Exploratory Surveys and Directed Studies of Rocky Mountain Ridged Mussel (*Gonidea angulata* Lea, 1839) in British Columbia

L. Stanton, R. Lauzier, S. MacConnachie, L. Nield, S. Pollard,
J. Heron, and S. Davies

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, British Columbia
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EXPLORATORY SURVEYS AND DIRECTED STUDIES OF ROCKY MOUNTAIN RIDGED MUSSEL (*Gonidea angulata* Lea, 1839) IN BRITISH COLUMBIA

by

L. Stanton[1], R. Lauzier[1], S. MacConnachie[1], L. Nield[2], S. Pollard[3],
J. Heron[3], and S. Davies[1]

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

[2]BC Ministry of Forests, Lands, and Natural Resource Operations

[3]BC Ministry of Environment

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ABSTRACT

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Exploratory surveys completed collaboratively by Fisheries and Oceans Canada, the British Columbia Ministry of Environment and the British Columbia Ministry of Forests, Lands and Natural Resource Operations from 2008-2011 verified the current distribution of *Gonidea angulata* in British Columbia. Live mussels were only observed in the Okanagan River Basin with five main aggregations identified in Okanagan Lake. Quantitative surveys conducted at Dog Beach, Summerland on Okanagan Lake estimated a current population of 4,000 individuals, likely representing the largest population of *G. angulata* in Canada and a potential site for future long term monitoring. Overwintering and density by depth surveys identified the proportion of mussels within the shallow littoral zone at risk of desiccation and increased predation. Results of these surveys will be incorporated into the Okanagan Fish and Water Management Tools System. Preliminary life history studies revealed mature glochidia are released within conglutinates at water temperatures above 15°C in early June and provides initial correlative information on fish species present in the area during glochidial release that may potentially serve as hosts including: Prickly Sculpin (*Cottus asper*), suckers (*Catostomus spp*.), Northern Pikeminnow (*Ptychocheilus oregonensis*) and Redside Shiner (*Richardsonius balteatus*).

RESUME

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.

Les relevés exploratoires réalisés par Pêches et Océans Canada en collaboration avec le ministère de l'Environnement de la Colombie-Britannique et le ministère des Forêts, des Terres et de l'Exploitation des ressources naturelles de la Colombie-Britannique de 2008 à 2011 ont permis de déterminer la répartition de *Gonidea angulata* en Colombie-Britannique. Des moules vivantes n'ont été trouvées que dans le bassin de la rivière Okanagan, y compris cinq principaux regroupements dans le lac Okanagan. Selon les relevés quantitatifs effectués à la plage des chiens à Summerland, sur le lac Okanagan, la population actuelle estimative s'élèverait à 4 000 individus, ce qui constitue la plus importante population de *Gonidea angulata* au Canada ainsi qu'un site potentiel de surveillance à long terme. Les relevés des concentrations d'hivernage et de la densité selon la profondeur ont montré que la population de moules résidant dans la zone littorale peu profonde était à risque de dessiccation et de prédation accrue. Les résultats de ces relevés seront saisis dans le système Okanagan Fish and Water Management Tools. Des études préliminaires du cycle biologique ont révélé que les glochidies matures sont libérées dans les conglutines lorsque la température de l'eau dépasse 15 °C au début de juin. Ces études ont également fourni de l'information corrélative préliminaire sur les espèces de poisson présentes dans la zone au moment de la libération des glochidies et qui pourraient servir d'hôtes, y compris le chabot piquant (*Cottus asper*), le meunier (*Catostomus spp*.), la sauvagesse du nord (*Ptychocheilus oregonensis*) et le méné rose (*Richardsonius balteatus*).

INTRODUCTION

Rocky Mountain ridged mussel, *Gonidea angulata* Lea, 1839, is a freshwater bivalve in the family Unionidae most closely related to the North American unionid Subfamily Ambleminae (Heard and Guckert 1971, Davis and Fuller 1981, Graf 2002). Taxonomically and morphologically unique, *G. angulata* is the only extant species within this genus and is consequently difficult to classify among the Unionidae (Graf 2002) Although Asian taxonomic affinities with *Gonidea* have been proposed, based on a number similar anatomical characteristics (Heard 1974, Watters 2001), no taxonomic and/or molecular studies have been conducted to confirm this relationship.

Clearly distinct from other freshwater mussels in northwestern North America, *G. angulata* is a large, thick shelled (5mm) trapezoidal shaped mussel (≤ 125mm long, ≤ 65mm high and ≤ 45mm wide) with a sharp and prominent posterior ridge, hence the common name Rocky Mountain ridged mussel (Clarke 1981)(Figure 1 and Figure 2). 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). Another distinguishing feature is the irregular and poorly developed hinge teeth; *Anodonta* species lack hinge teeth altogether while *Margaritifera falcata* teeth are more prominent in comparison to *G. angulata.*

G. angulata is restricted to the Pacific Drainages of western North America (Graff 2002) and historically its range extended from southern British Columbia (BC) to southern California and eastward to Idaho and Nevada (Taylor 1981, COSEWIC 2003) (Figure 3). Once commonly found in a number of rivers throughout California, it is now considered extirpated from the Central Valley and southern portions of the state. (Taylor 1981). Sporadic populations persist in the large tributaries of the Snake and Columbia Rivers in Washington, Idaho and Oregon, however a reduction in its original range has occurred. (Frest and Johannes 1995, Brim Box et al. 2006). According to NatureServe (2012), *G. angulata* is ranked globally as G3 (Vulnerable), nationally in Canada as N1 (critically imperilled) and nationally in the United States (US) as N3 (Vulnerable) but is not listed under the US Endangered Species Act or the International Union for Conservation of Nature (IUCN). Extant populations are present in the Okanagan Basin in BC, Washington, Oregon, southern Idaho, northern Nevada, and California (COSEWIC 2003, NatureServe 2012).

Within Canada, *G. angulata* reaches the northern limit of its global range in southern BC. Populations within the Okanagan Basin account for approximately 5% of the current global distribution. (COSEWIC 2010). According to Clarke (1981), *G. angulata* is distributed within the Columbia River system in southern BC which includes both the Okanagan and Kootenay Rivers. Unconfirmed historic records indicate that *G. angulata* may have been present in the Kootenay region and Vancouver Island (Table 1) (COSEWIC 2010). Previous surveys conducted by the BC Ministry of Environment (MoE) from 2005-2008 focused on five specific areas to confirm *G. angulata* presence in: (1) Vancouver Island (Bamfield and south), (2) the Similkameen Basin (Princeton south to the Canada/US border), (3) the Okanagan Basin (Vernon south to Osoyoos Lake), (4) the Kootenay Boundary (Kettle River east to Christina Lake) and (5) the Central and East Kootenays (Arrow Lakes east to Kootenay River) (Table 2, Figure 4). Despite a considerable amount of search effort, live *G. angulata* were only observed within the Okanagan Basin (COSEWIC 2010, BC Conservation Data Centre 2012). Current observational data have documented relatively large aggregations as well as single individuals in Okanagan Lake, Okanagan River, Skaha Lake, Vaseux Lake, and Osoyoos Lake (COSEWIC 2010, BC Conservation Data Centre 2012).

Prior to 2005, few standardized qualitative and no quantitative surveys had examined and documented the full range, distribution, and abundance of *G. angulata* in BC. This report documents the current distribution and provides preliminary population abundance and density estimates for *G. angulata* populations in BC and includes information on all qualitative and quantitative surveys led by the Department of Fisheries and Oceans Canada (DFO) from 2008-2011 and for all surveys for which data was made available. Additional qualitative surveys completed by the BC MoE have occurred concurrently from 2008-2011. Not all data from these surveys were available for inclusion within this report (S. Pollard pers. comm.).

G. angulata are typically observed in shallow waters (< 3m), in a variety of substrate types and water velocities (Clarke 1981, Spring Rivers 2007). In Canada, *G. angulata* are predominantly observed in lakes, and only a few specimens have been recorded in rivers or creeks (COSEWIC 2010; BC Conservation Data Centre 2012). Conversely, *G. angulata* are primarily found in rivers and creeks in the US and rarely occur in lakes or reservoirs (Frest and Johannes 1995). While *G. angulata* are typically observed in shallow waters, live specimens have been recorded at depths of 10-20 metres in Washington and Oregon (COSEWIC 2003). Few surveys in BC have attempted to locate *G. angulata* at depths greater than three metres. To date, all exploratory surveys have focussed on easily accessible and wade-able shoreline along the littoral zone.

The tendency of freshwater mussels to occupy shallow waters makes them susceptible to emersion (exposing mussels to air) when water levels decline (McMahon 1991, Burlakova and Karatayev 2007). Therefore, being stranded during extreme water fluctuations created through lake drawdowns and periods of drought can significantly increase unionid mortality through physiological disturbances such as desiccation, thermal stress, freezing, reduced feeding and nutrient uptake as well as an increased risk of predation (Vaughn 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 practises by satisfying resource management objectives to sustain or increase kokanee and sockeye salmon production and meet socioeconomic needs for irrigation and recreational purposes while reducing the risk of droughts or floods (Hyatt 2004, Hyatt and Bull 2007). Quantitative surveys to both monitor mussel populations along the littoral zone over the winter months and examine the density and distribution of mussel populations at various depths were conducted on Okanagan Lake in 2010 and 2011.

Freshwaters mussels have a distinctive life cycle including a parasitic larval stage (glochidia) requiring a fish host to complete their reproductive cycle (Neves et al. 1985). Female unionids brood glochidia in a modified portion of their gills, called marsupium, and expel glochidia using a wide range of species dependant mechanisms to find, lure, and attach to a suitable host fish (Kat 1984, Neves and Widlak 1988, Haag et al. 1995). Some species release free glochidia, others will produce packages of glochidia surrounded by mucous called conglutinates (Kat 1983), while other species modify their entire gill to produce superconglutinates that mimic fish prey or small fish to lure hosts (Haag et al. 1995). Once a suitable host is found, glochidia will attach to the gills, fins, or scales of the fish (encystment). The larvae will develop into juvenile mussels while attached to a fish host and are eventually released (excystment) to begin a free-living benthic lifestyle (Strayer 2008). Mussels are either host generalists - parasitizing a wide variety of fish (Trdan and Hoeh 1982, Haag and Warren 2003), or host specific – parasitizing one to a few closely related fish species (Zale and Neves 1982, Yeager and Saylor 1995).

The life history of *G. angulata* is not well documented and little is known of the factors affecting reproductive timing, and the effects of abiotic and biotic factors to reproductive success. Few studies have focussed on the reproductive traits and life history for *G. angulata* in Canada, however a comprehensive study was completed in California in 2004-2006 (Spring Rivers 2007). This study provided a detailed examination into the reproductive patterns of *G. angulata* documenting the occurrence of spawning, glochidial release, and periods of encystment and excystment and confirms fish hosts within the Pit River Drainage in northeastern California. The exact mechanisms by which *G. angulata* expel glochidia and attract host fish are unknown. Although they are thought to release free glochidia in a watery mucous (Barnhart et al. 2008), conglutinates were observed in Okanagan Lake (J. Heron and L. Nield pers. obs.). Preliminary studies focussing on the reproductive timing and identification of potential *G. angulata* fish hosts were undertaken by the BC Ministry of Forests, Lands, and Natural Resource Operations (FLNRO) in 2010 and 2011.

G. angulata was designated a species of special concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2003 and subsequently listed under the Canadian *Species at Risk Act* (SARA) in 2005. As a requirement of SARA, a management plan was developed in 2010 in collaboration with DFO Pacific Region and the BC MoE (DFO 2010). The status of *G. angulata* was re-examined in November 2010 and based on an updated COSEWIC assessment and status report documenting reduced abundance due to historic channelization of the Okanagan River, and in particular, the potential threat of introduced dreissenid (zebra and quagga) mussel infestation, it was designated as endangered. A recent risk assessment revealed the Okanagan Basin as particularly sensitive to dreissenid mussel infestation and once introduced could have devastating impacts on native mussels in the area (Mackie 2010). A Recovery Potential

Assessment (RPA) providing scientific background, identification of threats and probability of recovery of *G. angulata* in BC was completed in 2011 (DFO 2011).

This document summarizes field research completed on *G. angulata* as part of a collaborative partnership led by DFO and between the BC MoE, and the BC FLNRO. The specific objectives of this research were to:

1. Refine and test protocols for qualitative and quantitative survey methods.
2. Confirm historic records and document the current distribution and presence of *G. angulata* in B.C, the associated habitat in shallow littoral areas within the Okanagan Basin and the potential depth of occurrence.
3. Provide preliminary population abundance and density estimates, examining mussel density at various depths along the shallow littoral zone within Okanagan Lake.
4. Document life history information including timing of glochidial release and preliminary identification of potential fish hosts.

METHODS

The field studies conducted within this report can be divided into three categories: qualitative surveys, quantitative surveys, and life history studies. Although there was more than one field study for each category, the objectives of the surveys were similar. The objectives for the qualitative surveys was to verify the range and distribution of *G. angulata* in BC whereas quantitative surveys aimed to provide preliminary population and abundance estimates and understand the potential effects of fluctuating water levels and seasonal variability of Okanagan Lake. The life history studies were intended to increase our general understanding and knowledge of *G. angulata* biology in B.C

QUALITATIVE SURVEYS

Two types of qualitative surveys were conducted: broad brush surveys (snorkel, wading, and boat surveys) and reconnaissance dive surveys (SCUBA) to document the current range and distribution of *G. angulata* within BC and provide habitat descriptions, substrate composition and location of occupancy within the littoral zone and at depths >1.5m within Okanagan Lake. Various techniques were tested to refine existing survey protocols.

Broad Brush Surveys

Qualitative broad brush surveys were conducted throughout the study period during 2008-2011. Sites were determined based on historic records of *G. angulata* in BC and known current locations and local knowledge from BC MoE and DFO staff (BC Conservation Data Centre 2012; COSEWIC 2010) (Table 1). Surveys in 2008 attempted to locate unconfirmed reports of *G. angulata* in the Kootenay region, whereas surveys in 2009 concentrated on the Okanagan Basin   Surveys in 2010-2011 led by the BC FLNRO primarily focussed on both Osoyoos and Skaha Lakes, in addition to Okanagan Lake. It should be noted that additional surveys completed by the BC MoE have been ongoing and not all qualitative surveys conducted since 2008 are captured within this report.

Broad brush surveys typically involve a number of different techniques including snorkelling, wading or walking the shoreline of a lake, creek, or river. New qualitative techniques such as boat surveys where observers search the lake shoreline for evidence of shell or live mussels were tested as an alternative tool for detecting mussel populations. In addition, a short section of the west arm of Kootenay Lake and Okanagan Lake at Peach Orchard Beach in Summerland was searched testing the feasibility of using a towed camera. For each survey the date, geographic positioning system (GPS) coordinates, waterbody, location description, survey technique, and effort was recorded and is presented in Table 3. Search effort in person hours was calculated by multiplying the number of observers or participants by the amount of time, in hours, spent searching. Additional information was gathered including detailed location descriptions, substrate type, aquatic vegetation, water clarity and colour, temperature and conductivity when available and the presence/absence of freshwater mussel species, including *G. angulata*, *Margaritifera falcata*, *Anodonta californiensis* and/or *nutalliana* and *A. kennerlyi* and/or *oregonensis* (Figure 2). Only presence data was gathered at most sites due to the sporadic distribution of *G. angulata* in most areas and their cryptic nature in the substrate, resulting in infrequent detection.

Timed search surveys were also refined and tested as a method to target areas of known *G. angulata* occurrence or areas of suitable mussel habitat. Timed search techniques involved one to two snorkelers and occasionally one wader swimming or walking in a zig-zag pattern along the shoreline each covering different depths ranging from 0.5-1.5m with search times ranging from five minutes to one hour. Snorkelers and waders searched in a zig-zag rather than randomized fashion and remained in their assigned depth ranges in an attempt to standardize this protocol and eliminate overlap of search areas by surveyors. To enhance efficiency, only sites where mussel shells were directly observed or substrates that were deemed suitable to support *G. angulata* populations were searched by a timed snorkel approach. Mussels were located by both sight and/or touch and if necessary, were gently removed from the substrate for identification. Once it was determined that only *G. angulata* were observed in a certain area, mussels were enumerated and identified visually to avoid any harm or disturbance to the mussels. The GPS coordinates at the start and end of each timed search, amount of time spent searching, the distance and area covered was recorded, and the number of live *G. angulata* and substrate type was documented.

An additional timed search survey was performed on August 11, 2009 at Dog Beach, Summerland, in a location where high densities of *G. angulata* were observed. Two swimmers snorkelled a 30m x 2m area at depths between 1.0m and 1.5 m approximately 30m offshore with a $1m^2$ quadrat parallel to the shoreline and counting all live *G. angulata* within quadrats as they swam past. This survey was completed to provide a rough estimate of mussel abundance at a greater distance and at greater depths offshore.

Reconnaissance Dive Survey

To determine if *G. angulata* inhabits greater depths (>1.5m) within Okanagan Lake, reconnaissance dive surveys were performed by contract divers from Nautilus Diving Penticton on March 17-18 2011. Search effort focussed on extant *G. angulata* populations. Divers first located live *G. angulata* mussel beds and began their search in the same general area but at depths greater than 1.5 m. Only visual surveys enumerating mussels at the surface were performed to avoid handling mussels below water temperatures of 16°C. Each survey involved two divers in the water with one person supervising from shore. Four specific known aggregations were surveyed in Okanagan Lake: 1) Dog Beach and 2) Kinsmen Beach in Summerland and 3) Tronson Road boat ramp and 4) Kennedy Lane picnic site in Vernon. Divers recorded GPS coordinates, search area, temperature of lake, duration of search, maximum depth searched, substrate and mussels species observed. Search effort for each site was calculated by multiplying the number of observers by the time spent in hours searching.

QUANTATIVE SURVEYS

Three different quantitative studies (a population assessment, an overwintering study and a mussel density by depth study) were conducted to provide preliminary density and abundance estimates along the shallow littoral zone and to increase understanding of the threats associated with seasonal variation and fluctuation of water levels on Okanagan Lake.

Population Assessment

A two-stage sampling design was used to obtain preliminary estimates of relative abundance and population density of *G. angulata* on Dog Beach, Summerland in Okanagan Lake, 2009. A baseline length of 70 metres was placed parallel to the shoreline with 15 transects placed systematically every five metres starting at zero metres. Most transects were 30m long, except Transects 13 and 14, which were 41 and 59 metres, respectively. Transects were extended due to increased density of *G. angulata* observed at greater depths along those transects. One metre squared (1-m^2) quadrats were used and were continuously flipped end over end to cover the entire length of all transects, thereby maximizing the area surveyed and the number of mussels encountered. Results for the quantitative survey were analyzed using a statistical package in Microsoft Excel. Transect lengths were averaged to calculate the area surveyed, abundance, mean density, an estimate of population total, 95% confidence intervals and survey precision.

Additional biological measurements of *G. angulata* were concurrently recorded during the 2009 quantitative surveys at Dog Beach, Summerland. A 1m x 1m (1-m^2) quadrat was flipped along a 30m transect, placed approximately 30-40m offshore. Measurements of shell length, width, and height were taken using callipers and rounded to the nearest millimetre. Sediment sifting was not conducted to look for small juveniles buried within the sediment.

Overwintering Study

Lake levels in Okanagan Lake fluctuate seasonally and can cause mussels to be susceptible to disturbance, displacement, and predation. A preliminary study was conducted to monitor mussel populations from January to May 2010 occurring in shallow littoral zone and determine the seasonal difference in distribution.

To avoid physiological stress, individual mussels should not be handled below water temperatures of 16°C (between October and May in Okanagan Lake). As an alternative to tagging individuals during the winter months, short pieces of rebar were hammered flush into the sediment and marked with unique numbers on high visibility plastic caps at the surface of the sediment. These markers were used as reference points to enumerate mussels in delineated areas. Fourteen markers were placed in areas where mussels were observed in shallow waters off Dog Beach in Summerland. Care was taken to avoid any harm or disturbance by not placing any markers adjacent to or directly beside individual mussels. The number of mussels within a one-metre radius encircling each marker was enumerated by snorkel divers on January 25, 2010 and May 3, 2010. GPS coordinates, depth and predominant substrate type surrounding each marker was recorded. Due to bad weather conditions, depth was not recorded on May 3, 2010. A depth estimate for May 3, 2010 was extrapolated using the known stage height or mean level of Okanagan Lake on those specific dates. The mean level and temperature of Okanagan Lake is measured daily from Kelowna and can be obtained from the Environment Canada Wateroffice website (www.wateroffice.ec.gc.ca). Mean values of January and May counts at each marker were compared using a two-sample t-test, assuming equal variances in Microsoft Excel.

Density by Depth Study

Quantitative surveys examining the density and distribution of *G. angulata* at various depths along the littoral zone were conducted on October 20 and 21st, 2011. Three sites were chosen to determine the average and mean depth of occurrence along the littoral zone of Okanagan Lake in the Summerland area. For purposes of this study, two study sites were completed within Dog Beach, designated as Dog Beach #1 and Dog Beach #2, at the southern end and northern end of the beach, respectively. Dog Beach runs in a north south direction and has a distinctive point extending approximately 5-10 metres into the lake. The beach was split at the point and study sites were chosen on either side of the point. The southern side or Dog Beach #1 was slightly less exposed and more protected from the winds. A third survey was completed at Kinsmen Beach, Summerland. A two-stage sampling design was used in all three surveys. The baseline for each survey was placed parallel to the shoreline with transects placed systematically every 3m at Dog Beach and every 5m at Kinsmen Beach starting at 0 m. Length of baseline, number and length of transects, maximum depth range searched, and number of quadrats varied for each survey and is summarized in Table 4. A one metre squared (1-m^2) quadrat was used for all surveys to enumerate mussels visible at the surface of the sediment every other metre along all transects starting at 2m. Mussels were not disturbed, handled, or removed from the substrate in order to avoid any physiological stress at cold temperatures. The baseline at Kinsmen beach ran parallel to the majority of the shoreline excluding a small 10-20 metre section where a small embayment was located creating a small shallow pool. To incorporate any mussels located in this shallow pool, quadrats along two transects (transect 5 and 6) began at -2m and -4m from the baseline and the quadrats at three transects (transects 7, 8 and 9) began at 0 m. Therefore, the length of each transect, the maximum depth surveyed and number of quadrats varied for each transect. Quadrats were placed every other metre along transects. Depth was recorded and taken from the southwest corner of each quadrat. Surveys involved a two-person snorkel team to place transects and quadrats and document mussel density. An additional observer was located on shore recording data.

Histograms detailing frequency or number of mussels occupying various depth ranges were created in MS excel. Population estimates for relative abundance and density were also determined using a statistical package in MS Excel. The length of transects were averaged to calculate the total area surveyed, abundance, mean density, an estimate of population total, variance, 95% confidence intervals and survey precision for each survey.

LIFE HISTORY STUDIES

Two separate life history studies documenting the timing of glochidial release and providing preliminary host fish sampling research were conducted to increase the knowledge of the basic biology of the *G. angulata* life cycle including possible environmental triggers for glochidial release and potential fish hosts within the Okanagan Basin.

Timing of Glochidial Release

Snorkel surveys were conducted on Okanagan Lake in Summerland at both Dog Beach and Kinsmen Beach in 2010 and 2011 to observe and record the timing of glochidial release. Surveys started in early June in 2010 and May in 2011 and for both years visual observations continued periodically (every three or four days) into early July.

Reference points (trees) were selected on both Kinsmen beach (GPS start coordinates 49°.599015, -119°.650863) and Dog Beach (GPS start coordinates: 49°.607654, -119°.650722) to survey within and encompassed the main point at Dog Beach. Two or three people snorkelled between the reference points approximately 200m in length in a randomized fashion looking for *G. angulata* conglutinates at the bottom of the substrate. Glochidia were observed as conglutinates, were identified visually, and were left undisturbed. Conglutinate density was recorded as the number of patches or clusters due to their small size (rice like) and practicality of counting each individual conglutinate. Survey efforts were focused within the shallow littoral zone in depths ranging from 0.5m-2.5m. Water temperature data for Okanagan Lake was obtained from the Environment Canada Wateroffice website (www.wateroffice.ec.gc.ca) located at the Kelowna station, near Mission Creek approximately 40km north of Summerland.

Surveys plots were established at the same site to monitor the length of time conglutinates remained on the lakebed in both 2010 and 2011. Permanent plots were established on the lake bottom at depths of 1-2m using rebar markers hammered into the substrate. Plots were visited periodically over the survey period and were visually monitored and photographed. In 2010, two plots (1.5m x 1.5m) were placed at Dog Beach and in 2011 three plots (1m x1m) were placed at Dog Beach and three at Kinsmen Beach. Surveys were conducted during June 7- July 5 in 2010 and during May 13- July 5, 2011.

Individual glochidia contained within conglutinates were collected from Dog Beach in 2010 and examined microscopically by an MoE Aquatic Species at Risk Specialist, Sue Pollard. Microscopic images of glochidia were also reviewed by Mussel Specialist Todd Morris with DFO in order to determine if conglutinates contained mature or immature glochidia.

Preliminary Host Fish Research

During the 2010 timing of glochidial release surveys, additional preliminary host fish research was undertaken at Dog Beach (GPS coordinates: 49°.607357, -119°.649945). Following the guidelines outlined within the host fish protocol created by DFO staff (unpublished) and advice provided by MOE Aquatic Species at Risk Specialist, minnow traps were employed at Dog Beach to capture potential host fish specimens. Specifically, 9 minnow traps were set between 0.5-2 metres of water on June 14^{th} and 15^{th}, 2010. To attract fish wet cat food and sardines were placed in the traps and left overnight. Plastic bottle floats were used to mark and locate traps. Fish collected from traps were placed carefully and directly into plastic zip lock bags to ensure any glochidia remained on gills or within the sample bags. Bags were then placed in a cooler and transported to the local MoE office where they were immediately frozen. Fish captured from the minnow traps were identified and examined for the presence of glochidia in March of 2012. The gills of fish were viewed using a Leica M80 dissecting stereomicroscope at 10-40x magnification.

In order to catch larger sized fish and a wider range of fish species, additional fish collection was completed on June 29, 2010 using a 3-panel gill net. A 50 foot long 3 panel gill net which included 3, 4 and 4.5” nets (net gang) was placed perpendicular to shore of the point at Dog Beach in Summerland. The net was set at 8:30pm and pulled at 11:00pm totalling 2.5 hours of trapping. A two member team used a boat to set and pull the net. As the net was pulled, fish were carefully removed from the net and were placed in plastic bags. Fish were separated by species to eliminate contamination influence of glochidia. Fish were killed in the bags to ensure any glochidia that fell off during euthanization remained in collection bag.

RESULTS

QUALITATIVE SURVEYS

Broad Brush Surveys

During 2008-2011, 114 sites were surveyed for the presence of *G. angulata* in the Columbia, Kootenay, Okanagan, and Similkameen River Basins (Table 3, Table 5, and Figure 5). In total, over 133 hours were spent searching and only 20 sites or 17.5 % of all sites examined were found to support live *G. angulata*. All reported sightings occurred within the Okanagan Basin. Twenty two sites were surveyed in the Kootenay region in 2008, however no *G. angulata* were observed after searching approximately 2.5 km of shoreline for 24.5 person hours. In the Okanagan Basin 89 sites were surveyed from 2008-2011. *G. angulata* were recorded at 20 or 22.5 % of all sites surveyed in the area (Figure 6). A total of 37.1 km of shoreline was searched for over 108.33 person hours in the Okanagan region, and among those 20 sites approximately 1000 *G. angulata* were observed. Two separate surveys covering a small 1000m stretch of the Similkameen River near the US/Canada border and another survey covering a large area (430m x 60m) of the Similkameen River near the town of Keremeos revealed no *G. angulata* however, a number *Margaritifera falcata* were observed.

Sixty percent of all sightings were from Okanagan Lake. These were concentrated on the southwest side of the lake in the Summerland area containing four main apparent aggregations: Crescent Beach, north of the Summerland Boat Launch, Dog Beach, and Kinsmen Beach (Figure 6). A fairly large population was also observed in Vernon on the northeast side of Okanagan Lake within Beachcomber Bay and one live *G. angulata* was detected at Naramata public beach (Manitou Park) on the Southeast side of Okanagan Lake. Approximately 20 individuals were recorded in Okanagan River between the McIntyre Dam and the Highway 97 Bridge upstream of Oliver. A very limited search in Vaseux Lake also yielded three live individuals. No live *G. angulata* were observed in Skaha or Osoyoos lakes in 2009, but a few broken unidentified shells were seen in Skaha Lake. An additional 12 survey sites searching over 17 person hours and 2.7 km of shoreline revealed two locations in Osoyoos Lake in 2010 with two live *G. angulata* individuals. (One live *G. angulata* was observed on the south side of Haynes point in the south basin and the other on the northwest shore of the north basin). Similarly, a further 10.41 person hours searching 1.1km of shoreline of Skaha Lake in 2011 recorded two sites containing live *G. angulata*. A total of 13 live specimens were observed on the eastern shoreline of Skaha Lake on beach access points off Highland Road and East Side road less than 1km apart. A summary of all broad brush surveys are presented in Table 3. Table 5, Figure 5, and Figure 6 and the results of the timed snorkel/swims are provided in Table 6.

When encountered, *G. angulata* were commonly observed in a cobble, sand and silt substrate (Table 6), often wedged between cobbles or buried completely within the sediment with only their siphons exposed. Most mussels were observed close to shore, within 30 m and in shallow water depths ranging from 0.5-1.5m. In addition to a cobble, sand and silt substrate *G. angulata* were also occasionally recorded in muddy, silty substrates and at water depths greater than 7.0m as was the case in Vaseux Lake and 2.4m in Okanagan Lake near Vernon.

Reconnaissance Dive Survey

Of the four sites surveyed by Nautilus Divers in March 2011, live *G. angulata* were observed in only two sites: Kinsmen Beach, Summerland and Kennedy Lane Picnic Site, Vernon beyond 1.5m (1.8m and 2.1-2.4m, respectively) (Table 7). The maximum depth searched ranged from 4.27 to 7.62m and the general search area encompassed the 1.0-3.0m depth range. Temperatures of Okanagan Lake ranged from 4°C in Summerland on March 17, 2011 to 5.5 °C in Vernon on March 18, 2011. No live or dead *G. angulata* were encountered past 2.4m in depth, although dead *G. angulata* shells were observed between 1.8-2.4m at Tronson Rd, boat ramp in Vernon and live Anodontids were also seen at this site at a depth of 6.1m. Dog Beach, Summerland was the largest area surveyed and no *G. angulata* were observed at diving depths. All four sites contained similar substrate types with either a cobble/mud substrate at Kinsmen Beach, and Dog Beach in Summerland or a cobble/sand substrate at both the Vernon sites. *G. angulata* were encountered in both the cobble/sand or cobble/ mud substrate. Details of the sites surveyed including GPS coordinates, total area surveyed, time of search, effort, maximum depth searched, substrate and mussel species observed are provided in Table 7.

QUANTITATIVE SURVEYS

Population Assessment

The quantitative survey conducted at Dog Beach in Summerland surveyed a total area of 2, 343 m^2 with a total population estimate of 1,146± 444 individuals. The mean density estimate of 0.49± 0.19 mussels/m^2 was obtained with an upper confidence interval of 0.68 and a lower confidence interval of 0.30. Upper and lower confidence intervals for estimated density and estimated total populations as well as survey precision are provided in

Table 8. A total of 246 mussels were recorded including six mussels < 60 mm long. Densities per 1m^2 quadrat ranged from zero to as high as 8 mussels per quadrat. The highest densities and most populated area of mussels were located between transects 11-14.

The dominant substrate where the highest densities of mussels were recorded was a combination of cobble, gravel, and sand. In general, substrates varied from 100% soft sediment and sand where few to zero mussels were observed to a mix of cobble, gravel, and sand where most *G. angulata* were located. A dense layer of fine sediment was noticed on all substrates and areas where wave action was greatest the sediment layer was the lightest. Numerous unidentified sculpin species were observed in the area.

Biological measurements of *G. angulata* showed that 95% of all mussels in the survey were large adults greater than 70mm in length, with the majority (28%) of mussels measuring between 81-85mm (Figure 7). Of the 78 mussels sampled only three were less than 60mm in length, two of which were dead. The average length, width, and height of the *G. angulata* specimens were 82, 39, and 29 mm, respectively (Figure 7, Figure 8, and Figure 9). Of note, two of the 1m^2 quadrats recorded 24 and 26 live *G. angulata*, representing the most densely populated quadrats of all quantitative surveys conducted within this study.

Overwintering Study

All mussels encountered were in either a cobble/gravel or a sand/cobble substrate and recorded depths in January were at their lowest level for the duration of the study. Depth at markers varied from 0.61 - 0.94m in January to 0.80-1.13m in May. The total area surveyed for each marker was 3.14m^2 and densities as high as 15.2 mussels/m^2 were observed. The average density for markers was higher in January at 4.25mussels/ m^2 than that observed in May 3.57mussels/ m^2 (Table 9). With the exception of three markers, all markers experienced a decrease in the number of mussels from January to May, with some markers losing as many 10 or 13 mussels or a percentage decrease ranging from -67 and -43%. Overall, the total number of mussels decreased by 30 or 16 % from January to May (n = 187 and n = 157, respectively) (Table 9). However, the average count per marker only decreased by approximately two mussels; 13.4 in January compared to 11.2 in May. A two-tailed two-sample t-test failed to find a significant difference between January and May counts ($t=0.629$, $P > 0.05$) (Table 10).

The stage height of Okanagan Lake increased steadily from 341.470 metres on January 25, 2010 to 341.660 metres on May 3, 2010, with a difference of +0.19m. Lake temperature on January 26, 2010 was 4.95°C and 8.40°C on May 3, 2010. The lowest recorded mean stage height of Okanagan from 2009-2010 occurred in January 2010.

Density by Depth Study

The highest density and overall greatest number of mussels (n=498) was recorded at Dog Beach # 1 on the southern portion of the beach. The frequency of mussels increased as depth increased with the maximum detected occurrence (26% or 129 mussels) observed between 0.81-0.90m followed by a decline in frequency at depths greater than 0.91m (Figure 10). Only one mussel was viewed past 1.30m and 9 mussels were recorded below 0.4m. Fewer mussels and lower densities were observed (n=176) at Dog Beach # 2, at the northern end of the beach. The frequency of mussels at Dog Beach # 2 sharply increased at the 0.51-0.60m depth range with a steady and gradual decline in frequency after 0.60m (Figure 11). The highest number of mussels (n=53 or 30%) was observed between 0.51-0.60m. It should be noted that a large number of mussels were seen outside the surveyed quadrats, approximately 13m from shore at depths between 0.58-0.64m that were not included in our survey. No mussels were recorded past 1.20m and only 5 mussels were seen below 0.40m. Kinsmen beach in Summerland proved challenging due the presence of aquatic plants, reducing visibility at depths greater than 0.70m in some transects. A total of 106 mussels were observed in this survey and the frequency of mussels at depth at Kinsmen Beach (n=106) displayed a very different pattern to what was detected in Dog

Beach #1 and #2. Two peaks were observed at the 0.4 1-0.50m and 0.71-0.80m depth ranges, accounting for a total of 57% or 20% and 37% of all the mussels encountered, respectively (Figure 12). 10 mussels were observed below 0.4m and again due to sampling restrictions and low visibility, no mussels were enumerated past one metre in depth.

Combining all three density by depth surveys (n=780) showed a clear and steady pattern of increasing abundance with increasing depth until 0.71-0.80m (Figure 13). The highest density of mussels (n=343 or 44%) was observed between 0.71- 0.90m and then a sharp decrease in density was noticed after 0.91m in depth. Overall, the highest density or the majority (n=560 or 72%) of mussels occupied the 0.51-0.90m depth range. Relatively few mussels were recorded below 0.50m (n=75 or 9.6%) or above 0.91m (n=145 or 18.6%). The stage height of Okanagan Lake on October 20 and 21, 2011 when this study was conducted was ~ 341.8m and water temperatures of Okanagan Lake ranged between 11 and 14°C.

Population abundance and density estimates including: total area surveyed, upper and lower confidence intervals, as well as, survey precision are summarised in Table 11. The total area surveyed for the two separate Dog Beach surveys were very similar in size with Dog Beach #1 being slightly larger at 1,705m^2 than Dog Beach # 2 at 1,612m^2. Dog Beach #1 on the southern portion of the beach had a much higher mean density (1.77 ±0.30 mussels/ m^2) compared to Dog Beach # 2 on the northern section of the beach (0.65 ± 0.24 mussels/ m^2). Kinsmen beach with a small total area surveyed (874 m^2) had a mean density of 1.16 ± 0.30 mussels/ m^2.The maximum quadrat density was 14 and 15 mussels/m^2 in Dog Beach #1 and Dog Beach # 2, respectively and only 5 mussels/m^2 at Kinsmen Beach. Estimated population totals were highest for Dog Beach #1 at 3,022±518 mussels and both Dog Beach #2 and Kinsmen Beach had similar total population estimates at 1,051± 396 and 1,018±269, respectively, despite the large difference in the total area surveyed 1,612m^2 versus 874 m^2.

LIFE HISTORY STUDIES

Timing of Glochidial Release

Glochidia were released within conglutinates, approximately 1cm long, were oblong in shape, creamy-white in colour and occurred in clusters or patches (Figure 14). Conglutinates were observed at all survey sites in both 2010 and 2011. In 2010, the total number of conglutinate patches counted was 182. Water temperatures ranged from 13-17^{o}C during the survey period. On June 10th, the average daily water temperature reached 15^{o}C for the first time that year. Conglutinates were seen on all survey days with the majority or 100 conglutinate patches observed on June 11th at a water temperature of 15.1°C and 50 observed on June 17th at 15.6°C (Table 12). In 2011, conglutinates were only observed on three of the 13 survey days. The total number of conglutinate patches observed on both Kinsmen Beach and Dog Beach in 2011 was 117. Most conglutinate patches (n=109) were observed at Kinsmen Beach and the remaining few (n=8) were observed at Dog Beach (Table 13). A temperature of 15^{o}C was reached on June 13th while the peak spat was observed at both sites on the following day on 14th of June. It was noted by surveyors that visibility was greatly reduced and posed a problem at Dog Beach on June 14th. Although temperatures at the study site were not recorded on 14th of June, surveyors did note that the water temperature was warmer at Kinsmen Beach than Dog Beach. Water temperatures during survey dates ranged from 8 ^{o} C to 16^{o} C.

The majority of conglutinates were released during water temperatures of 14-16°C in both 2010 and 2011 surveys, with no conglutinates being observed after mid to late June once water temperatures reached 17°C in 2011. The average temperature for the peak counts was 15.39^{o}C with a standard deviation of 0.30. However, when including all dates when conglutinates were observed the average temperature was 15.56^{o}C with a standard deviation of 1.07. Peak temperatures for Okanagan Lake in 2011 reached 22^{o} C in August.

In both years conglutinates did not remain on the bottom between survey dates. The large spat of conglutinates in 2010 was observed on June 11th and when visited again three days later on June 14th, conglutinates were not seen. Similarly, in 2011, a large spat was observed on June 14th and when the site was revisited on June 18th, the conglutinate had disappeared. In 2010 it was recorded on one survey day that conglutinates were observed covered in fine sediment and very difficult to see. While examined microscopically by the Ministry of Environment, conglutinates were believed to contain both mature and immature glochidia (Figure 15). Microscopic images reviewed by DFO mussel specialist, Todd Morris, confirmed that the glochidia observed resembled mature glochidia.

<u>Preliminary Host Fish Research</u>

Minnow traps collected 33 fish from three different genera. 13 Prickly Sculpin (*Cottus asper.*) and one Redside Shiner (*Richardsonius balteatus*) were captured on June 14th and 18 Prickly Sculpin (*Cottus asper*) and one Northern Pikeminnow (*Ptychocheilus oregonensis*) on June 15th. All *Cottus asper* specimens caught were between 2.5 and 9cm in length. The gill net set on June 29th caught five fish from two genera: three suckers (*Catostomus* spp.) and two Northern Pikeminnow *(Ptychocheilus oregonensis). Catostomus* were not identified to species but only two species of sucker are present in Okanagan Lake the Largescale sucker (*Catostomus macrocheilus*) and Longnose sucker (*Catostomus catostomus*) (McPhail 2007). Glochidia were observed on the gills of both the Northern Pikeminnow (*Ptychocheilus oregonensis*) and the Prickly Sculpin (*Cottus asper*) and ranged in size from 0.15-0.4mm. No visible hooks were observed.

DISCUSSION

Freshwater mussels or unionids are considered one of the most endangered groups of organisms in North America (Williams et al. 1993; Lydeard et al. 2004; Strayer et al. 2004). Mussels in Canada are highly imperilled, with over 50% of species identified as potentially at risk (Metcalfe-Smith and Cudmore-Vokey 2004). This drastic decline in freshwater mussels has been linked to a number of anthropogenic effects such as habitat loss, habitat degradation (pollution and sedimentation) habitat modification, through excessive damming of waterways, and the introduction of exotic species (e.g., zebra mussels) (Williams et al. 1993, Bogan 1993, Lydeard et al. 2004). Continued loss and degradation of habitat due to past and current foreshore/riparian development, historic riverbed channelization and hydrograph modification through creation of dams and weirs within the Okanagan Basin have been identified as predominant threats facing *G. angulata* in addition to the potentially devastating impacts of introduced species such as zebra and quagga mussels (COSEWIC 2010, DFO 2010).

Specific information on the biology, ecology, abundance, and distribution of *G. angulata* within BC is limited and/or non-existent. Until recently, little work has been done locating these mussels and determining their exact range and abundance. No information is available on the sampling methodology and search effort prior to surveys conducted in 2005. Therefore, with the limited amount of recent or historical data it is difficult to establish current population trends. Research completed for this report such as refining existing protocols for qualitative and quantitative surveys, documenting the current distribution, providing preliminary population abundance and density estimates and preliminary investigations into life history characteristics all work towards addressing some of the objectives, knowledge gaps and suggested research activities identified within the Management Plan and RPA for *G. angulata* (DFO 2010, 2011).

QUALATATIVE SURVEYS

Broad Brush Surveys

G. angulata was detected in 20 of the 114 sites sampled during this study or 17.5% of all sites examined. All observations were recorded within the Okanagan Basin and none were documented from the Kootenay or Similkameen Basins. Previous surveys conducted by both the BC MoE from 2005-2008 (not included in our results; see Table 2) and DFO in 2008 (included within this report) focussed on the Kootenay region. Despite a combined search effort of over 96 person hours and 52 km of shoreline searching at 100 sites, no *G. angulata* have been recorded from this region. There remains a possibility that *G. angulata* never did occur in the Kootenay region or have become locally extirpated. The single historic record is somewhat suspect; the exact date and collection location of this specimen was left unrecorded and the museum specimen has never been located and was only briefly mentioned by Clarke (1981) (COSEWIC 2010). Similarly, a single specimen labelled “Vancouver Island” dated 1890 has not been verified by historic or recent search efforts (COSEWIC 2010) (Table 2).

The majority of *G. angulata* sightings were observed on Okanagan Lake, from Crescent Beach to just South of Kinsmen Beach, in Summerland, occupying a linear distance of 3160m x 30m of the littoral zone with an estimated area of approximately 94,890 m^2 or 0.095 km^2. The four notable aggregations (Crescent Beach, north of Summerland Boat Launch, Dog Beach and Kinsmen Beach) are likely all part of the same population, given their close proximity and what little is known of the larval dispersal mechanisms. Further research including genetic testing would be required to conclusively determine if these aggregations are all part of a single continuous population. Another large population is located in northeast Okanagan Lake in Beachcomber Bay, Vernon. Few mussels were located outside of Okanagan Lake with small and often sporadic aggregations observed in Okanagan River, Vaseux Lake and Skaha Lake as well as two individual specimens in Osoyoos Lake. The current confirmed range of *G. angulata* in Canada is exclusively in the Okanagan River watershed with the northernmost live record from Okanagan Lake in Vernon and the southernmost live record from Osoyoos Lake.

Surveys conducted during the summer months of 2008 and 2009 revealed no new populations or locations with *G. angulata.* Some sites where empty shells were once recorded in both Osoyoos (1990) and Skaha Lakes (from 1991-2006) did not present any evidence of *G. angulata* shells either dead or alive. Therefore, these survey efforts would suggest that their current range may have decreased from previous years. However, further search efforts consisting of an additional 28 person hours exploring over 3.8km of shoreline concentrated on Skaha and Osoyoos Lakes in 2010 and 2011 revealed four sites with live *G. angulata* specimens. A small aggregation of 13 live *G. angulata* on the eastern shore of Skaha Lake, one individual from the North Basin and one individual from Haynes Point in the South Basin of Osoyoos Lake were observed. Prior to 2010, surveys in 2008 and 2009 only spent 1.95 and 2.86 person hours on a number of different sites on Osoyoos and Skaha Lakes, respectively. Metcalfe-Smith et al. (2000) found that sampling effort of timed search surveys can significantly affect the ability to detect rare species and that 4.5 person hours/site or more may be required to detect rare or endangered species.

Further work is needed to refine existing qualitative survey protocols and could include standardizing the time allotted or search effort for each site or location surveyed. For example, as mentioned above, 4.5 hours/site could be used as the minimum amount of search effort required to obtain a negative result or conclude that no mussels are present at a specific site. Survey effort is often wasted re-surveying the same sites year after year and could be avoided if this approach was applied. Qualitative surveys should be designed to maximize the chances of detecting target species (Mackie et al. 2008) Therefore, surveys should focus efforts in: 1). favourable habitats and/or preferred substrates, 2) the appropriate seasons, between June and September when water temperatures exceed 16°C and when mussels are more visible on the surface of the substrate. Finally, GPS coordinates and area surveyed should always be recorded. In addition, surveys should adopt a standardized method of surveying the shoreline such as each surveyor being assigned a particular area or depth range and searching in a zig-zag rather than randomized fashion in order to avoid overlap.

Timed snorkel searches and boat searches were tested as a qualitative method for sampling *G. angulata* populations within the Okanagan River Basin. Searching the lake shoreline utilizing a boat that is able to manoeuvre in shallow waters was a great new tool used in 2009 to search for the presence of freshwater mussels, however good water clarity or visibility is required, and often a narrow depth range or portion of the shoreline is searched possibly resulting in overlooked or missed populations. Despite this drawback, boat searches still provide a fairly quick and easy way to locate and target *G. angulata* populations over a broad geographic range allowing for greater search distances along lake shorelines. Qualitative sampling methods such as timed snorkel, SCUBA, and wading are recommended and are considered more efficient than quantitative surveys at detecting rare or endangered species, especially when trying to determine distributional patterns of a particular species (Obermeyer 1998, Metcalfe-Smith et al. 2000). Although qualitative sampling cannot provide population density estimates, they are useful for identifying mussel beds and potential sites for quantitative surveys and the subsequent long term monitoring of populations over time. A study by Villella and Smith (2005) categorized low and high density sites based on the number of mussels observed during timed searches of one person hour, either <30 mussels/p-h or >30 mussels/p-h, respectively. Distinguishing a priori which areas are considered high or low density might be a useful tool to determine which sites should be examined quantitatively to monitor population abundance and density. Under these criteria, timed snorkel searches already completed in our qualitative surveys, would indicate that the Summerland aggregations and Beachcomber Bay in Vernon would be considered high density and could be used as potential future index sites to monitor *G. angulata* populations over time.

Attempts to venture into deeper depths in Okanagan Lake utilizing a submersible video camera in 2008 and limited snorkelling in 2009 to document the presence of *G. angulata* proved to be ineffective for conclusively detecting live mussels. Mussels at depths greater than 1.5m are difficult to detect due to visibility and depth constraints of snorkelers. In spite of challenges with detecting mussels deeper than 1.5m in the Okanagan Basin, *G. angulata* specimens have been observed at depths of ~7.5 metres in Vaseux Lake and ~2.4m Okanagan Lake, Vernon. In addition, a large aggregation of 150 individuals was observed at Dog Beach in Summerland during a timed search in a shallow (~1m) cobble and boulder habitat approximately 30 metres offshore. Highlighting the need for more quantitative and qualitative broad brush surveys exploring greater distances offshore and depth ranges where substrate conditions seem suitable and in areas where mussels are known to occur.

<u>Reconnaissance Dive Survey</u>

Surveys conducted both at greater distances from the shoreline and at deeper depths used SCUBA divers to provide a better estimate of distributional patterns within Okanagan Lake. However, preliminary reconnaissance dive surveys conducted at Summerland and Vernon in 2011 ventured into deeper depths between 1-7.5 metres by SCUBA, but did not detect any live *G. angulata* populations past 2.5 metres in depth. Hence, *G. angulata* may be limited to more shallow areas within Okanagan Lake. Conversely, it should be noted that SCUBA surveys were conducted in late winter when lake temperatures were below 6°C. Therefore, population numbers may have been severely underestimated or may be highly biased towards non detection due to cold water temperatures as mussels may have burrowed beneath the sediment and were not present at the surface. Future dive surveys should be conducted during the summer months when water temperatures exceed 16 °C (Mackie et al. 2008).
Freshwater mussels are generally thought to occupy shallow waters less than 2-3 metres in depth however, very little is known about their actual depth range and the factors that

determine or limit their depth distribution in lakes (Cyr 2008). *G. angulata* have been encountered at depths of 10 metres from the Little Granite Reservoir in Washington and approximately 20m from the lower Columbia River in Washington and Oregon (COSEWIC 2003). Future dive surveys could focus on Vaseux Lake where mussels have been observed at depth (S. Pollard and D. Biffard pers.comm.). Furthermore, most qualitative surveys have focussed on lake habitats with few surveys being conducted on rivers and creeks within the Okanagan Basin. Given that most *G. angulata* populations are observed in creeks and rivers in the United States, more riverine habitats need to be surveyed for *G. angulata* populations in BC.

QUANTITATIVE SURVEYS

Population Assessment

The quantitative survey using a two stage sampling design provided some preliminary estimates on abundance and density of *G. angulata* at Dog Beach, Summerland. The quadrat mean or density was low with an average of 0.49 mussels/ m^2. The calculated survey precision was 38.7%; generally, a survey precision of 30% is considered acceptable (T. Norgard pers.comm.). Future surveys should attempt to accurately define the bed area, add more transects or increase the number of samples to increase survey precision and confidence in the analysis. At 1,146 individuals, Dog Beach, Summerland currently supports the largest identified population of *G. angulata* in southern BC and should become a useful site for future long term monitoring.

When comparing our results to similar quantitative studies conducted in the US, *G. angulata* exhibited low population densities at Dog Beach in Summerland with a mean density of 0.49 mussels/m^2. In Washington State individual mussels were observed at densities as low as 0.04/m^2 in the Lower Granite Reservoir and as high 16.0 mussels /m^2 in the Okanogan River. (T.J. Frest, unpublished data, as cited in COSEWIC 2010). Densities in the Salmon River Canyon, Idaho ranged from 5.5 to 183 mussels/m^2, depending on the composition of the substrate) (Vannote and Minshall 1982). High density mussel beds with ~ 575mussles/m^2 were also observed in the Middle Fork John Day River in Oregon (Brim Box et al. 2003).

Similar to the biological measurement survey, almost all *G. angulata* in the quantitative survey (both conducted at Dog Beach, Summerland) were large adults >70mm long and between the two surveys only seven mussels < 60mm were observed. Juvenile mussels are generally defined as mussels that have not yet reached sexual maturity (Neves and Widlak 1987). In the absence of life history characteristics for this species on both the age of sexual maturity and the exact lifespan of *G. angulata,* it would be difficult to categorize what would be considered a juvenile mussel. Reported maximum ages for *G. angulata* have varied from 24 to 60 years by Vannote and Minshall (1982), Frest and Johannes (2006), respectively. COSEWIC (2003) states that *G. angulata* may reach sexually maturity by three years of age however, this is only speculative and most freshwater mussels are thought to reach maturity between 6-12 years of age (McMahon 1991).

Juvenile freshwater mussels are thought to remain buried in the sediment for a few years before emerging to the surface (Strayer et al. 2004) and are small, transparent and non-calcareous (soft) making them extremely difficult to detect. Juvenile mussels were observed leaving trails or signs of horizontal movement and were buried under approximately 5cm of sand in the shallow littoral zone of Okanagan lake at Dog Beach, Summerland in 2009. (L. Stanton pers. obs.). A varied range of size classes could provide evidence of recent reproduction and successful recruitment; whereas size classes skewed towards larger and older animals might suggest poor recruitment (Morris and Edwards 2007, Morris et al. 2007). Shell lengths from the biological measurement in this survey recorded very few small or young mussels and a preponderance of large, older individuals. However, it should be noted that substrate shifting to detect for small juveniles (generally less than 30mm long) was not conducted in these quantitative surveys.

The life history characteristics of unionids such as high adult survivorship, low juvenile survivorship, and long life spans may explain the observed predominance of large adult mussels in natural populations (Negus 1966, Bauer 1983, James 1985). However, the absence of juveniles may also indicate a relict or aging population that could be considered functionally extinct or may represent an "extinction debt" (Tilman et al. 1994), where populations have either ceased reproducing altogether or are exhibiting poor recruitment (Bogan 1993, Cosgrove et al. 2000, Strayer et al. 2004). Successful recruitment may be a limiting factor inhibiting recovery, as many unionid populations are known to persist for long periods with negative population growth (Strayer et al. 2004). Evidence to support the existence of non-reproducing populations or populations that are considered not currently viable or functionally extinct include the presence of dead shell and no live mussels, historical populations with no live records in over 10 years, and areas where live adults but no juveniles are observed (Cosgrove et al. 2000). Future quantitative surveys should incorporate substrate sifting or sieving to detect for the presence of juveniles to confirm and increase our understanding of recruitment within the Okanagan Basin.

Overwintering Study

The overwintering study provided some preliminary information regarding seasonal mussel movement and the potential impacts of water level fluctuations within Okanagan Lake. Despite a slight decrease in the number of *G. angulata* encountered in May compared January, this difference was not found to be significant. Visibility was poor during the May count due to stormy weather conditions and the presence of algae on the surface of the substrate, making it difficult to accurately enumerate the number of *G. angulata* present.

Freshwater mussels have evolved a number of behavioural and physiological mechanisms to avoid or tolerate periods of emersion. In general thin-shelled species are less emersion tolerant than thick-shelled species (Byrne and McMahon 1994). *G. angulata* with its thick shell is probably much more able to withstand periods of dewatering and desiccation than thin-shelled species such as the sympatric Anodontids. Some unionids such as *Elliptio complanata* will undergo horizontal movement during spring and summer months prior to spawning (Amyot and Downing 1997), but it is unknown if *G. angulata* exhibits this behaviour or is capable of any substantial horizontal movement. However, the observation of a large foot extruding from the valves and grasping on large substrates indicates movement within the substrate is possible (R. Lauzier pers. obs.) Low visibility and horizontal movement of mussels to adjacent areas may explain the decrease in the number of mussels observed from January to May, however we cannot discount the possibility of increased mortality due to predation or freezing. The lowest average recorded stage height of Okanagan Lake from 2009-2010 was observed during the month of January 2010 at ~341.465m. The stage height of Okanagan Lake from January to May 2010 increased steadily, thereby minimizing these mussels to any further threats of desiccation and physiological disturbances during the study period.

Although not apparent from the numbers observed in the results, some freshwater mussels will also burrow deeper into the substrate during fall and winter emerging to the surface in the spring, resulting in lower than expected surface counts during colder periods when water temperatures are below 16°C (Balfour and Smock 1995, Amyot and Downing 1997, Mackie et al. 2008, Martel et al. 2010). Seasonal burrowing is thought to protect freshwater mussels from the effects of emersion, low temperatures, and freezing in shallow waters and can provide protection against predation, displacement from spring floods or wave action during storms (Negus 1966, Hinch et al. 1989, Amyot and Downing 1997). It is unknown whether *G. angulata* display this seasonal burrowing behaviour but, *G. angulata* are often encountered completely buried within the substrate and should be considered fully capable of vertical movement. For example, Vannote and Minshall (1982) witnessed vertical migration of *G. angulata* (5cm/hr at 20°C) in response to varying rates of sedimentation in a controlled laboratory experiment.

In order to quantify threats of fluctuating water levels and determine the extent to which exposure to emersion, cold and freezing increases the risk of physiological disturbance, predation, or mortality in *G. angulata* populations the survey design would need to be improved considerably. Future surveys could be designed to tag individual mussels and/or count the number of dead shells throughout the survey in relation to water level fluctuations to provide a rough estimate of mortality rates and a possible correlation between the number of dead shells observed and water levels (Burlakova and Karatayev 2007).

Density by Depth Study

The main objective of the density by depth study was to determine if *G. angulata* are at an increased risk to periods of dewatering and emersion as a result of decisions made by the Okanagan Watershed fish and water management tools (FWMT) system. Therefore, results from these surveys will be incorporated into the FWMT model in order to reduce uncertainties and will allow water managers to be aware of potential consequences and risks of reducing water levels to endangered *G. angulata* populations. For more detailed information and specific details of the water management practises please refer to the

Canadian Okanagan Basin Technical Working Group website (www.obtwg.ca) or Hyatt and Bull (2007).

Preliminary results from the three combined density by depth surveys indicate that a large proportion (72%) of mussels occupy a narrow 0.4m depth range within Okanagan Lake at Summerland between 0.51-0.90m. Given that freshwater mussels have limited mobility, lake drawdowns of ≤ 0.5m could leave 9.6% of surveyed individuals at risk of increased mortality caused by desiccation and/or predation and drawdowns ≤ 0.9m could leave an astonishing 81% of mussels at risk. It is well documented that desiccation can lead to high mortality of unionids (Fuller 1974, Strayer 1983, Miller et al. 1984). More recently, Burlakova and Karatayev (2007) found that dramatic decreases in water level due to regulated lake drawdowns or periods of drought were a major cause of unionid mortality, through increased predation.

Regulated drawdowns in the Okanagan watershed occur between mid-October and end of February and are normally reduced by approximately 0.35m. This would put approximately 3% of the overall surveyed population in Summerland at risk of desiccation or predation during the winter months when mussels exhibit decreased metabolism and limited ability for movement. However, it is important to note that *G. angulata* inhabit shallower depths in certain areas and may be more susceptible to even small decreases in lake levels. For example, regulated drawdowns of 0.35m may put greater than 10% of the Kinsmen population at risk. The stage height of Okanagan Lake is generally the lowest in the winter months of December and January and peaks in June and July. Annual fluctuations in lake levels can vary from ±0.5m in 2009 to ± 0.9m in 2010. In periods of drought or years with little rainfall within the Okanagan, lake levels may drop significantly stranding a larger proportion of mussels for prolonged periods. Again, it should be noted that density by depth surveys were conducted in October at lake temperatures between 11-14°C. Therefore, due to colder temperatures these surveys may have underestimated density as mussel may have already undergone seasonal burrowing, potentially leaving many mussels undetectable at the surface of the substrate.

Another important consideration with respect to the fish and water management tools system (FWMTS) are the regulated flow regimes of Okanagan River. Preferred flows for sockeye salmon are provided in Hyatt and Bull (2007) and are adjusted to prevent desiccation of salmon eggs at low flows and reduce redd scour mortality at high flows. High flows (> 9.3 $m^3.sec^{-1}$) within the Okanagan River during periods of spawning, glochidial release or juvenile excystment may adversely affect *G. angulata* reproductive potential and may be a major factor limiting mussel recruitment (Layzer and Madison 2006, Spring Rivers 2007). Flow regulation during periods of glochidial release may desynchronize timing and potential interaction with potential fish hosts (Spring Rivers 2007). Water flows can be increased during the summer to levels as high as 37 $m^3.sec^{-1}$ to reduce the risk of flooding in Okanagan Lake as was the case in late June 2005 (Hyatt and Bull 2007). It is unknown exactly when *G. angulata* juveniles are released from their fish hosts within the Okanagan basin but, high water velocities during this time can displace settling juveniles (Holland-Bartels 1990, Layzer and Madison 2006) resulting in increased mortality and reducing successful recruitment of juveniles within Okanagan

River. Spring Rivers (2007) recommend that pulsed flows in Pit River, California should be limited or avoided during periods of glochidial release and encystment from April to August.

Live *G. angulata* within the Okanagan River watershed were observed in a diverse range of substrate types but were most abundant in cobble, gravel, and sand. The highest density of mussels was recorded in southern areas of Summerland (Kinsmen Beach and Dog Beach #1) where the predominant substrate was a mix of cobble, gravel, sand, and boulder. Fewer mussels were observed in soft sand substrates that dominated areas such as Dog Beach # 2 and Crescent Beach. Mussels at exposed sites may favour or cluster around cobbles and boulders which may provide protection from wave action. Exceptions include Vaseux Lake and Okanagan Lake near Vernon where specimens were recorded in muddy sand substrate at depths of ~ 7.5m and 2.4m, respectively. Similar to studies conducted in BC, Spring Rivers (2007) viewed *G. angulata* tightly wedged between boulders, cracks of bedrock or deeply burrowed in sand or silt. Vannote and Minshall (1982) suggested that *G. angulata* preferred sand and gravel substrates and may be more tolerant to the effects of sedimentation than *M. falcata*, perhaps making them more pollution tolerant than other unionids (Frest and Johannes 1995). Conversely, COSEWIC 2003 reports that this species has a reduced tolerance to nutrient loading, siltation and low flow; however, this remains to be confirmed within the Okanagan Basin. In general, it is thought that most freshwater mussels including *G. angulata* prefer areas that exhibit stable habitat conditions avoiding areas with shifting substrates, extreme water or oxygen fluctuations, and high turbidity (COSEWIC 2003, Strayer 2008).

All three density by depth surveys (Dog Beach #1, Dog Beach #2, and Kinsmen Beach) provided preliminary quantitative estimates of population abundance and density of *G. angulata* in Summerland. According to this most recent survey, Dog Beach currently supports over 4,000 individuals and Kinsmen Beach approximately 1,000 individuals. Survey precision values were generally high in areas exhibiting higher densities, such as Dog Beach #1 and Kinsmen Beach. Lower density sites such as Dog Beach #2 with scattered and sparse *G. angulata* populations will require more quadrats to achieve better precision and more accurate estimates of population abundance. The largest estimated population of *G. angulata*, with the highest observed densities (1.77mussels/m^2) occupies the southern section of Dog Beach in Summerland. It is unclear why this particular area is able to support a relatively larger aggregation of *G. angulata* compared to other adjacent areas such as Dog Beach #1 (0.65 mussels/ m^2) and Kinsmen Beach (1.16 mussels/ m^2). Although habitat descriptions such as substrate type or sediment size along with current speed, water depth and distance from shore are commonly thought to limit unionid populations these factors are usually ineffective at predicting the abundance and occurrence of mussels (Strayer 2008 and references therein). Instead, Strayer (2008) suggests considering what a mussel requires from its habitat or the “functional characteristics of suitable mussel habitat.” Furthermore, it is apparent that availability of suitable fish hosts is likely an extremely important factor limiting the distribution of mussel populations.

The quantitative survey in 2009 was completed in the same general location as the Dog Beach #2, 2011 density by depth survey. The Dog Beach #2 (2011) density by depth survey covered a much smaller area (1,612m^2 compared to 2,343m^2) than the original 2009 survey, therefore direct comparisons would be difficult to make. Despite the difference in total area surveyed, Dog Beach #2 (2011) had a slightly higher density 0.65 individuals/m^2 compared to 0.49 individuals/m^2 for the original 2009 survey and both surveys resulted in similar estimate of total population size 1,051 and 1,146, respectively. Given these results, it seems this population has remained stable over the past two years and it would be difficult to conclude that a reduction or an increase in population size has occurred in this area. However, it is imperative that index sites are identified so populations can monitored over time for any changes in population abundance and density.

It is important to note that although higher densities of G. *angulata* were observed in Summerland during the density by depth surveys in 2011 compared to the quantitative survey performed in 2009, densities less than 1-2 mussels/m^2 could still be considered fairly low. *G. angulata* densities have been observed higher densities within their American Range from 5.5 mussels/ m^2 to183 mussels/ m^2 in Idaho (Vannote and Minshall 1982) and in extremely dense beds with ~ 575 mussels/ m^2 in Oregon (Brim Box et al. 2003)(See discussion on densities above). In addition, reproductive success may be poor when large distances between populations and individuals are observed and when densities are less than 1mussel/m^2 (Martel et al. 2010).

LIFE HISTORY STUDIES

<u>Timing of Glochidial Release</u>

Based on the data collected, temperature is likely a key factor contributing to or signalling the timing of glochidial release. The largest spat of conglutinates seemed to be released once water temperatures exceeded 15^{o}C. A number of studies have shown the relationship between glochidial release and temperature (Österling at al. 2008, Hastie and Young 2003) and numerous mussel species are thought to release glochidia in response to increasing water temperatures (Neves and Widlak 1988). Nevertheless, other factors may contribute to the timing of glochidial release and have not been considered in this study. Further data collection over more years will allow for more conclusions and may confirm a correlation between temperature and the timing of glochidial release.

G. angulata is considered a short-term brooder (tachytictic) where spawning begins in spring and hookless glochidia are released during the same season in the summer months (Spring Rivers 2007). The Spring Rivers (2007) study conducted in northeastern California, spawning was observed to begin in spring when water temperatures exceeded 10-12°C which occurred in late March in northeastern California. These temperatures would not be expected to be reached until May in Okanagan Lake, potentially delaying the reproductive timing of *G. angulata* by approximately one month in Canadian populations. Gravid females were observed in California from early April to mid-July and glochidia were observed on host fish from late March to late July/early August with juveniles dropping off hosts in June and July. Gravid periods in Pit River, California were shown to end soon after a peak in water temperatures in mid-July however, the peak in water temperature of Okanagan Lake occurred in mid-August in 2010 and late august in 2011. The gravid periods for females were not examined in this study and observations for the presence of conglutinates were completed prior to the peak in water temperatures in Okanagan Lake. Therefore, it is unknown if *G. angulata* continue to release glochidia throughout July and August. Periods of encystment and excystment for *G. angulata* have not been examined in BC.

Glochidia will only survive a limited period of time (generally a few hours to days) before they must find and successfully attach to a suitable fish host (Neves and Widlak 1988, O'Brien and Williams 2002).Conglutinates observed on Okanagan Lake were fragile and disintegrated easily with limited disturbance and wave action (L. Nield pers.obs.). Further studies need to confirm if glochidia are free floating in the water column once disturbed and determine if exposure to host fish and encystment has occurred before the full implications of habitat alterations or disturbance can be understood during *G. angulata* reproduction in spring and early summer.

G. angulata conglutinates have not been observed in other populations within the US and are generally thought to release free glochidia. Puerile conglutinates, or immature eggs released prematurely due to stress, have been documented in *G. angulata* (Barnhart et al. 2008), and may explain what was seen in Okanagan Lake. However, microscopic examination of individual glochidia contained within released *G. angulata* conglutinates from Summerland, BC have been confirmed to contain mature glochidia. Given that *G. angulata* commonly inhabit flowing rivers in the U.S and that conglutinates in Okanagan Lake were observed to disintegrate quickly with minimal disturbance, may explain why conglutinates have not been observed elsewhere across their range. Another possibility is that what is being observed are not true conglutinates but are simply a mass of glochidia similar to what is seen in *Lampsilis fasciola* (T. Morris pers. comm.).

Preliminary Host Fish Research

Fish species observed concurrent with glochidial release at Dog Beach include Prickly Sculpin (*Cottus asper*.), suckers (*Catostomus* spp.), Northern Pikeminnow (*Ptychocheilus oregonensis*), and Redside Shiner (*Richardsonius balteatus*). Although not all captured fish were examined for the presence of glochidia, these results provide correlative information on the species present in the area during glochidial release that could serve as potential fish hosts for *G. angulata* within Okanagan Lake. Fish infected with *G. angulata* glochidia can only be identified as potential and/or unconfirmed fish hosts. Confirmed fish hosts must be verified in a laboratory setting once successful metamorphosis of glochidia on the host fish has occurred resulting in a juvenile mussel.

The glochidia of *G. angulata* can be distinguished from *Anodonta* species found in Okanagan Lake and that of *Margaritifera falcata* found in Okanagan River based on size and shape. Anodontids have relatively large triangular glochidia (shell lengths between 0.2-0.4mm) with ventral shell hooks allowing them to attach to the fins or gills of their hosts (Spring Rivers 2007, Brim Box et al. 2003, Kat 1984, Heard 1974). *G. angulata* have smaller white (average shell length ~ 0.15mm) unhooked glochidia that attach to the hosts gills (Spring Rivers 2007, Brim Box et al. 2003, Kat 1984). *Margaritifera falcata* also have unhooked but extremely small glochidia with shell lengths averaging ~0.057mm (Spring Rivers, 2007).

Glochidia were observed on the gills of *Cottus asper* and *Ptychocheilus oregonensis*. However, due to the larger sizes of some glochidia observed it was unclear if glochidia belonged to *G. angulata* or an *Anodonta* species. Given that no prominent hooks were observed and that Anodontine unionids are not known to inhabit the general Dog Beach vicinity, that spawning generally occurs in fall/spring and glochidia preferentially attach to fish fins as opposed to gills (Martel and Lauzon-Guay 2005) it is possible that the glochidia observed do possibly belong to *G. angulata.* Therefore, potential unconfirmed fish hosts for hosts for *G. angulata* include the Prickly Sculpin (*Cottus asper)* and Redside Shiner (*Ptychocheilus oregonensis).*

A number of fish species have been identified and confirmed as hosts within the Pit River Drainage in northeastern California and include: Pit Sculpin (*Cottus pitensis*), Tule Perch (*Hysterocarpus traski*), and Hardhead (*Mylopharodon conocephalus*)(Spring Rivers 2007), however these species are absent from the Okanagan Basin. Unconfirmed fish species in California include Sacramento Pikeminnow (*Ptychocheilus grandis*), Pit Roach (*Lavinia symmetricus mitrulus*), Rainbow Trout (*Oncorhynchus mykiss*), Green Sunfish (*Lepomis cyanellus*), Black Crappie (*Pomoxis nigromaculatus*) and Mosquitofish (*Gambusia affinis*) (Spring Rivers 2007). Of these species only the Black Crappie (*Pomoxis nigromaculatus*) and Rainbow Trout (*Oncorhynchus mykiss*) occur in the Okanagan basin and may also serve as fish hosts within the Okanagan Basin.

The decline, displacement, or loss of natural fish populations may adversely affect freshwater mussel populations including *G. angulata* by limiting or changing their dispersal patterns, chances of recruitment, reproductive success, and overall fecundity. The knowledge of *G. angulata* glochidia fish hosts would greatly enhance conservation programs for this species as well as providing important information on the potential distribution of these mussels within the Okanagan Basin. Detailed knowledge of fish hosts is key to determining limiting factors to recruitment as well as providing important information for the enhancement, protection and restoration *G. angulata* and their habitat. Future research should concentrate on confirming fish host species and confirming periods of glochidial encystment and excystment.

CONCLUSION

The exploratory surveys outlined in this report together with documented occurrence records prior to 2008 housed by the BC Conservation Data Centre documents the most current confirmed distribution of *G. angulata* within BC. Quantitative surveys included within this report provide a preliminary estimate of abundance at what may be the largest known population of *G. angulata* in Canada. Due to a lack of historical data documenting the distribution and abundance of *G. angulata,* it is not possible to evaluate current population trends, however these exploratory surveys together with evidence from current trends in the US indicates their range and population numbers may have decreased from previous years. Given that, in Canada, *G. angulata* is a species at the northern edge of its range, its sporadic distribution and the very few individuals observed outside of Okanagan Lake, this species most likely represents a declining or relict population at risk of extirpation within the Okanagan Basin. Future work is needed to verify the persistence, document the current population trends and abundance, and determine if recruitment is occurring in areas such as Skaha Lake, Osoyoos Lake, Okanagan River, and Park Rill Creek.

Standardized protocols for long term assessment and monitoring are required which should include annual quantitative relative abundance estimates at designated index sites, periodic assessment of recruitment and periodic qualitative or exploratory surveys at previously observed or historic sites as outlined in the RPA for Rocky Mountain ridged mussel *(Gonidea angulata)* (DFO 2011). Although threats have been identified by the Management Plan (DFO 2010), further studies need to be conducted on the biology of these mussels and confirm suitable fish hosts which may provide important clues to issues surrounding distribution, critical habitat, and factors limiting abundant populations. The RPA suggested to reduce the risk of extirpation the following biological information is required for a successful management plan: confirmation of host fish and evaluation of glochidial dispersal, determine minimum viable population size, assessment of predator pressure and sources of mortality and finally assessment of microhabitat features that support *G. angulata*. Confirmation of the current distribution of *G. angulata* and the monitoring of population trends are critical components to managing an endangered species, thereby identifying populations at risk of extirpation. Confirming the location and distribution of *G. angulata* will facilitate long term monitoring necessary to assess recruitment, growth, and better understand the population dynamics, biology, and ecology of this species.

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Table 1. Historical records of *Gonidea angulata* (1906-2002) (COSEWIC 2010).

Collection Date	Location	Specimens live or dead	Collector	Museum	Museum Collection No.	Source
1906-03	Penticton; Okanagan River	unknown (2 empty shells but fairly fresh)	G.E. Winkler	Canadian Museum of Nature	CMNML 093118	Canadian Biodiversity Information Facility 2005; Gagnon pers.comm. 2005
1991-08-09	Penticton; Skaha Lake	unknown; (the 2 specimens are shells)	D.W. Taylor	Royal British Columbia Museum	RBCM 993-00004-003	Sendall pers. comm. 2008
1960-08-19	Okanagan Falls	empty old shells	R.J. Drake	Canadian Museum of Nature	CMNML 016017	Canadian Biodiversity Information Facility 2005; Gagnon pers.comm. 2005
1960-08-20	Okanagan Falls	empty old shells	R.J. Drake	Canadian Museum of Nature	CMNML 009683	Canadian Biodiversity Information Facility 2005; Gagnon pers.comm. 2005
1963-06-12	Okanagan River, Okanagan Falls	unknown if collected live or dead	D.W. Taylor	Smithsonian National Museum of Natural History	NMNH 652845	NMNH 2009
1972-08-06	Vaseux Lake	4 live	A.H Clarke, B.T. Kidd	Canadian Museum of Nature	CMNML 067553	Clarke 1981; Canadian Biodiversity Information Facility 2005; Gagnon pers. comm.2005
2002-08-02	Park Rill Creek	½ a shell	Osoyoos Lake Water Quality Society			COSEWIC 2003
1983-10-04	Half way between Oliver and Osoyoos Lake entrance	3 live	T. Tuominen, S.Yee	Canadian Museum of Nature	CMNML 086690	Canadian Biodiversity Information Facility 2005; Gagnon pers.comm. 2005
1982-10-27	Half way between Oliver and Osoyoos Lake entrance	1 live	T. Tuominen, S.Yee	Canadian Museum of Nature	CMNML 086691	Canadian Biodiversity Information Facility 2005; Gagnon pers.comm. 2005

Table 1. continued.

Collection Date	Location	Specimens live or dead	Collector	Museum	Museum Collection No.	Source
1982-10-28	Okanagan River	1 live	T. Tuominen, S.Yee	Canadian Museum of Nature	CMNML 086692	Canadian Biodiversity Information Facility 2005; Gagnon pers.comm. 2005
1983-10-04	Okanagan River	3 live	T. Tuominen, S.Yee	Canadian Museum of Nature	CMNML 086693	Canadian Biodiversity Information Facility 2005; Gagnon pers.comm. 2005
1990-08-16	Osoyoos Lake North side of Haynes Point	2 shells (?)	D.W. Taylor	Royal British Columbia Museum	RBCM 993-00003-002	Sendall pers. comm. 2008
unknown	Kootenay River	unknown	unknown			Clarke, 1981
1890’s	Vancouver Island	unknown	From the Rush collection	University of Michigan Museum of Zoology	107902	Appleton pers. comm. 2008

Table 2. Recent search effort conducted by the British Columbia Ministry of Environment targeting *Gonidea angulata* (2005-2008). (COSEWIC 2010).

Search Area	Number of sites	Search Effort (person-hours)	Shoreline (linear) distance searched (km)	*G. angulata* observed?
Vancouver Island	8	13.6	5.3	No
Similkameen Basin	7	13.2	4.0	No
Okanagan Basin	86	147.4	31.5	Yes
Kootenay Boundary	15	9.3	2.1	No
Central and East Kootenay	63	62.6	47.9	No
Total	179	429.7	90.8	

Table 3. Site description, survey technique and effort expended for all sites surveyed in the Columbia, Kootenay, Okanagan and Similkameen River basins during 2008-2011.

Date (dd/mm/yy)	LATITUDE	LONGITUDE	Waterbody	Location description	Survey Technique	Effort (person-hours)
18/08/2008	49.619117	-119.657367	Okanagan Lake (Southwest)	Summerland Peach Orchard Beach	Boat-camera tow	4.0
18/08/2008			Okanagan Lake (Southwest)	Summerland Peach Orchard Beach	Snorkel	1.16
19/08/2008	49.015167	-119.453633	Osoyoos Lake (Southwest)	Haynes Point Provincial Park	Wade	1.0
20/08/2008	49.588283	-119.59650	Okanagan Lake (Southeast)	Naramata Manitou Park	Wade	0.75
20/08/2008	49.538350	-119.576350	Okanagan Lake (Southeast)	Naramata 3 Mile Point Beach	Snorkel	1.5
08/09/2008	49.473257	-115.451267	Little Bull Creek	Cranbrook area	Snorkel	0.67
08/09/2008	49.542683	-115.483817	Peckhams Lake	Norbary Lake Park	Wade	0.08
08/09/2008	49.377967	-115.291917	Little Sand Creek	Jaffray	Snorkel/wade	3.0
08/09/2008	49.370750	-115.242950	Sand Creek	South of Jaffray	Snorkel/wade	1.33
08/09/2008	49.789583	-115.740983	Wasa Lake	Wasa Lake Provincial Park	Snorkel	1.66
08/09/2008	49.781733	-115.785300	Cherry Creek	Northeast of Kimberly on HWY 95A	Wade	2.0
09/09/2008	49.607050	-116.170483	St. Mary's Lake	West of Kimberly Lake	Snorkel/wade	0.75
09/09/2008	49.615750	-116.268600	St. Mary's Lake	West of Kimberly Lake	Snorkel/wade	0.5
10/09/2008	49.911433	-115.768633	Skookumchuck Creek	Skookumchuck, East Kootenays	Snorkel/wade	1.5
10/09/2008	50.317400	-115.859167	Columbia River, Upper	South of Fairmont Hotsprings	Snorkel/wade	2.0
10/09/2008	50.282033	-115.852950	Columbia Lake	South of Fairmont Hotsprings	Snorkel/wade	2.0
10/09/2008	50.513717	-116.022678	Windermere Lake	James Chabot Provincial Park	Snorkel	1.5
11/09/2008	50.144583	-115.459750	Whiteswan Lake	East of Canal Flats	Snorkel/wade	2.0
11/09/2008	50.323917	-115.864333	Columbia River, Mouth	South of Fairmont Hotsprings	Wade	0.5
12/09/2008	49.378933	-115.364167	Koocanusa Lake	South of Cranbrook	Wade	0.17
12/09/2008	49.368900	-115.289283	Little Sand Creek	Jaffray	Wade	0.33
12/09/2008	49.350700	-115.296433	Sand Creek	South of Jaffray at confluence	wade	1.5
12/09/2008	49.267950	-115.241830	Kikomun Creek	South of Jaffray	Wade	0.67
12/09/2008	49.322867	-115.177883	Caithness Creek	South of Galloway	Wade	0.17
12/09/2008	49.413950	-115.302556	Tie Lake	North of Jaffray	Snorkel/wade	0.17
07/10/2008	49.602967	-117.029333	Kootenay Lake	West Arm, East of Harrop	Boat-camera tow	1.0
10/10/2008	49.590550	-117.174167	Kootenay Lake	West Arm Provincial Park	Snorkel	1.0
14/07/2009	49.610183	-119.651967	Okanagan Lake (Southwest)	Summerland Boat Ramp	Snorkel	0.08

Table 3. Continued.

Date	LATITUDE	LONGITUDE	Waterbody	Location description	Survey Technique	Effort (person-hours)
14/07/2009	49.619117	-119.657367	Okanagan Lake (Southwest)	North of Summerland Boat Ramp	Snorkel/wade	3.0
14/07/2009	49.634733	-119.677667	Okanagan Lake (Southwest)	North of Crescent Beach	Boat search	0.63
14/07/2009	49.628183	-119.662750	Okanagan Lake (Southwest)	Point South of Crescent Beach	Boat search	0.67
14/07/2009	49.538350	-119.576350	Okanagan Lake (Southeast)	3 mile beach north of Penticton	Snorkel/wade	0.3
14/07/2009	49.536883	-119.571233	Okanagan Lake (Southeast)	South side of 3 Mile Point Beach	Boat search	0.33
14/07/2009	49.556400	-119.577500	Okanagan Lake (Southeast)	South of Naramata	Boat search	0.33
14/07/2009	49.573383	-119.586833	Okanagan Lake (Southeast)	South of Naramata	Boat search	0.13
14/07/2009	49.583550	-119.591000	Okanagan Lake (Southeast)	South of Naramata	Boat search	0.83
14/07/2009	49.588283	-119.596500	Okanagan Lake (Southeast)	Naramata Manitou Park	Snorkel/wade	0.5
14/07/2009	49.540000	-119.624100	Okanagan Lake (Southwest)	Kickininee Provincial Park	Boat search	0.23
14/07/2009	49.542640	-119.627750	Okanagan Lake (Southwest)	Soorimpt Picnic area	Boat search	0.2
14/07/2009	49.549783	-119.633233	Okanagan Lake (Southwest)	Pyramid Picnic area	Boat search	0.47
14/07/2009	49.563533	-119.623233	Okanagan Lake (Southwest)	Kickininee Provincial Park	Boat search	0.13
15/07/2009	49.440683	-119.614616	Skaha Lake (Northwest)	South of Penticton, along HWY 97	Boat search	0.8
15/07/2009	49.429117	-119.608400	Skaha Lake (Northwest)	South of Penticton, along HWY 97	Boat search	0.2
15/07/2009	49.416283	-119.600900	Skaha Lake (West/Central)	North of Kaleden	Boat search	0.2
15/07/2009	49.382700	-119.578766	Skaha Lake (West/Central)	North of Kaleden	Boat search	0.27
15/07/2009	49.378950	-119.578866	Skaha Lake (West/Central)	South of Ponderosa Point	Boat search	0.3
15/07/2009	49.356300	-119.580170	Skaha Lake (Southwest)	Okanagan Falls	Boat search	0.23
15/07/2009	49.347883	-119.579367	Skaha Lake (Southwest)	Okanagan Falls	Boat search	0.17
15/07/2009	49.386500	-119.561983	Skaha Lake (Southeast)	South of Okanagan Falls	Boat search	0.43
15/07/2009	49.439583	-119.579117	Skaha Lake (Northeast)	South of Penticton	Boat search	0.26
16/07/2009	49.610183	-119.651967	Okanagan Lake (Southwest)	Summerland Dog Beach	Snorkel/wade	2.25
16/07/2009	49.599750	-119.651083	Okanagan Lake (Southwest)	Summerland Kinsmen Beach	Snorkel/wade	1.0
16/07/2009	49.624817	-119.630333	Okanagan Lake (Southwest)	Summerland Crescent Beach	Snorkel/wade	1.0
10/08/2009	49.246518	-119.530032	Okanagan River	South of Vaseux Lake	Snorkel	4.0
10/08/2009	49.245975	-119.529798	Okanagan River	South of Vaseux Lake	Snorkel	6.0

Table 3. Continued.

Date	LATITUDE	LONGITUDE	Waterbody	Location description	Survey Technique	Effort (person-hours)
10/08/2009	49.004833	-119.458450	Osoyoos Lake (Southwest)	Central/south of Haynes point	Boat search	0.12
10/08/2009	49.012117	-119.451967	Osoyoos Lake (Southwest)	Central/south of Haynes point	Boat search	0.25
10/08/2009	49.015167	-119.453633	Osoyoos Lake (Southwest)	Haynes point	Boat search	0.08
10/08/2009	49.015550	-119.458000	Osoyoos Lake (Northwest)	North side of lake near boat ramp	Boat search	0.08
10/08/2009	49.007350	-119.438383	Osoyoos Lake (Southeast)	South side of lake	Boat search	0.42
10/08/2009	49.286333	-119.523388	Vaseux Lake (Southeast)	East side of lake of HWY 97	Snorkel	1.23
11/08/2009	49.607330	-119.649263	Okanagan Lake (Southeast)	Summerland Dog Beach	Snorkel	0.27
12/08/2009	50.246319	-119.307433	Okanagan Lake (Northwest)	Vernon, Beachcomber Beach	Snorkel	2.5
12/08/2009	50.246319	-119.307433	Okanagan Lake (Northwest)	Vernon, Beachcomber Beach	Snorkel	1.0
12/08/2009	50.207267	-119.403633	Okanagan Lake (Northeast)	near Vernon, East Arm	Boat search	0.25
12/08/2009	50.202617	-119.412417	Okanagan Lake (Northeast)	near Vernon, East Arm	Boat search	0.35
12/08/2009	50.180750	-119.441083	Okanagan Lake (Northeast)	Ellison Provincial Park	Boat search	0.35
12/08/2009	50.180450	-119.441266	Okanagan Lake (Northeast)	Ellison Provincial Park	Snorkel	0.5
12/08/2009	50.176883	-119.443800	Okanagan Lake (Northeast)	Ellison Provincial Park	Snorkel	0.37
12/08/2009	50.152883	-119.449650	Okanagan Lake (Northeast)	South of Ellison Prov. Park	Boat search	0.35
12/08/2009	50.110967	-119.497283	Okanagan Lake (Northeast)	Cedar Grove Boat Launch	Boat search	0.5
12/08/2009	50.107733	-119.465583	Okanagan Lake (Northeast)	Cedar Grove Boat Launch	Snorkel	0.46
12/08/2009	50.138400	-119.491250	Okanagan Lake (Northwest)	Fintry Provincial Park	Boat search	0.4
12/08/2009	50.140650	-119.492950	Okanagan Lake (Northwest)	Fintry Provincial Park	Snorkel	0.62
13/08/2009	49.599750	-119.651083	Okanagan Lake (Southwest)	Summerland Kinsmen Beach	Snorkel	1.2
13/08/2009	49.666483	-119.651100	Okanagan Lake (Southeast)	Across from Summerland	Snorkel	0.63
13/08/2009	49.679433	-119.672283	Okanagan Lake (Southeast)	Van Hyce Beach	Snorkel	0.46
13/08/2009	49.699683	-119.689550	Okanagan Lake (Southeast)	Commando Beach	Snorkel	0.87
13/08/2009	49.711733	-119.704400	Okanagan Lake (Southeast)	Buchan Bay Park	Snorkel	0.23
13/08/2009	49.703667	-119.696750	Okanagan Lake (Southeast)	Squally Point	Snorkel	0.5
13/08/2009	49.253213	-119.527515	Okanagan River	South of Vaseux Lake	Snorkel/wade	8.0
13/08/2009	49.253213	-119.527515	Okanagan River	South of Vaseux Lake	Snorkel/wade	2.0
14/08/2009	49.198983	-119.846885	Similkameen River	Keremeos Bridge	Snorkel	3.23

Table 3. Continued.

Date	LATITUDE	LONGITUDE	Waterbody	Location description	Survey Technique	Effort (person-hours)
28/09/2009	49.748100	-119.714650	Okanagan Lake (Southeast)	Rattlesnake Island	Boat search	0.17
28/09/2009	49.747717	-119.715883	Okanagan Lake (Southeast)	Rattlesnake Island	Boat search	0.08
28/09/2009	49.766950	-119.683667	Okanagan Lake (Southeast)	Rattlesnake Island	Boat search	0.08
28/09/2009	49.786533	-119.680230	Okanagan Lake (Southwest)	Peachland	Boat search	1.42
28/09/2009	49.776017	-119.734017	Okanagan Lake (Southwest)	Peachland	Boat search	0.5
28/09/2009	49.751183	-119.743750	Okanagan Lake (Southwest)	South of Peachland	Boat search	0.17
28/09/2009	49.748433	-119.759250	Okanagan Lake (Southwest)	South of Peachland	Boat search	0.17
28/09/2009	49.741533	-119.760217	Okanagan Lake (Southwest)	South of Peachland	Boat search	0.25
29/09/2009	49.920067	-119.506817	Okanagan Lake (Central,West)	North of West Kelowna	Boat search	0.25
29/09/2009	49.919450	-119.500500	Okanagan Lake (Central,East)	Kelowna City Park	Boat search	0.25
29/09/2009	49.800783	-119.663917	Okanagan Lake (Central, West)	Westbank	Boat search	0.08
29/09/2009	49.807800	-119.639683	Okanagan Lake (Central, West)	South of Westbank	Boat search	0.33
29/09/2009	49.008266	-119.701042	Similkameen River (South)	Near US Border	Snorkel	3.75
29/09/2009	49.029220	-119.698728	Similkameen River (South)	Forbidden Fruit Vineyard	Snorkel	2.85
30/09/2009	49.708567	-119.747016	Okanagan Lake (Southwest)	North of Greata Ranch	Boat search	0.5
30/09/2009	49.700383	-119.739916	Okanagan Lake (Southwest)	Greata Ranch	Boat search	0.67
30/09/2009	49.692333	-119.730317	Okanagan Lake (Southwest)	Okanagan Lake Provincial Park (North)	Boat search	0.33
30/09/2009	49.685333	-119.723883	Okanagan Lake (Southwest)	Okanagan Lake Provincial Park (South)	Boat search	0.67
28/01/2010	49.925579	-119476433	Okanagan Lake (Central, East)	North of Kelowna, Paul's Tomb	Wade	1.5
17/09/2010	49.019494	-119.442715	Osoyoos Lake (Southwest)	Haynes Point	Snorkel	0.5
17/09/2010	49.065581	-119.517541	Osoyoos Lake (Northwest)	North Basin (North end)	Snorkel	1.16
30/07/2010	49.043049	-119.466231	Osoyoos Lake (Northwest)	North Basin (South end), Spartan Drive	Snorkel	1.5
30/07/2010	49.015563	-119.453670	Osoyoos Lake (Southwest)	South side of Haynes Point	Snorkel	1.0
30/07/2010	49.012557	-119.451197	Osoyoos Lake (Southwest)	South side of Haynes Point	Snorkel	1.0
05/08/2010	49.065589	-119.517623	Osoyoos Lake (Northwest)	North Basin (North end), 91st Street	Snorkel	2.0
05/08/2010	49.073171	-119.526743	Osoyoos Lake (Northwest)	North Basin, North shore/Willow Beach	Snorkel	2.0
05/08/2010	49.063313	-119.508143	Osoyoos Lake (Northwest)	North Basin (North end)	Snorkel	2.0

Table 3. Continued.

Date	LATITUDE	LONGITUDE	Waterbody	Location description	Survey Technique	Effort (person-hours)
05/08/2010	49.020723	-119.465223	Osoyoos Lake (Southwest)	North of Haynes Point	Snorkel	0.5
05/08/2010	49.015307	-119.455996	Osoyoos Lake (Southwest)	North of Haynes Point	Snorkel	2.0
09/06/2011	50.242312	-119.383999	Okanagan Lake (Northeast)	Vernon, Beachcomber Bay, Tronson Rd.	Snorkel	2.0
02/08/2011	49.397488	-119.565378	Skaha Lake (East, Central)	Highland Road	Snorkel	2.0
02/08/2011	49.412532	-119.573774	Skaha Lake (East, Central)	East Side Road by North Pond	Snorkel	2.0
03/08/2011	49.405450	-119.567806	Skaha Lake (East, Central)	East Side Road	Snorkel	1.66
03/08/2011	49.425386	-119.574654	Skaha Lake (Northeast)	Doggie Beach	Snorkel	1.0
04/08/2011	49.380246	-119.576082	Skaha Lake (West, Central)	Kaleden, Ponderosa Point	Snorkel	2.0
04/08/2011	49.347822	-119.572901	Skaha Lake (South)	Okanagan Falls, Christie Memorial Park	Snorkel	1.0
05/08/2011	49.347218	-119.576601	Skaha Lake (South)	Okanagan Falls, Kenyon Park	Snorkel	0.75
24/08/2011	49.606074	-119.650581	Okanagan Lake (Southwest)	Summerland, Ferry dock to Rotary Beach	Snorkel	1.0
24/08/2011	49.610322	-119.652473	Okanagan Lake (Southwest)	Summerland, Peach Orchard Beach	Snorkel	2.0
24/08/2011	49.680741	-119.716018	Okanagan Lake (Southwest)	Okanagan Lake Provincial Park (South)	Snorkel	2.33
24/08/2011	49.624882	-119.663595	Okanagan Lake (Southwest)	Summerland, Crescent Beach	Snorkel	1.66
26/08/2011	49.067172	-119.518840	Osoyoos Lake (Northwest)	North Basin	Snorkel	1.5
26/08/2011	49.019562	-119.442896	Osoyoos Lake (Southwest)	South side of Haynes Point	Snorkel	2.5
02/09/2011	50.249771	-119.350849	Okanagan Lake (Northeast)	Vernon, Beachcomber Bay, Kin Beach	Snorkel	6.0

Table 4. Summary of survey methods utilized for the density by depth study conducted on Okanagan Lake, Summerland on October 20-21, 2011.

Location	Total area surveyed (m^2)	Baseline length (m)	# of transects	Transect length (m) * average length	Maximum Depth Range (m)	# of quadrats/ transect *average	Total # of quadrats	Quadrat size (m^2)	Area surveyed by quadrats (m^2) quadrat area x quadrat #	% of area surveyed
Dog Beach #1	1,705	55	19	31*	0.78-1.42	15*	281	1	281	17.0 %
Dog Beach #2	1,612	52	18	31	0.94-1.22	15	270	1	270	16.7 %
Kinsmen Beach	874	46	10	19*	0.7-1.0	9*	91	1	91	11.0 %

Table 5. Summary of all sites surveyed in 2008-2009 including distance of shoreline searched, effort expended, the number of sites surveyed and the number of live *Gonidea angulata* as well as other mussels observed in each drainage/river basin or waterbody.

Drainage/River Basin	Waterbody		Shoreline (linear) distance (km)	Search effort (person-hours)	# of sites surveyed	# of sites with *G. angulata*	# of live *G. angulata*	Other mussels observed
Okanagan			37.1	108.3	89	20	>1000	Anodontids; *M. falcata*
	Okanagan Lake		24.99	54.22	51	12	>975	Anodontids, *M. falcata*
		Northeast	5.29	15.14	9	3	374	*A. kennerlyi/oregonensis*
		Northwest	1.1	1.02	1	0	0	Anodontids; unidentified
		Central	1.22	2.41	5	0	0	Anodontids; unidentified
		Southeast	5.18	7.69	11	1	1	*A. californiensis/nutalliana, A. kennerlyi/oregonensis*
		Southwest	12.20	27.96	25	8	>600	*A. californiensis/nutalliana, A. kennerlyi/oregonensis*
	Skaha Lake		4.9	13.27	16	2	13	Anodontids
	Osoyoos Lake		3.84	19.61	17	2	2	Anodontids; unidentified
	Vaseux Lake		0.05	1.23	1	1	3	Anodontids
	Okanagan River		3.32	20.0	4	3	12	*M. falcata*
Similkameen	Similkameen River		1.51	9.8	3	0	0	*M. falcata*
Columbia-Kootenay			2.55	24.5	22	0	0	—
	Little Bull Creek		0.15	0.67	1	0	0	—
	Peckhams Lake		0.02	0.08	1	0	0	—
	Little Sand Creek		0.15	3.33	2	0	0	*M. falcata*
	Sand Creek		0.25	2.83	2	0	0	*M. falcata*
	Wasa Lake		0.2	1.66	1	0	0	*A. californiensis/nutalliana*
	Cherry Creek		0.2	2.0	1	0	0	—
	St. Mary's Lake		0.075	1.25	2	0	0	—

Table 5. Continued.

Drainage/river basin	Waterbody	Shoreline (linear) distance (km)	Search effort (person-hours)	# of sites surveyed	# of sites with *G. angulata*	# of live *G. angulata*	Other mussels observed
	Skookumchuck	0.05	1.5	1	0	0	—
	Columbia River	0.4	2.5	2	0	0	*A. californiensis/nutalliana*
	Columbia Lake	0.15	2.0	1	0	0	Anodontids; unidentified
	Windermere Lake	0.1	1.5	1	0	0	Anodontids; unidentified
	Whiteswan Lake	0.2	2.0	1	0	0	—
	Koocanusa Creek	0.05	0.17	1	0	0	—
	Kikomun Creek	0.03	0.67	1	0	0	—
	Caithness Lake	0.025	0.17	1	0	0	—
	Tie Lake	0.1	0.17	1	0	0	—
	Kootenay Lake	0.2	1.0	2	0	0	Anodontids; unidentified
Total		41.16	133.3	114	20	>1000	

Table 6. Summary of timed-snorkel swims and site characteristics where *Gonidea angulata* were encountered within the Okanagan Basin during all surveys conducted from 2008-2011(Note the width of some shoreline distances were estimated based on the number of people snorkelling).

Location	Latitude	Longitude	Shoreline (linear) Distance (m)	Approximate Search Area (m^2)	Time of Search (minutes)	Effort (person-hours)	Substrate	# of live *G. angulata*
Ok. Lake; Summerland; Peach Orchard Beach (2008)	—	—	200 x 10	2,000	40	1.16	Gravel	9
Ok. Lake; Summerland; Crescent Beach (2009)	49.624817	-119.630333	40 x 10	400	20	1.0	Sand, silt, cobble	8
Ok. Lake; Summerland; North of Boat Launch (2009)	49.619117	-119.657367	170 x 10	1,700	60	3.0	Sand, cobble	38
Ok. Lake; Summerland; Boat Launch to Dog Beach (2009)	49.610183	-119.651967	300 x 10	3,000	45	2.25	Sand, cobble, silt	181
Ok. Lake; Summerland; Dog Beach (2009)	49.607329	-119.649262	30 x 2	60	8	0.27	Cobble, gravel, sand	155
Ok. Lake; Summerland; Kinsmen Beach (2009)	49.59975	-119.651083	30 x 6	180	20	1.0	Sand, silt, cobble, boulder	123
Ok. Lake; Summerland; Kinsmen Beach (2009)	49.599750	-119.651083	100 x 2	200	35	1.2	Sand, silt, cobble, boulder	>100
Ok Lake; Naramata (2009)	49.588283	-119.5965	50 x 3	150	10	0.5	Sand, gravel, cobble	1
Ok. Lake; Vernon; Beachcomber Beach (2009)	50.246319	-119.367433	30 x 10	300	50	2.5	Mud, sand, cobble, boulder	4
Ok. Lake; Vernon; Beachcomber Beach (2009)	50.246319	-119.367433	300 x 10	3,000	45	1.5	Mud, sand, cobble, boulder	46
Vaseux Lake (2009)	49.286333	-119.523388	50 x 10	500	37	1.23	Mud, sand, cobble	3
Ok. River; South of Vaseux Lake (2009)	49.246518	-119.530031	100 x 20	2000	60	4.0	Large cobble, gravel, sand	2
Ok. River; Old Rail Crossing (2009)	49.253212	-119.527515	610 x 20	12,200	120	8.0	Cobble, boulder	4
Ok. River; Inventory Site (2009)	49.253212	-119.527515	213 x 20	4,260	30	2.0	Cobble, boulder	6
Osoyoos Lake; South Haynes Point (2010)	49.015563	-119.453670	380 x 6	2, 280	30	1.0	Cobble, sand, silt	1
Osoyoos Lake; North Basin (2010)	49.665589	-119.517623	200 x 6	1, 200	60	2.0	Cobble, silt	1

Table 6 continued.

Location	Latitude	Longitude	Shoreline (linear) Distance (m)	Approximate Search Area (m^2)	Time of Search (minutes)	Effort (person-hours)	Substrate	# of live *G. angulata*
Skaha Lake; Highland Rd. (2011)	49.397488	-119.565378	120 x 6	720	60	2.0	Sand, silt	1
Skaha Lake; East Side Rd. (2011)	49.412532	-119.573774	100 x 6	600	50	1.66	Sand, cobble	12
Ok. Lake; Summerland; Ferry dock to Rotary Beach (2011)	49.606074	-119.650581	120 x 6	720	30	1.0	Sand, cobble	50
Ok. Lake; Summerland; Peach Orchard Beach (2011)	49.610322	-119.652473	270 x 6	1,620	60	2.0	Sand, silt	15
Ok. Lake; Summerland; Crescent Beach (2011)	49.624882	-119.663595	330 x 6	1, 980	50	1.66	Sand, cobble	23
Ok. Lake; Vernon; Beachcomber Bay; Kin Beach (2011)	50.249771	-119.350849	330 x 10	3, 300	120	6.0	Sand, cobble, silt	324

Table 7. Reconnaissance dive survey site characteristics of Okanagan Lake.

Site	Latitude	Longitude	Search Area (m^2)	Maximum Depth Searched (m)	Time of Search (minutes)	Effort (person-hours)	Substrate	Mussel Species Observed and depth (m)
Summerland; Dog Beach	46.624311	-119.500130	16,653	5.5	29	0.97	Mud	Live Anodontids
Summerland; Kinsman Beach	49.599933	-119.651425	4,941	4.3	25	0.83	Cobble, mud	Live *Gonidea* at 1.8m
Vernon; Tronson Rd. Boat Ramp	50.242894	-119.382761	1,971	7.6	23	0.77	Cobble, sand	Live Anodontids at 6.1m Dead Gonidea at 1.8-2.4m
Vernon; Kennedy Lane Picnic Site	50.246033	-119.365258	2,701	4.6	20	0.67	Cobble, sand	Live *Gonidea* at 2.1-2.4m Dead *Gonidea* at 3.0-4.6m

Table 8. Results of the quantitative survey conducted on Okanagan Lake, Summerland in August 2009.

Location	Latitude	Longitude	Total Area Surveyed (m^2)	Quadrat Mean (#/m^2)	Upper 95% Confidence Interval	Lower 95% Confidence Interval	Population Total	Upper 95% Confidence Interval	Lower 95% Confidence Interval	Survey Precision
Summerland; Dog Beach	49.607727	-119.650708	2,343	0.49	0.68	0.30	1,146	1,590	702	38.7%

Table 9. Evaluation of overwintering *Gonidea angulata* off Dog Beach at Summerland Beach Park in January and May 2010.

Marker #	Latitude	Longitude	Substrate	Jan. Depth (m)	May Depth (m)	Jan. Count	Jan, Density (#/m^2)	May Count	May Density (#/m$^{2)}$	Jan.->May change	% change
1	49.607866	-119.649916	Sand/Cobble			8	2.55	6	1.91	-2	-25
2	49.607883	-119.649866	Sand/Cobble	0.64	0.83	12	3.82	8	2.55	-4	-33
3	49.60785	-119.649933	Cobble/Gravel	0.70	0.89	8	2.55	12	3.82	4	50
4	49.60785	-119.649783	Cobble/Gravel	0.61	0.80	10	3.19	8	2.55	-2	-20
5	49.607883	-119.649733	Cobble/Gravel	0.80	0.99	9	2.87	12	3.82	3	33
6	49.607866	-119.6497	Cobble/Gravel	0.70	0.89	13	4.14	16	5.10	3	23
7	49.607883	-119.64965	Cobble/Gravel			15	4.78	5	1.59	-10	-67
8	49.607883	-119.6496	Cobble/Gravel	0.80	0.99	48	15.29	35	11.15	-13	-27
9	49.607883	-119.64955	Cobble/Gravel	0.80	0.99	9	2.87	8	2.55	-1	-11
10	49.607883	-119.649533	Cobble/Gravel	0.70	0.89	12	3.82	9	2.87	-3	-25
11	49.607916	-119.64955	Sand/Cobble	0.94	1.13	14	4.46	11	3.50	-3	-21
12	49.6079	-119.649483	Sand/Gravel	0.73	0.92	10	3.19	12	3.82	2	20
13	49.60785	-119.649566	Sand/Gravel	0.62	0.81	12	3.82	11	3.50	-1	-8
14	49.607916	-119.649466	Cobble/Gravel	0.80	0.99	7	2.23	4	1.27	-3	-43
Total						187		157		-30	-16
Average						13.3571	4.26	11.2143	3.57		-11

Table 10. Results of a two-sample t-test comparing the difference in counts between January and May 2010

	Jan 2010 Counts	*May 2010 Counts*
Mean	13.35714286	11.21428571
Variance	105.1703297	57.25824176
Observations	14	14
Pooled Variance	81.21428571	
Hypothesized Mean Difference	0	
Df	26	
t Stat	0.629109183	
P(T<=t) one-tail	0.267383274	
t Critical one-tail	1.705616341	
P(T<=t) two-tail	0.534766548	
t Critical two-tail	2.055530786	

Table 11. Population estimates of *Gonidea angulata* from density by depth surveys conducted on Okanagan Lake, Summerland in October 2011.

Location	Latitude	Longitude	Total Area Surveyed (m^2)	Quadrat Mean ($\#/m^2$)	Upper 95% Confidence Interval	Lower 95% Confidence Interval	Population Total	Upper 95% Confidence Interval	Lower 95% Confidence Interval	Survey Precision
Dog Beach #1	49.607066	-119.649733	1,705	1.77	2.08	1.47	3,022	3,540	2,504	17.1 %
Dog Beach # 2	49.607638	-119.649956	1,612	0.65	0.90	0.41	1,051	1,447	655	37.7%
Kinsmen Beach	49.598916	-119.650751	874	1.16	1.47	0.86	1,081	1,287	750	26.4%

Table 12. Timing of glochidial release at Dog Beach, Summerland, detailing the number of conglutinate patches observed and the average daily temperature of Okanagan Lake in June and July, 2010.

Sample Date	Daily Average Temperature (^oC)	No. of Conglutinate Patches (Dog Beach)
June-07-2010	14.06	10
June-11-2010	15.06	100+
June-14-2010	16.29	5
June-15-2010	16.11	2
June-17-2010	15.64	50
June-25-2010	17.43	15
July-09-2010	19.70	0

Table 13. Timing of glochidial release at Dog Beach and Kinsmen Beach, Summerland, detailing the number of conglutinate patches observed and the average daily recorded temperature of Okanagan Lake in May, June and July, 2011.

Sample Date	Daily Average Temperature (^oC)	No. of Conglutinate Patches (Dog Beach)	No. of Conglutinate Patches (Kinsmen Beach)
May-13-2011	8.87	0	0
May-19-2011	9.11	0	0
May-24-2011	11.06	0	0
May-27-2011	10.94	0	0
May-31-2011	12.28	0	0
June-03-2011	11.75	0	0
June-07-2011	14.09	2	8
June-11-2011	13.26	0	0
June-14-2011	15.46	6	100+
June-18-2011	13.86	0	0
June-22-2011	15.86	0	1
June-28-2011	16.13	0	0
July-05-2011	16.73	0	0

Figure 1. ***Gonidea angulata*** **adult specimen from Okanagan Lake observed at Dog Beach, Summerland in July 2009. (Note the prominent posterior ridge). Photo by L. Stanton.**

a). *Gonidea angulata*

b). *Margaritifera falcata*

c). *Anodonta califoriensis/nutalliana*

d). *Anodonta kennerlyi/oregonensis*

Figure 2. Internal and external valves of all four species of freshwater mussels documented within southern British Columbia (photos from Nedeau et al. 2009).

Figure 3. Historical range of *Gonidea angulata* in British Columbia and the western United States (COSEWIC 2003).

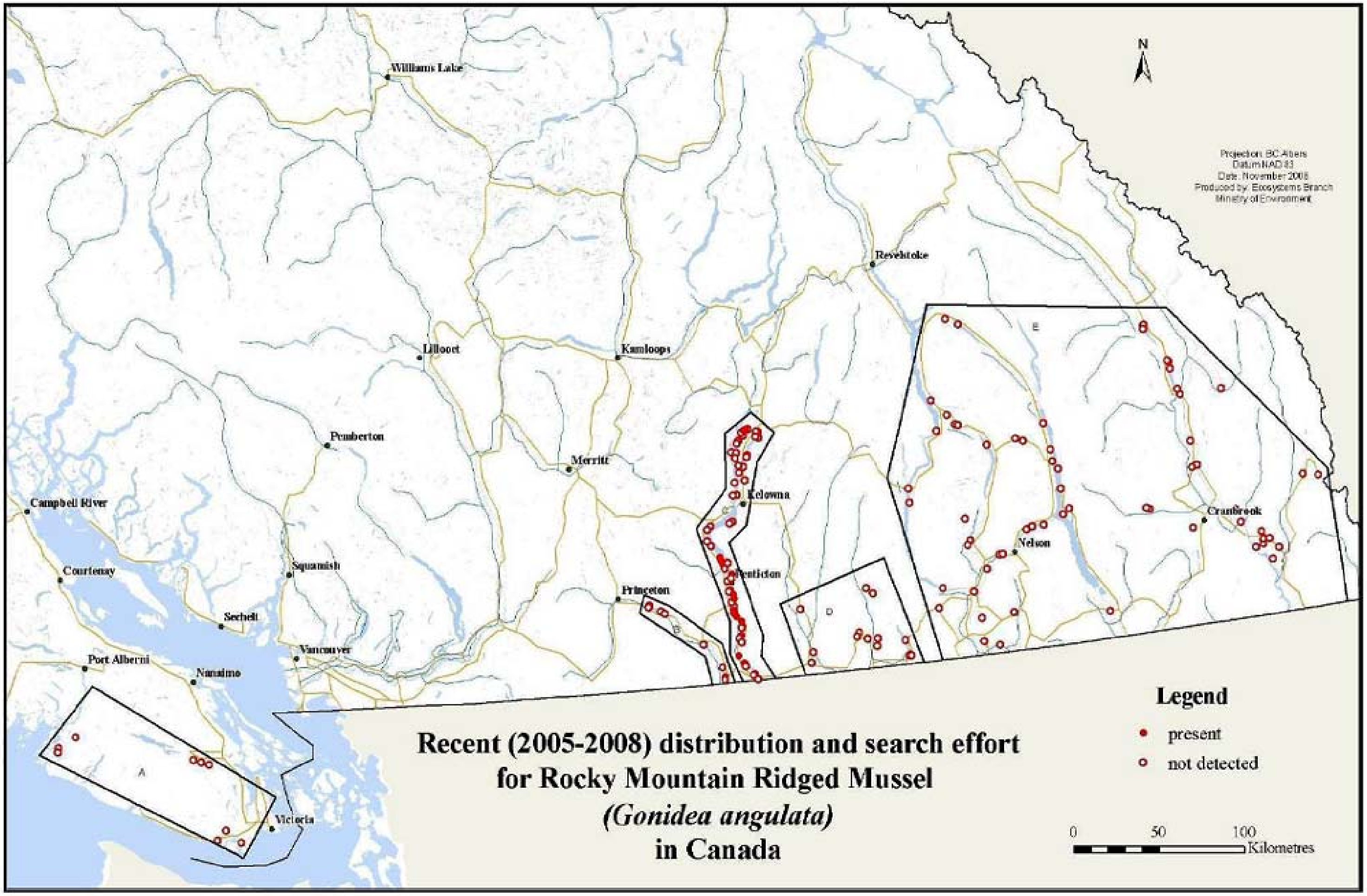

Figure 4. Recent (2005-2008) search effort and distribution of *Gonidea angulata* in British Columbia focussing on five different areas from west to east: (1) Vancouver Island, (2) Similkameen Basin, (3) Okanagan Basin, (4) Kootenay Boundary and (5) Central and East Kootenays. (COSEWIC 2010).

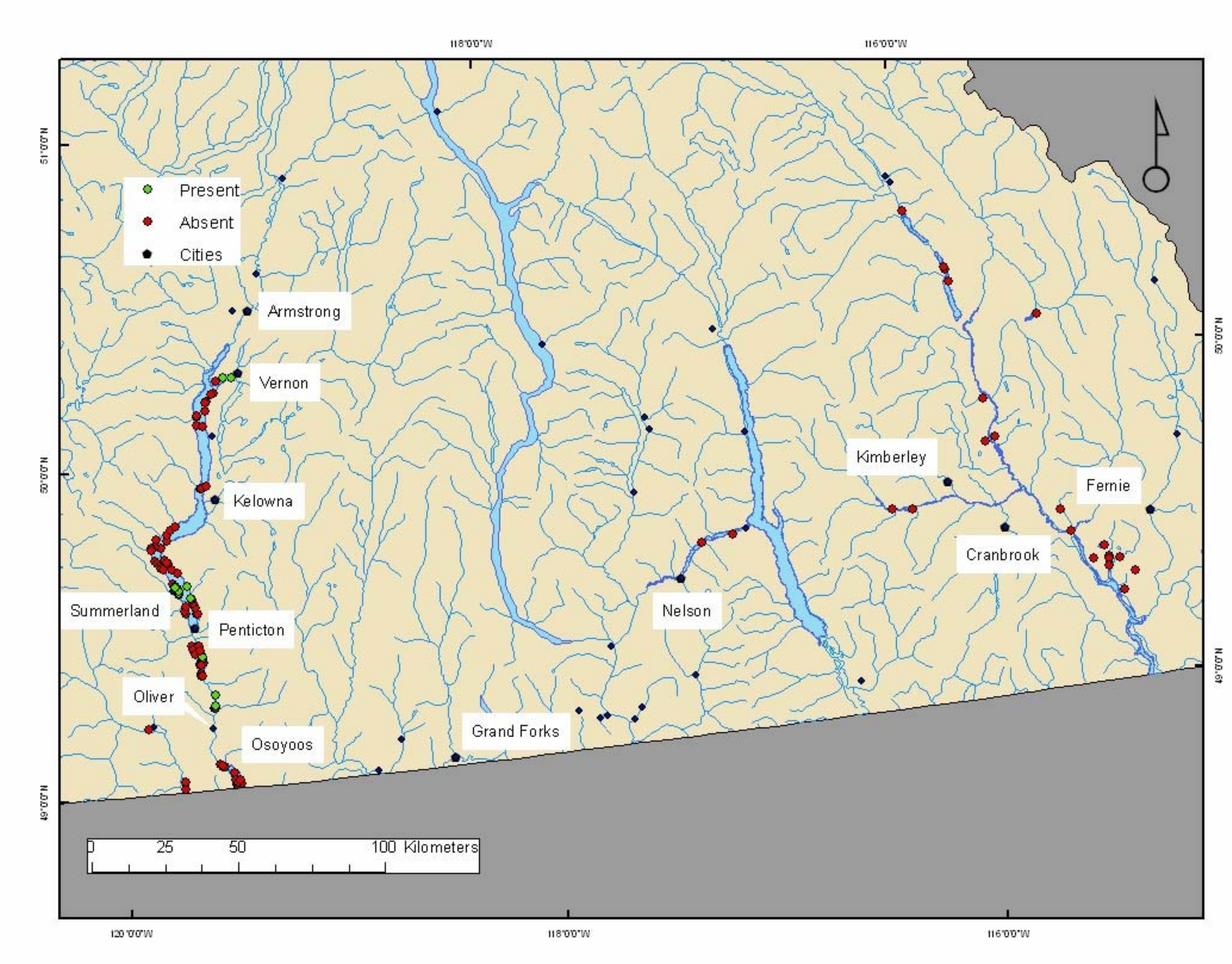

Figure 5. All *Gonidea angulata* survey locations conducted from 2008-2011 in southern British Columbia including the Columbia, Kootenay, Similkameen and Okanagan River Basins.

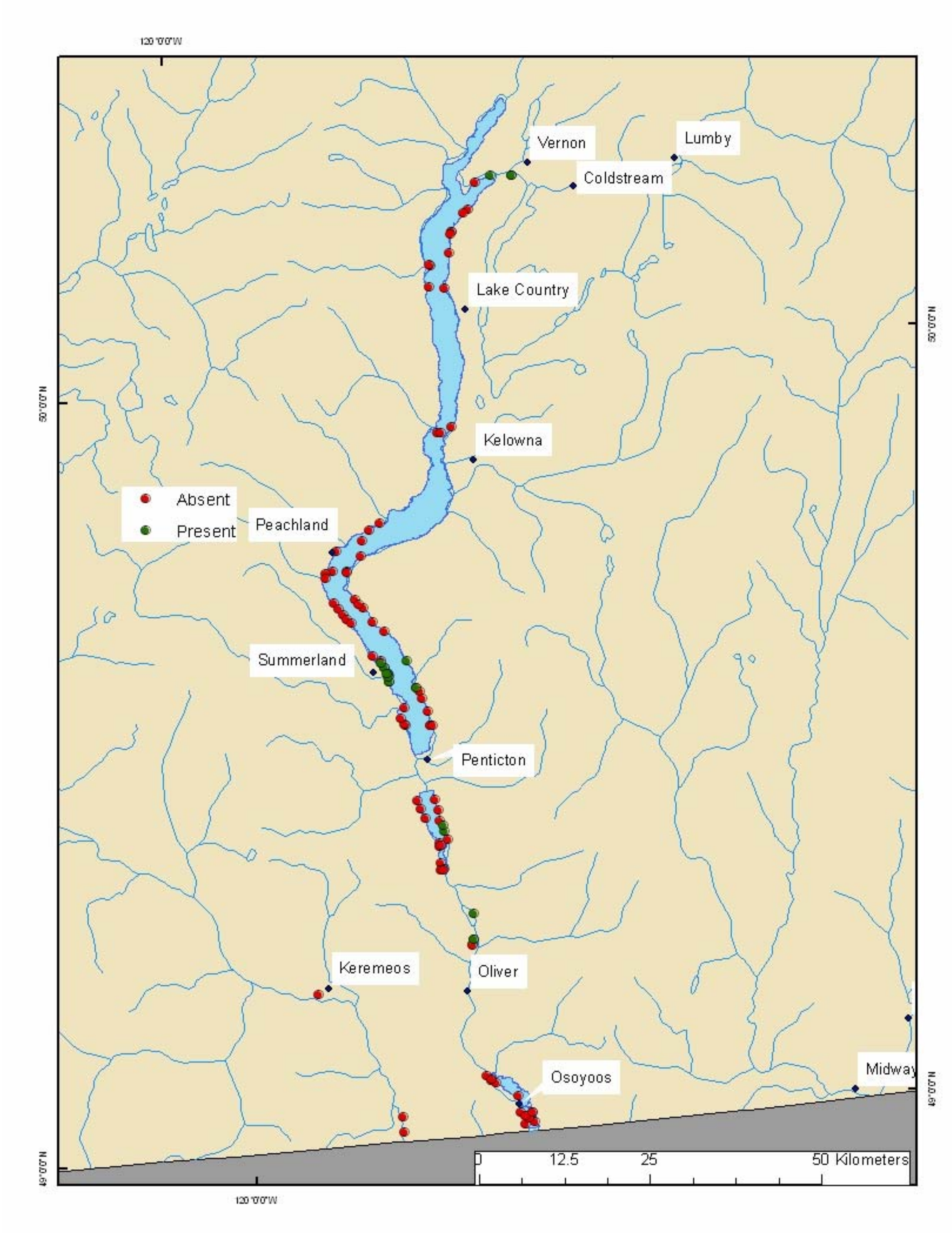

Figure 6. ***Gonidea angulata*** **survey locations conducted from 2008-2011 within the Okanagan Basin.**

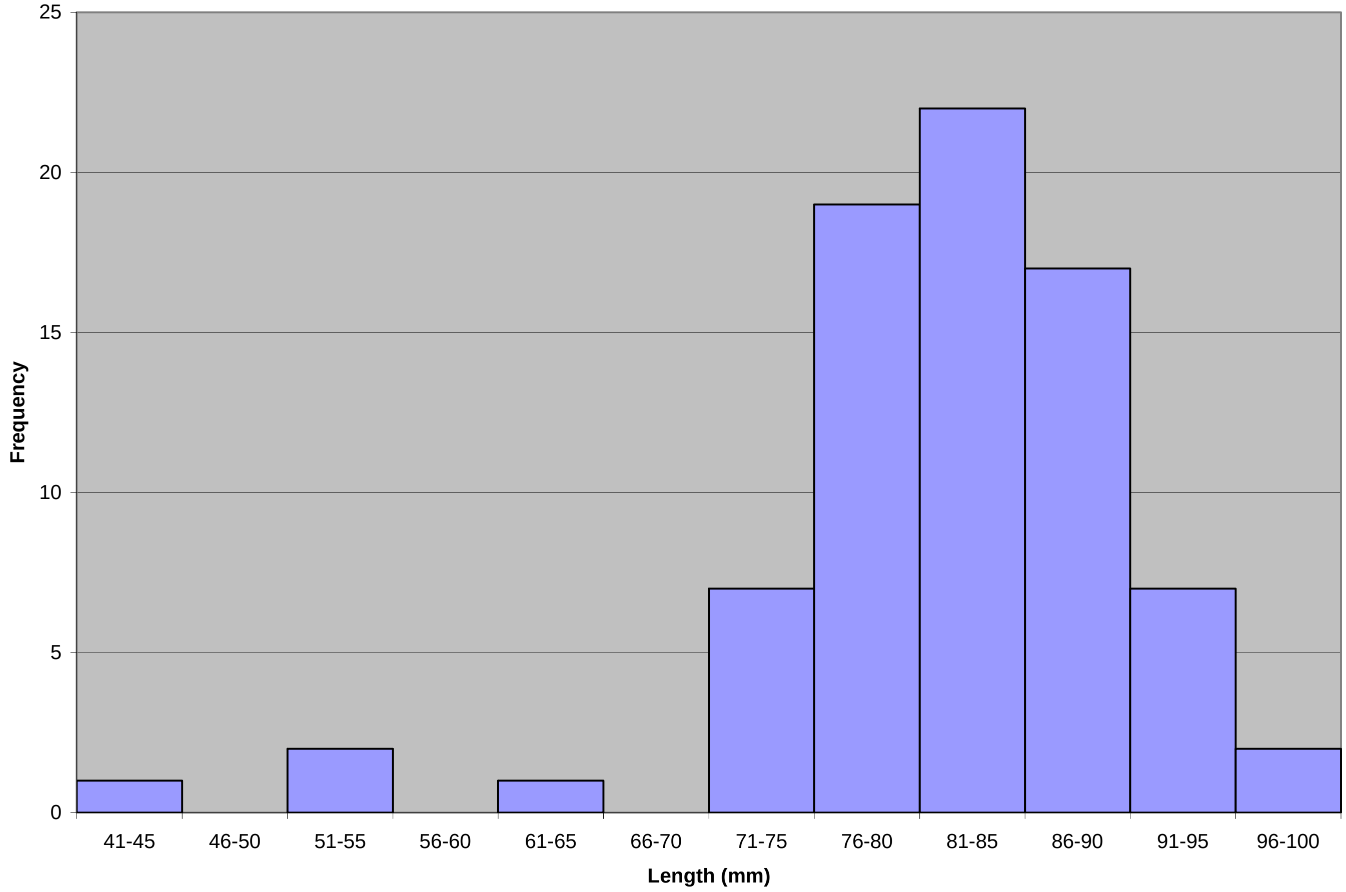

Figure 7. Length frequency distribution of *Gonidea angulata* collected from Dog Beach, Okanagan Lake in 2009 (n=78).

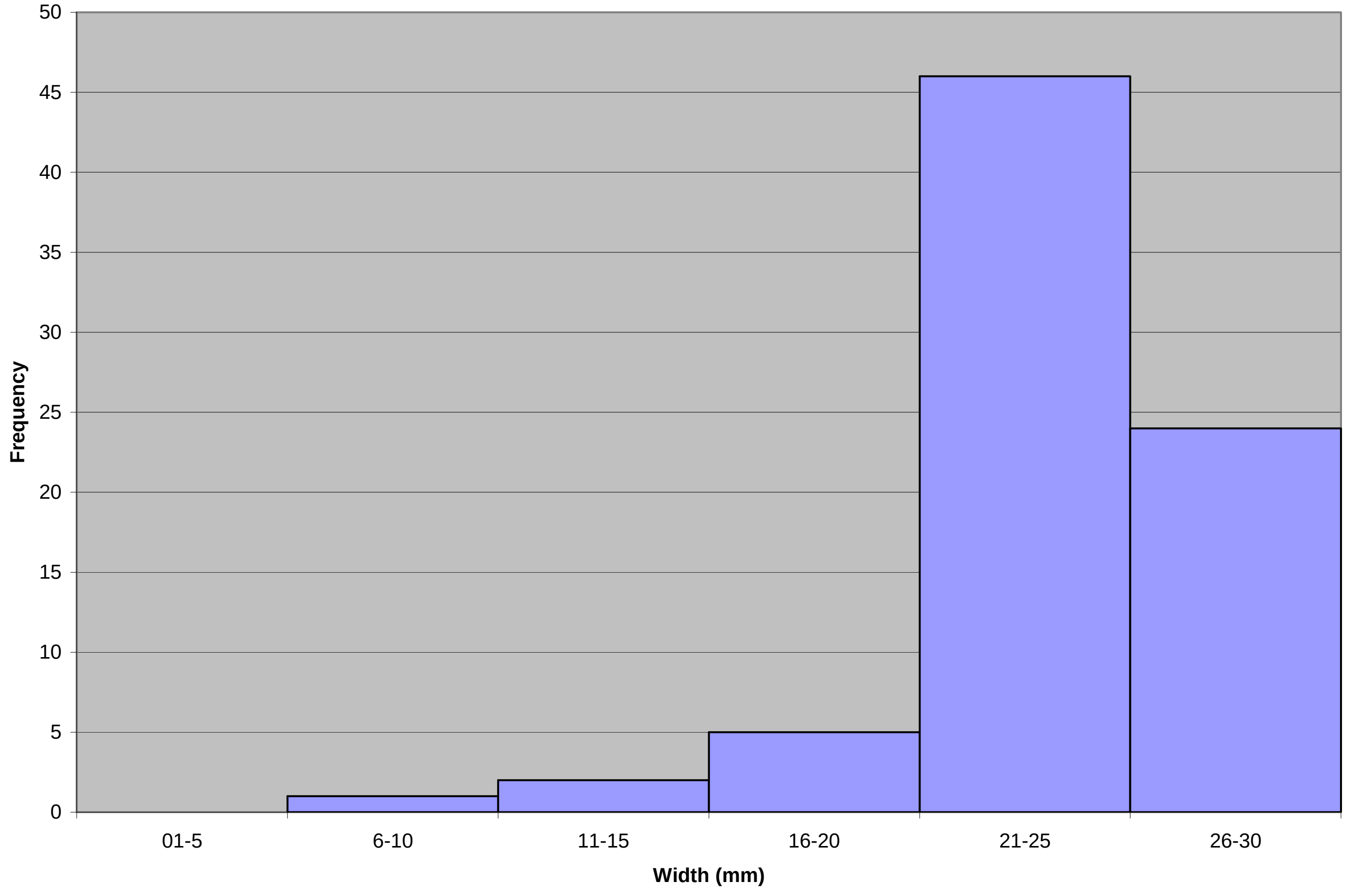

Figure 8. Width frequency distribution of *Gonidea angulata* collected from Dog Beach, Okanagan Lake in 2009 (n=78).

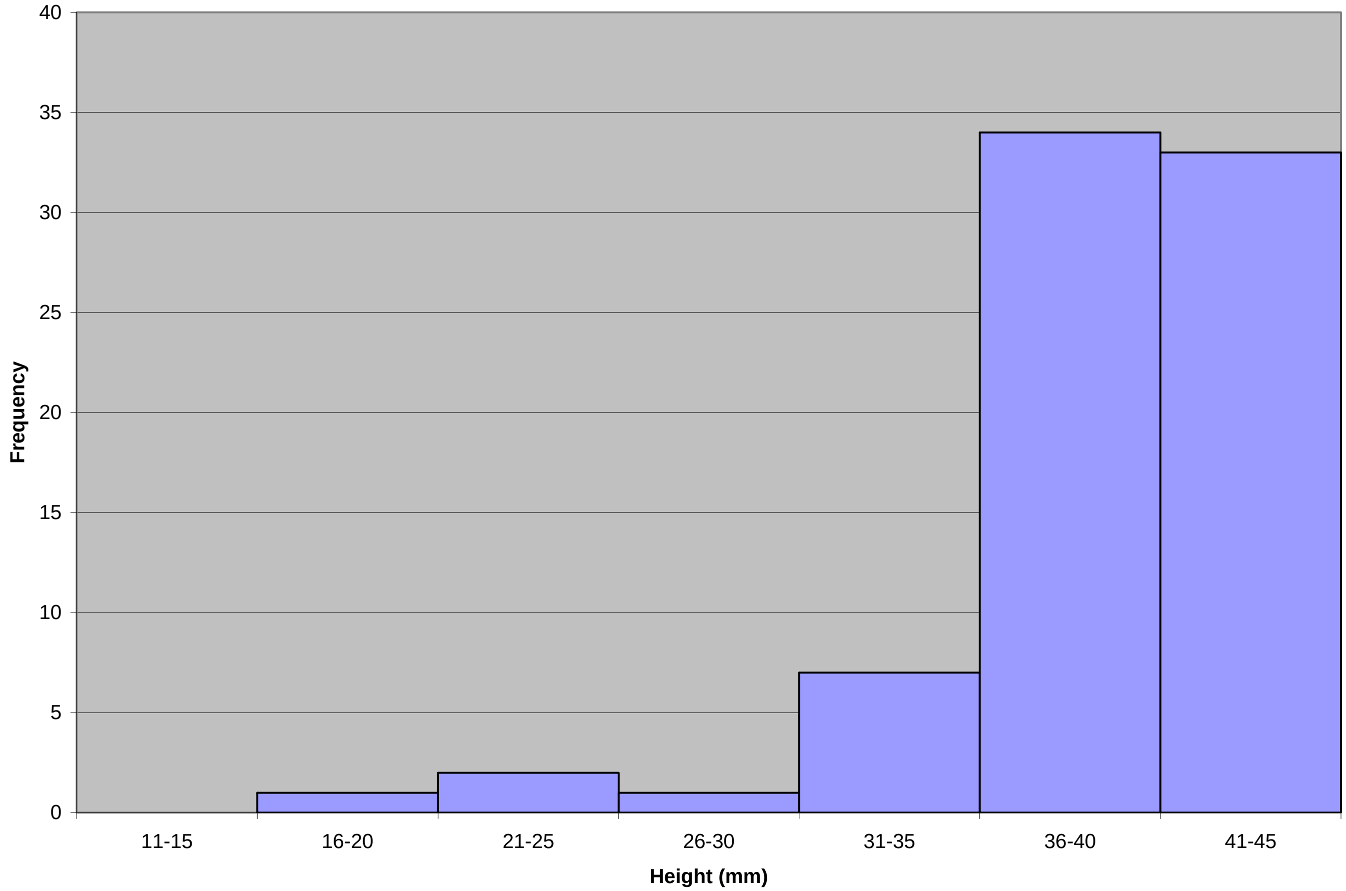

Figure 9. Height frequency distribution of *Gonidea angulata* collected from Dog Beach, Okanagan Lake in 2009 (n=78).

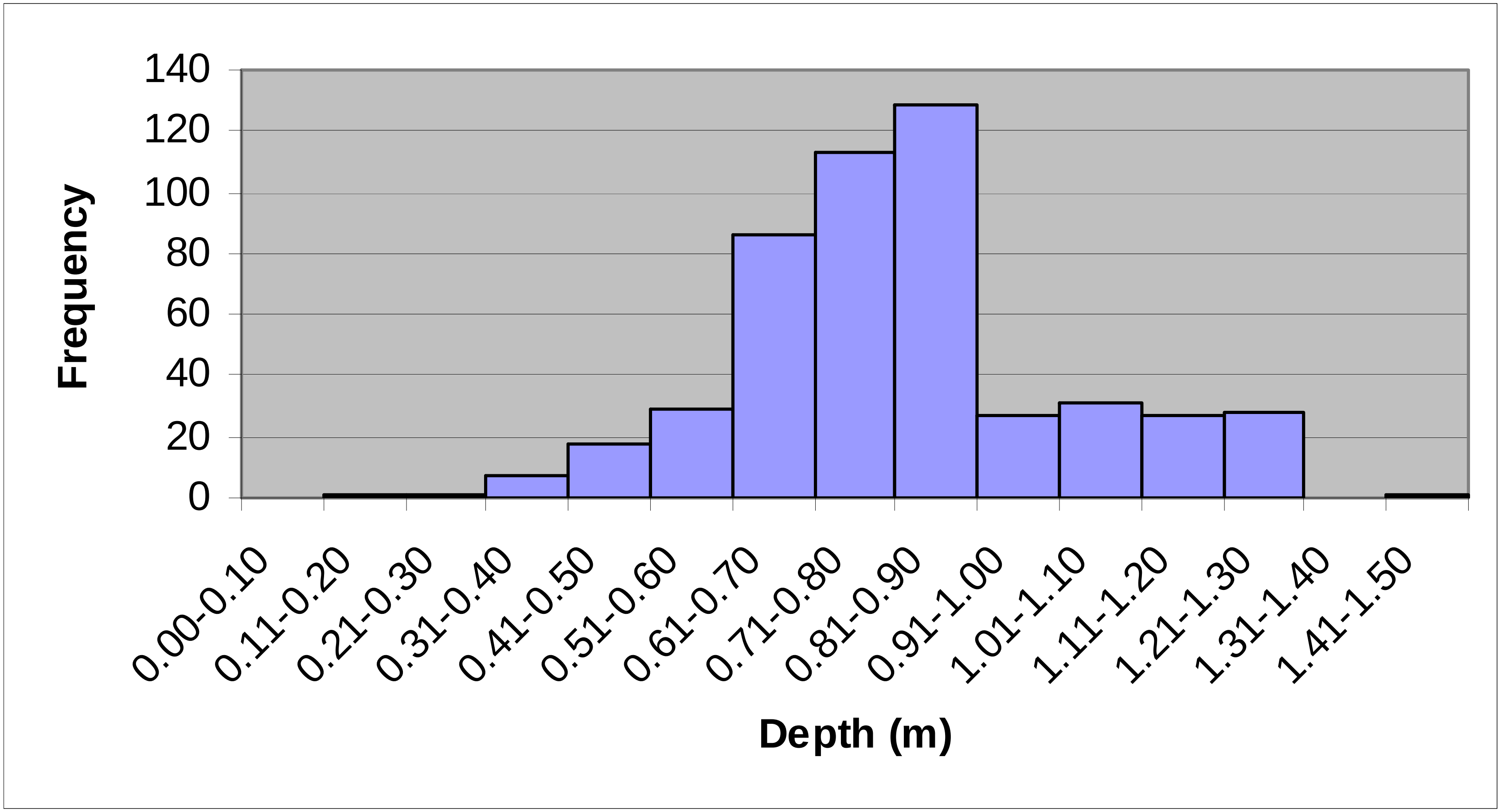

Figure 10. Frequency of *Gonidea angulata* occupying various depths at Dog Beach #1, Summerland (n=498)

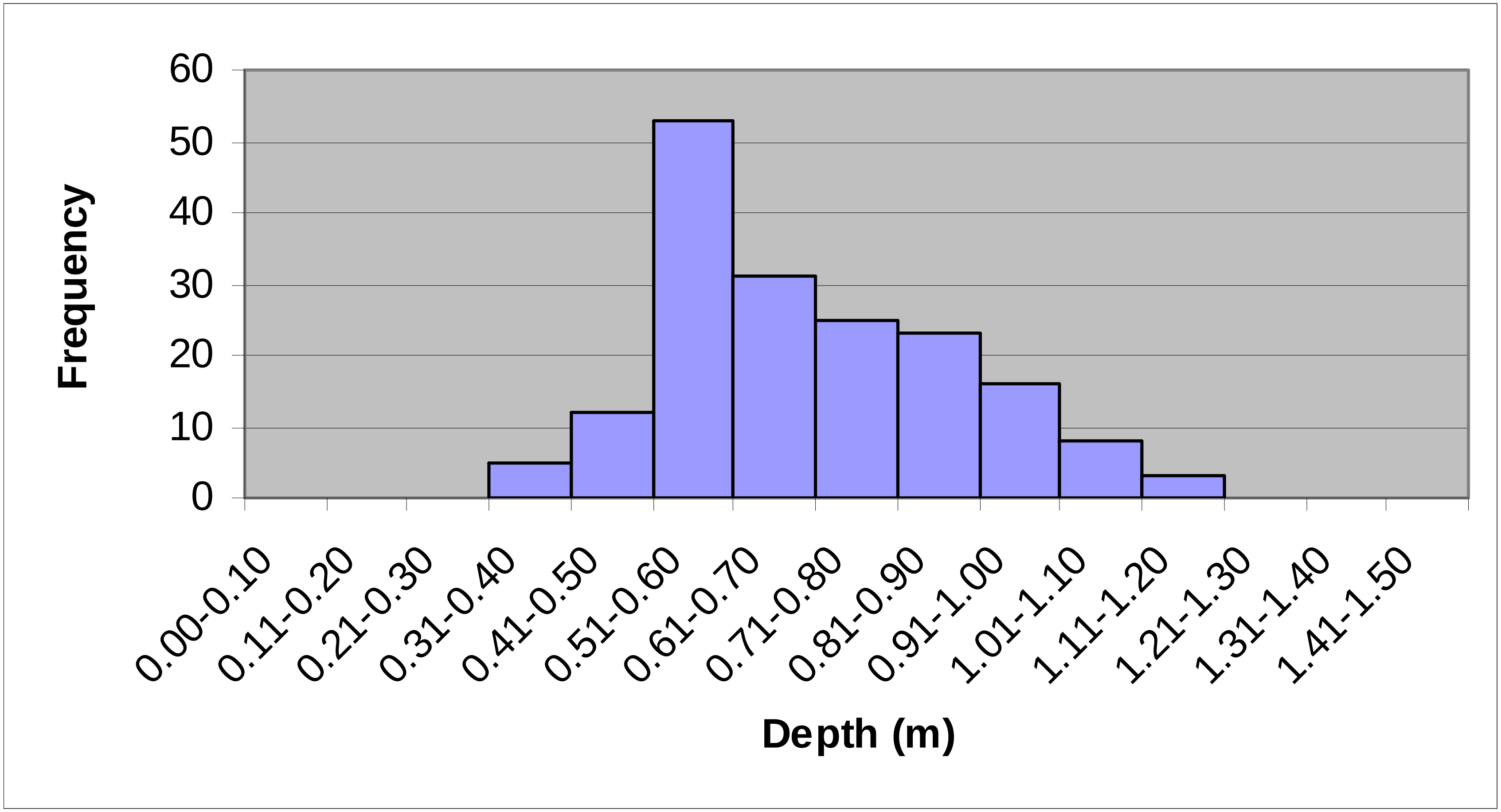

Figure 11. Frequency of *Gonidea angulata* occupying various depths at Dog Beach # 2, Summerland (n=176)

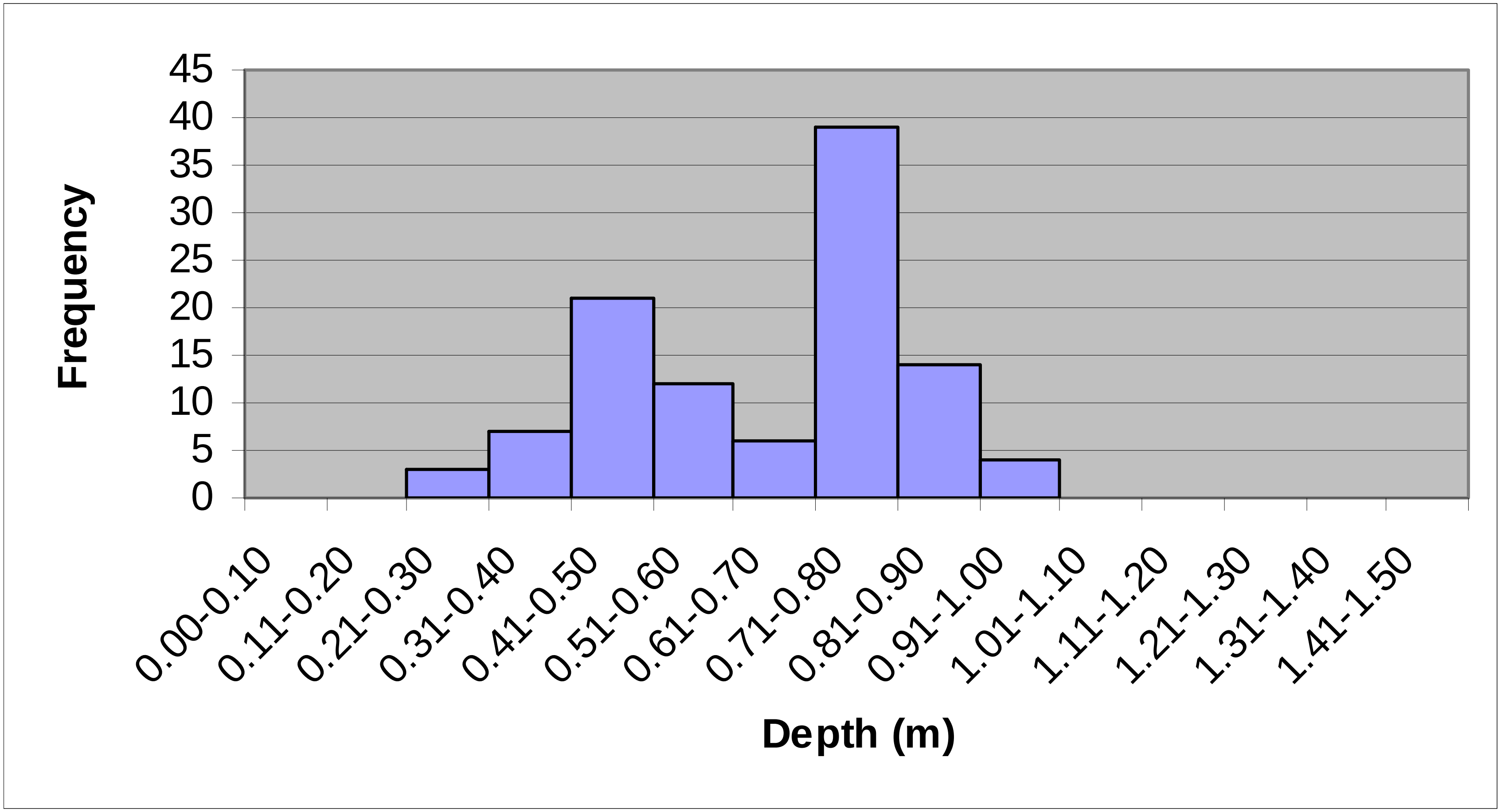

Figure 12. Frequency of *Gonidea angulata* occupying various depths at Kinsmen Beach, Summerland (n=106)

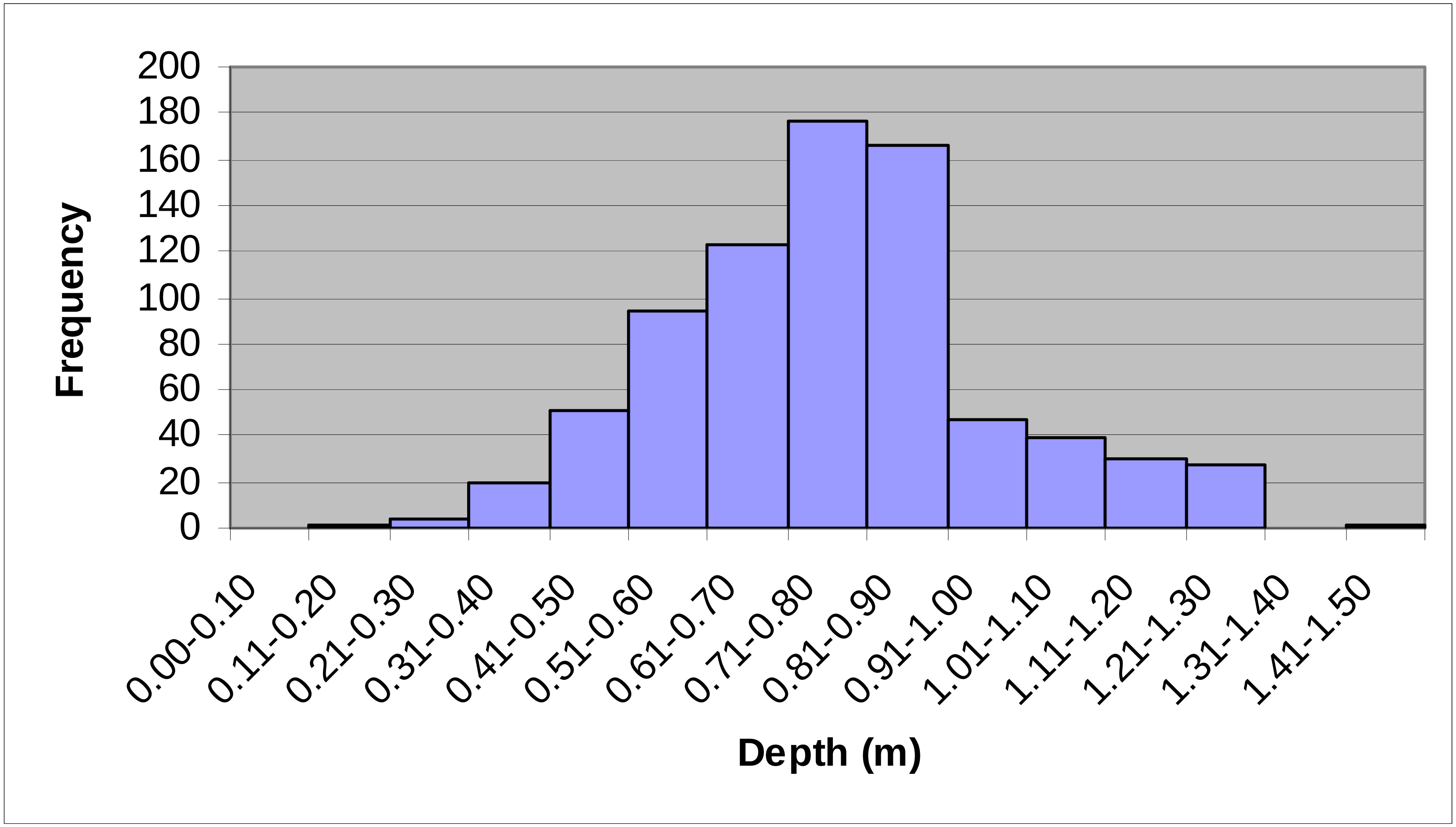

Figure 13. Frequency of *Gonidea angulata* occupying various depths at all three survey sites (Dog Beach #1, Dog Beach #2 and Kinsmen Beach) combined (n=778).

Figure 14. ***Gonidea angulata*** **conglutinates observed in Okanagan Lake at Dog Beach, Summerland in June 2010. Photo by L. Nield.**

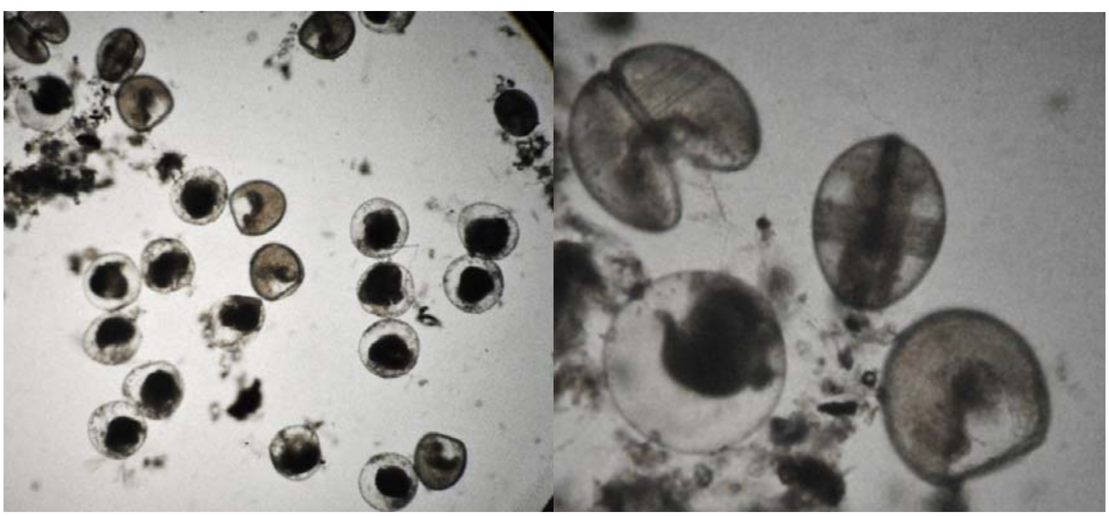

Figure 15. Microscopic images of glochidia contained within conglutinates collected from Dog Beach, Summerland in 2010. Photo by S. Pollard.