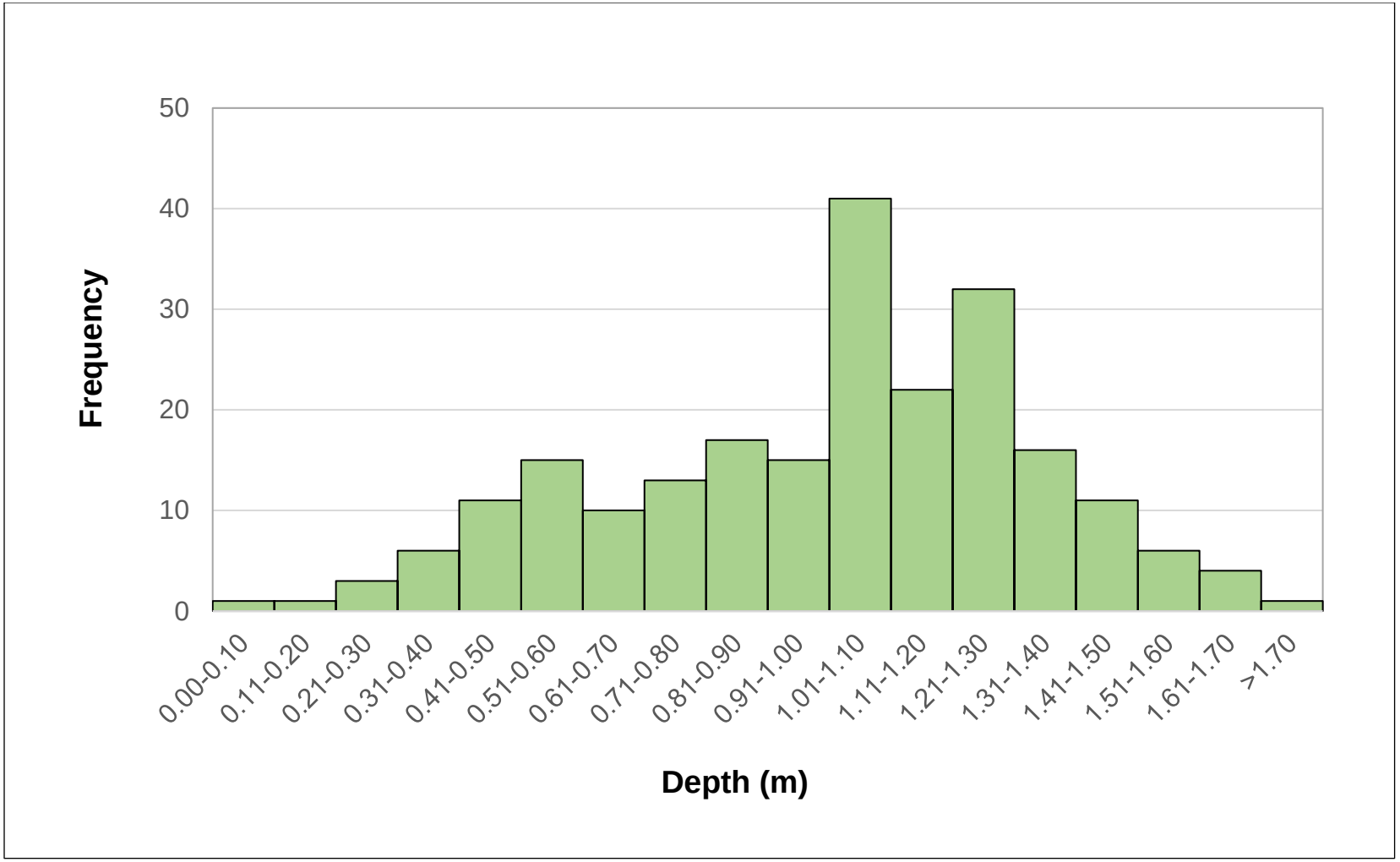


**Figure 7. Frequency of *Gonidea angulata* occupying various depths at Three Mile Beach index site in northeast Penticton, Okanagan Lake, British Columbia (n=225).**

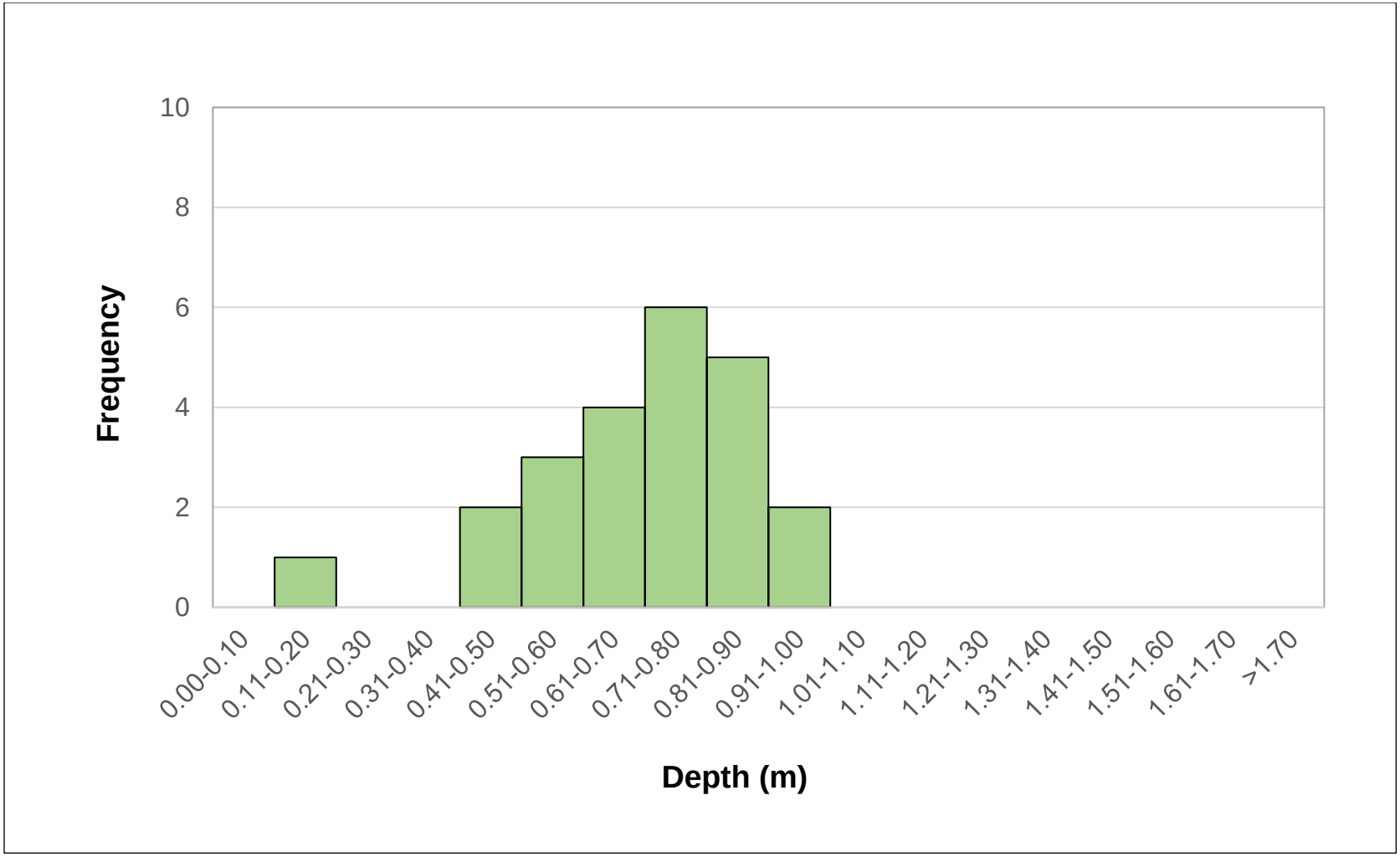


**Figure 8. Frequency of *Gonidea angulata* occupying various depths at Vaseux Lake index site on Vaseux Lake near Oliver, British Columbia (n=23).**

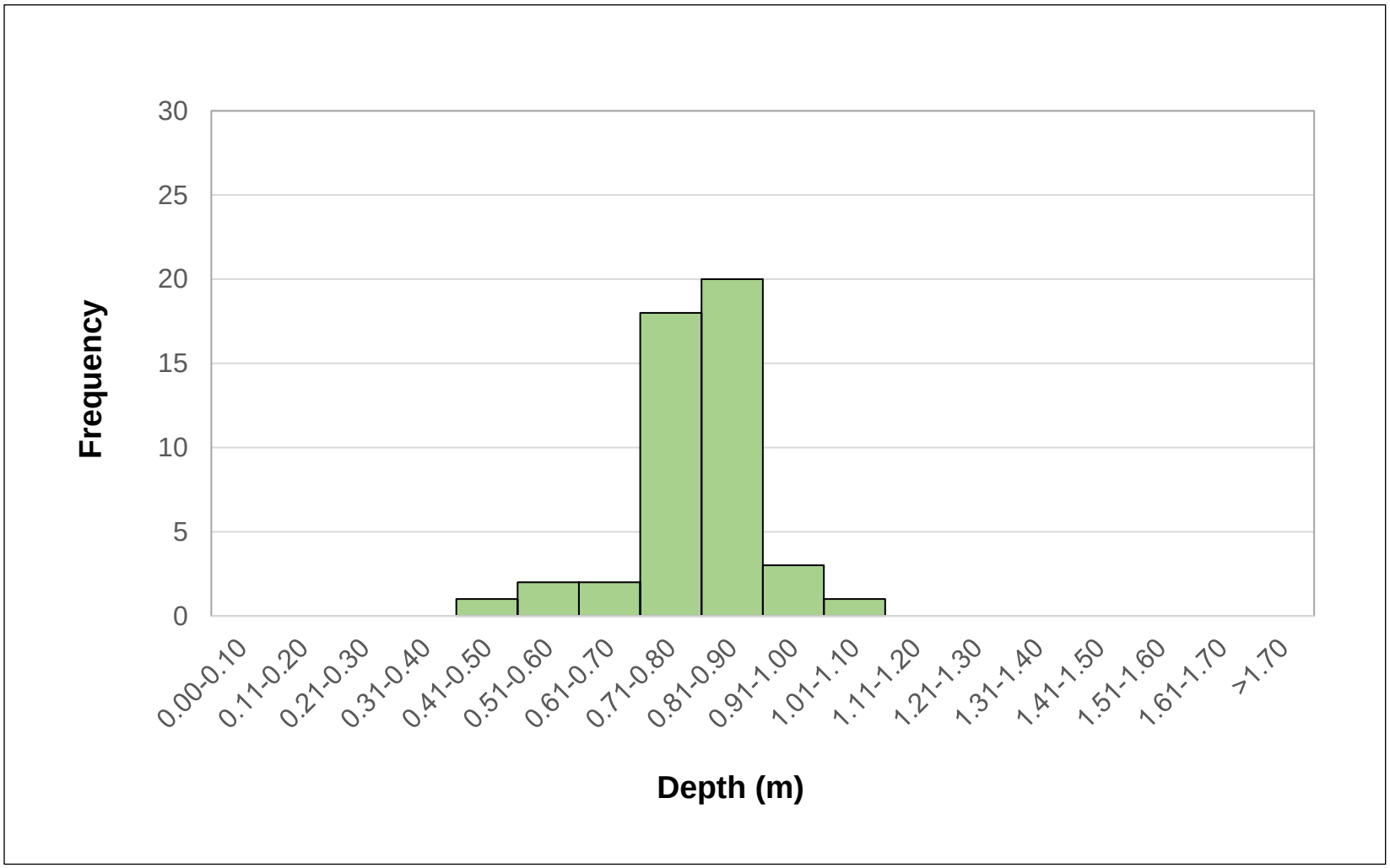


**Figure 9. Frequency of *Gonidea angulata* occupying various depths at Vernon index site in Vernon, Okanagan Lake, British Columbia (n=47).**