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Risk assessment of round goby (*Neogobius melanostomus*) to Lake Simcoe, Ontario: A Quantitative Biological Risk Assessment Tool (QBRAT) case study

Évaluation du risque présenté par le gobie arrondi (*Neogobius melanostomus*) pour le lac Simcoe, en Ontario : Étude de cas de l'Outil de quantification du risque biologique (OQRB)

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Abstract

A Quantitative Biological Risk Assessment Tool (QBRAT) was developed by Marten Koops and Becky Cudmore (Fisheries and Oceans Canada, Burlington, Ontario) to provide risk assessors a tool to more quantitatively assess the biological risk of aquatic invasive species. To evaluate how well the tool works on a variety of taxa, various degrees of data quality and quantity and geographic scales, several case studies were produced. One of these case studies was conducted to assess the biological risk associated with round goby (*Neogobius melanostomus*) to Lake Simcoe, Ontario. Round goby was first collected in a tributary to Lake Simcoe in 2004, and concerns were expressed about the potential impact of this species to the biological resources of the lake. Therefore, an assessment on the potential for arrival, survival, establishment, spread and impact was conducted using QBRAT. The results indicated that the total biological risk would be categorized as high – a critical impact that would require proper management or adaptation. The impact of widespread populations seemed to be the driver of this conclusion, suggesting that research should be directed towards predicting and understanding the potential for widespread distribution of round goby in Lake Simcoe. Also, as the risk substantially increased with the potential for widespread distribution, a recommendation was made to direct management efforts towards slowing, or decreasing, the spread of round goby within the lake. The case study indicated that QBRAT was a useful took for evaluating biological risk of an aquatic invasive species, especially in highlighting areas where further work can be done to strengthen the assessment and areas where resources could be directed to decrease risk. Several recommendations were made about the tool, including the suggestion that the opportunity to categorize impacts be provided as an option.

Résumé

Un Outil de quantification du risque biologique (OQRB) a été mis au point par Marten Koops et Becky Cudmore (Pêches et Océans Canada, Burlington, Ontario) en vue de fournir au évaluateurs du risque un moyen de mieux évaluer, quantitativement, le risque biologique d'une espèce envahissante. Afin de déterminer avec quelle efficacité l'outil peut s'appliquer à divers taxons, à diverses quantités et divers degrés de qualité des données et à différentes échelles géographiques, plusieurs études de cas ont été effectuées. L'une d'entre elles visait à évaluer le risque biologique associé au gobie arrondi (*Neogobius melanostomus*) pour le lac Simcoe, en Ontario. Le gobie arrondi a été capturé pour la première fois dans un tributaire du lac Simcoe en 2004; des préoccupations ont été exprimées à propos des incidences possibles de cette espèce sur les ressources biologiques du lac. Par conséquent, une évaluation des possibilités d'arrivée, de survie, d'établissement, de propagation et d'incidences a été entreprise à l'aide de l'OQRB. Les résultats ont révélé que le risque biologique total serait classé comme élevé – une conséquence critique qui nécessiterait une gestion ou une adaptation appropriée. L'incidence de la propagation étendue des populations a semblé être l'élément moteur de cette conclusion, indiquant que les recherches devraient être orientées vers la prévision et la compréhension du potentiel de propagation étendue du gobie arrondi dans le lac Simcoe. De plus, puisque le risque augmente substantiellement avec la possibilité de propagation, une recommandation a été formulée, favorisant l'orientation des efforts de gestion vers le ralentissement ou la diminution de la propagation du gobie arrondi dans le lac. L'étude de cas a montré que l'OQRB était un outil utile pour évaluer le risque biologique d'une espèce aquatique envahissante, surtout pour définir les aspects qui nécessitent plus de recherche afin d'étayer l'évaluation, et les domaines vers lesquels ils convient d'orienter les ressources pour diminuer les risques. Plusieurs recommandations ont été faites à propos de cet Outil, notamment que soit ajoutée une option, celle d'avoir la possibilité de catégoriser les répercussions.

1.0. Introduction

Round goby (*Neogobius melanostomus*) (Figure 1) is a small benthic fish native to the Ponto-Caspian region including the Aral, Azov, Black, Caspian and Marmara seas (Dillon and Stepien 2001). It was transported from Eurasia via ballast water to the Great Lakes and was first collected in Lake St. Clair in 1990. It has since rapidly spread throughout the Great Lakes and St. Lawrence River basins (Figure 2).

Until 2004, round goby had not been collected from the Lake Simcoe watershed, the largest inland lake in southern Ontario (Figure 3). In August of that year, round goby was angled from a Lake Simcoe tributary; the vector of introduction was likely associated with the live bait trade.

There was concern expressed for the potential impact of the Lake Simcoe biological resources. Lake Simcoe supports a recreational fishery which includes fishes such as lake whitefish (*Coregonus clupeaformis*), lake trout (*Salvelinus namaycush*) and smallmouth bass (*Micropterus dolomieu*). Systematic surveys of Pefferlaw Brook and the Lake Simcoe shoreline at the mouth of Pefferlaw Brook through to fall of 2005 indicated that round goby seemed to be confined to a 5 km stretch of Pefferlaw Brook. A decision was made to attempt eradication of round goby from Pefferlaw Brook to prevent this species from entering Lake Simcoe. Eradication, using rotenone, was conducted in the fall of 2005.

Follow up surveys in spring and summer of 2006, indicated that although round goby individuals were collected from Pefferlaw Brook, the numbers had been drastically decreased. However, despite the attempt to prevent round goby from entering the lake, several individuals have since been found in Lake Simcoe beyond the mouth of the river.

The two objectives of this case study were to: 1) assess the biological risk of round goby to Lake Simcoe; and, 2) to use the case study to evaluate a Quantitative Biological Risk Assessment Tool (QBRAT).

Methodologies

The Ontario Ministry of Natural Resources (OMNR) is in the process of mapping the physical and chemical parameters of Lake Simcoe (J. Borwick, OMNR, pers. comm.). The Lake Simcoe Geographic Information System (GIS) project was initiated in 2002 and included fish habitat mapping as one of the primary objectives of the program (Johanson 2004). To date, nearshore habitat (Figure 4) and bathymetry (Figure 5) mapping have been completed.

This GIS methodology described here for the Lake Simcoe GIS project is from McNiece and Borwick (unpub. data). The nearshore habitat dataset contains Nearshore Sampling Community Index Netting (NSCIN) data and Lake Simcoe littoral zone study data in a simple XYZx format. X and Y fields refer to UTM coordinates, followed by various Z fields representing the presence (1) or absence (0) of a particular habitat attribute at that location. Habitat attributes include substrate types (rock, boulder, gravel, rubble, sand, clay, muck, marl and detritus) and vegetation types (emergent, submergent, floating or algae).

To test these data, a database of spatially referenced nearshore habitat data from a well-studied section of shoreline (Figure 6) was created. The database summarizes much of the 1982-1995 Lake Simcoe Littoral Zone Study data (Puglsey and Black 1982, Lange 1999) and Nearshore Community Index Netting (NSCIN) data since 2002.

Habitat locations were validated and repositioned based on information contained in OMNR littoral zone study reports (Puglsey and Black 1982, Foster and MacDonald 1986, Stanford and Foster 1986, Foster *et al.* 1987, Ross and Dean 1989, Houser and Mason 1995, Middel *et al.* 1995, Dean and Ross 1992), aerial photographs and Natural Resources Values and Information Systems (NRVIS) shapefiles. In addition, site repositioning reflects the gear and sampling limitations of program methodologies (e.g. littoral study sample points positioned at 15m from the shoreline to reflect the 15m seine extent and within the 3m depth contour).

Once validated, sample points were converted to polygons based on the actual area represented when sampling (Figure 7). For example, NSCIN points were converted to 200m diameter polygons and to 200m diameter point congregations to reflect the total area observed when recording habitat information (Stirling 1999). All polygons were then converted to points and all points for each substrate were interpolated. A 200m shoreline buffer polygon was created and clipped to the test area identified in Figure 6. This 200m barrier was then converted to a polyline, then to equidistant points at 10m intervals using the X-Tools extension in ArcMap. This dataset was then merged with the nearshore habitat dataset to limit interpolations of habitat data to the nearshore zone.

The Inverse Distance Weighting (IDW) interpolation method was selected to interpolate the habitat data because it: a) supports the use of barrier layers, b) works well to interpolate irregularly spaced data if it's dense enough to capture local variation in the attributes being mapped, and c) treats each area as a series of local regions allowing for more prediction of complex surfaces.

The 200m buffer polygon was converted to a 50m resolution raster referenced to the extent and cell size of the bathymetry layer. The 200m buffer raster was reclassified such that all values within the raster were "0" and all values outside the raster were "NoData". Analysis of habitat data was referenced to the bathymetry raster to ensure that all cells line up.

After raster interpolations were performed for each substrate type, values for each substrate raster were reclassified. Each substrate was assigned a unique value that would not overlap when added to the value of another substrate or combination of substrates (Table 1). All reclassified substrate rasters were then added together and to the 200m buffer raster using the Raster Calculator function in Spatial Analyst to create a raster representing each substrate or combination of substrates within the nearshore zone.

Identified substrate preferences of round goby were mapped onto substrate categories of high and medium preferences each for adult and juvenile habitats, and spawning depth. The total nearshore habitat area containing these substrate categories was calculated.

To evaluate QBRAT's ability to incorporate expert opinion, an online questionnaire was developed (http://www.surveymonkey.com/Default.aspx). The questionnaire consisted of 25 questions (Appendix A) relating to the input boxes in QBRAT to answer probabilities of arrival, survival, establishment, spread and impact. Respondents also provided a level of certainty associated with their answer, and were also provided the opportunity to comment on any of their answers. The link to the online questionnaire was sent to 20 people, considered to have expert knowledge of round goby, aquatic invasive fishes in Ontario and/or Lake Simcoe. Of the experts invited to contribute to the online questionnaire, 12 completed the survey. Respondents also had the option to provide their names.

Results were compiled and used to enter information into QBRAT. For the probability sections (p) of QBRAT, the mean probability from all the respondents was entered (Figure 8). For the impact (I) sections of QBRAT, the percent frequency of each impact category was calculated (Figure 9). The modal response was then translated from text to a numerical category based on a $\log_{10}$ scale (Figure 10a). The $\log_{10}$ scale was chosen after testing several potential scales against the results of the grass carp risk assessment (Mandrak and Cudmore 2005). The textual results of the grass carp risk assessment best fit with the $\log_{10}$ scale (Figure 10b). It was decided by the authors to deviate from this methodology for I_5. As there was a range of impact categories chosen by respondents (Figure 7), this resulted in 50% of respondents choosing low-medium categories, and 50% of respondents choosing high-very high categories, we decided to apply the precautionary approach and enter an impact of high (1000) for I_5.

Relative certainty was entered into QBRAT using the modal response from the online expert opinion questionnaire associated with each probability (p) (Figure 8) and impact (I) (Figure 9) assigned. Percents associated with certainty categories were derived from Fisheries and Oceans Canada's Integrated Risk Management manual (DFO 2003) and were provided to respondents as a guide for choosing certainty (see Appendix A). These percentages were included in the relative certainty categories in QBRAT.

For the Monte Carlo simulation, 5000 trials and 95% confidence intervals were used.

2.0. Biological Synopsis

2.1. General

Round goby has the ability to proliferate in new surroundings due to its tolerance of a wide range of environmental conditions, diverse diet, aggressive behaviour, ability to spawn up to four times in one growing season, parental care, and large body size compared to other benthic fish species (Charlebois *et al.* 2001). In 1999, round goby reached an estimated peak population size of 350 million fish in the central basin of Lake Erie alone (Bunnell *et al.* 2005) and 9.9 billion in western Lake Erie in 2002 (Johnson *et al.* 2005). It has been found that newly colonized round goby in the freshwaters of the Great Lakes, and the brackish waters of the Gulf of Gdansk are smaller, mature earlier, are shorter lived and populations have a more male-biased sex ratio than those from their native marine habitats (Corkum *et al.* 2004). The average life span for round goby in the Detroit River was found to be approximately four years (MacInnis and Corkum 2000b). This differs from the typical seven to eight year life span of round goby in their native range (MacInnis and Corkum 2000b).

2.2. Size

Mean total length of more than 32,000 round goby from Lake Erie was 75 mm, with the majority of individuals between 30-79 mm TL. Individuals larger than 160 mm were all male, and individuals between 120-159 mm were 90% male (Bunnell *et al.* 2005). Round goby are smaller at a given age in the Detroit River than in Europe (MacInnis and Corkum 2000). In their native habitat, round goby found in marine waters are called “normal morph” and those found in brackish or freshwater are called “dwarf morph” (Corkum *et al.* 2004).

Below are growth data for round goby collected from the Detroit River in 1996 (MacInnis and Corkum 2000).

Age (years)	Female (mean SL)	Male (mean SL)
1	58.4	62.8
2	64.6	75.9
3	82.7	None caught

2.3. Habitat

The wide dispersion of round goby is a result of its exceptional ability to live in a wide range of conditions. During spawning, it inhabits 0.2-0.5 m depths but in winter it moves to 10-15 m depths in the Black Sea and the Sea of Azov, and down to 60-70 m in the Caspian Sea (Moskal’kova 1996). In the upper Detroit River, round goby was almost always found at <4 m depths, rarely deeper than 5 m (MacInnis and Corkum 2000). However, recent data from Hamilton Harbour, indicate round goby were found at depths greater than 10m (Leisti and Koops unpubl. data).

Round goby prefer a habitat with plenty of hiding places such as rocks and concrete structures covered with mussels. Although preferring hard, rocky substrates, it will use sandy and silty bottoms (Sapota 2004). In rocky and cobble substrates, round goby were found at very high densities of 40-100 fish/m in Lake Erie (Bunnell *et al.* 2005). In stream habitats in Pennsylvania, round goby were most abundant in areas with moderate flow with a gravel/rock substrate (Phillips *et al.* 2003).

Round goby are capable of living in wide euryhalinity, as the Caspian Sea has 40.5% salinity (Moskal’kova 1996). Egg and embryonic development also continues in both fresh- and saltwater habitats. Round goby is capable of respiration through its skin and can survive in stagnant and slow-flowing waters with low oxygen (Moskal’kova 1996). Round goby can live in water temperatures between -1 to 30°C; although, activity decreases below 6°C. Its native latitudinal range is between 35° and 55° N. (Jude *et al.* 1992).

2.4. Spawning and Fecundity

Spawning takes place when water temperatures reach 12°C and occurs approximately every 21 days between mid-May and mid-August; usually four spawning episodes each year in Lake Erie (Bunnell *et al.* 2005). Charlebois *et al.* (1997) reports spawning temperatures between 9° to 26°C. Rapid maturation occurs in the Great Lakes region with age 1 females producing eggs. Males generally mature at age 2-3 (MacInnis 1997). The ratio of males to females is 3 or 2:1 (Sapota 2004). Spawning males have enlarged cheeks and an overall black colour. Spawning occurs in near-shore zones from 0.2-0.8 m. Nests are composed of solid material from stones and rocks to wood, roots or dumped waste and are constructed under rocks or logs or in a suitable cavity (Sapota 2004). Nests may be as close together as 1 cm (Sapota 2004). Females lay their eggs in several nests, which are guarded by males. Fertilization rates may be as high as 95% and a male may have a 95% hatching success in his nest. The male may guard the eggs of up to 15 females at a time (MacInnis 1997). The male guards the eggs from predators, cleans the nest of silt and aerates the eggs with his paired fins. The male does not feed while guarding the nest and likely dies after one spawning season (MacInnis and Corkum 2000). Eggs have a high fat and protein content and hatch when they are already quite well developed in 14-20 days (Moskal'kova 1996). The larval fish begins to feed one day after hatching (Moskal'kova 1996).

Below is a table of fecundity for the Sea of Azov from Kovtun (1977), with length data taken from Simonovic *et al.* (2001).

Age of females	Maximum length (mm)	Mean fecundity	Absolute individual fecundity
0	50		
1	99	1548	328-3735
2	116	2195	988-4221
3	123	3032	1665-5221

Depending on body size, mature females in the Detroit River had a batch fecundity of 64-606 ripe eggs per female and an absolute fecundity of 252-1818 eggs per female (MacInnis and Corkum 2000).

2.5. Diet

A diet study in the central basin of Lake Erie found that dreissenid mussels dominated round goby diet at approximately 50% of all food items, followed by chironomids, non-dreissenid molluscs and zooplankton (Bunnell *et al.* 2005). The proportions of dreissenids in round goby diet increased with substratum complexity, but visibility/water clarity had no significant effect on diet choice (Diggins *et al.* 2002). There was a higher consumption rate of amphipods over dreissenids in a bare tank without substratum, indicating an inherent preference for amphipods. The large consumption rate of dreissenids in the Great Lakes may only reflect a lower encounter with motile amphipods and other prey (Diggins *et al.* 2002). In Lake Michigan, it was found that round goby prefer smaller sized zebra mussels as they are easier to remove from the substrate (Djuricich and Janssen 2001). The main food source for young round goby includes plankton and small benthos (Moskal'kova 1996). In the lab, juveniles can survive up to 20 days without food (Moskal'kova 1996). In the Gulf of Gdansk, as fish size increased, the importance of bivalves in the diet increased, while the role of crustaceans and polychaetes decreased (Skora and Rzeznik 2001). The diet of round goby includes amphipods, chironomids, cladocerans, crayfish, dragonflies, dreissenids, isopods, mayflies, fish eggs and larvae in the Great Lakes basin, with specimens larger than 7 cm feeding mainly on dreissenids (Corkum *et al.* 2004). In tributary streams of Lake Erie, round goby of all size classes fed almost exclusively on benthic macroinvertebrates, primarily aquatic insects (Phillips *et al.* 2003). Round goby are reported to feed actively at night in the Great Lakes (Jude *et al.* 1995).

2.6. Genetics, Morphology and Parasites

The level of genetic variation for round goby was similar between the invasive population of Lake St. Clair and the native population studied from the Black Sea indicating a large founding population and lack of bottlenecks (Dillon and Stepien 2001).

Round goby has robust molariform pharyngeal teeth that are typical of molluscivorous fishes. Similar to other benthic fishes, the larval and adult round goby lack a swim bladder which enables them to rest on the bottom.

Round goby has been infected with several freshwater parasites even when they occur in saltwater. There are fewer parasites found on round goby in the Great Lakes than in their native distribution. From the St. Clair River, the parasite *Diplostomum spathaceum*, a trematode, was the most common parasite found in 65% of round goby surveyed (Pronin *et al.* 1997).

2.7. Impact

Round goby has been implicated as the cause for year-class failure in the mottled sculpin (*Cottus bairdii*) in Lake Michigan (Jude *et al.* 1995). Both species are benthic and have similar requirements for nesting, feeding and shelter (Charlebois *et al.* 2001). The aggressive behaviour of round goby toward mottled sculpin has been documented (Dubs and Corkum 1996). Interaction with round goby may have also caused the decline of the logperch (*Percina caprodes*) in the St. Clair River (Jude *et al.* 1995). Other Great Lakes benthic fishes may also be affected by round goby, such as: darters (*Etheostoma* spp., *Percina* spp.); sculpins (*Cottus* spp., *Myoxocephalus thompsonii*); and, madtoms (*Noturus* spp.). Although round goby prefer inshore waters, they may also spread to offshore areas and compete with the slimy (*Cottus cognatus*) and deepwater (*Myoxocephalus thompsonii*) sculpins. Studies in the St. Clair River indicate that diet overlap occurs in nearshore areas < 1 m, as round goby, logperch and rainbow darters fed on small macroinvertebrates. At 3 m, both northern madtom and round goby consumed ephemeropteran nymphs (French and Jude 2001). Round goby are also known to eat young-of-the-year, larval and small adult fish species (Charlebois *et al.* 2001). In the laboratory, round goby feed on the eggs and fry of lake trout (*Salvelinus namaycush*) and field studies show that they feed on the eggs of lake sturgeon (*Acipenser fulvescens*) (Corkum *et al.* 2004). A study in Lake Erie, involving the effects of round goby on smallmouth bass was conducted by Steinhart *et al.* (2004). When nest-guarding smallmouth bass were removed by angling, round goby quickly entered the nest and consumed, on average, 2,000 eggs before the guarding male was returned. When guarding males were present over the nest, eggs and larvae were not consumed by round gobies, nor were the free-swimming larvae or juveniles.

Although round goby consume large quantities of zebra mussels in Lake Erie, it actually accounts for less than 1% of the zebra mussel population (Bunnell *et al.* 2005).

Recently it has been suggested that round goby is linked to the deaths of many migratory bird species in Lake Erie due to botulism (*Clostridium botulinum*); however, further research is necessary to confirm this link (Corkum *et al.* 2004).

Round goby have become prevalent in the diets of smallmouth bass, yellow perch (*Perca flavescens*), white bass (*Morone chrysops*), walleye (*Sander vitreum*) and burbot (*Lota lota*) in Lake Erie (Bunnell *et al.* 2005). In the Gulf of Gdansk, round goby was the dominant food source of cormorants, constituting 90% of the fish eaten and were present in over 90% of the cormorant pellets analysed (Bzoma 1998). In Hamilton Harbour, round goby was present in the regurgitated stomach contents of Double-crested Cormorant chicks in a total of 18% of nests surveyed (Somers *et al.* 2003).

2.8. Spread

Round goby is notorious in its ability to spread quickly in new surroundings. It was first collected in the St. Clair River in 1990. By 1993, it had been collected from the north end of Lake St. Clair, Lake Erie and from southern Lake Michigan near Chicago. By 1995, round goby had been collected in Lake Superior near Duluth (Clapp *et al.* 2001).

In 2001, round goby was captured in the upper Illinois River, suggesting that it has traveled via Lake Michigan through the Chicago Sanitary and Ship Canal. This spread further south into the Upper Mississippi River basin will likely continue (Bernstein and Olson 2001). To track the spread of round goby in Lake Michigan, it was found that both survey and angler samples complemented each other, as anglers generally collected larger specimens from areas that were difficult to sample using conventional gear (Clapp *et al.* 2001). To deter the movement of round goby, an electrical barrier has been successfully tested in the lab and in the Shiawassee River, Michigan and perhaps could be used to inhibit the spread of this invasive species (Savino *et al.* 2001).

3.0. QBRAT Supporting Evidence

3.1. Arrival – p_1=1.00; very certain

Monitoring of Pefferlaw Brook and Lake Simcoe following the eradication effort in 2005 resulted in the capture of several individuals of round goby in Lake Simcoe in 2006.

3.2. Impact (does not arrive) – I_1=0; very certain

There is no biological impact of non-arrival.

3.3. Survival – p_2=0.94; reasonably certain

Much of the evidence suggests that round goby will be able to survive in Lake Simcoe as there is every indication that enough appropriate biological and physical resources exists in the lake. Preliminary nearshore habitat mapping conducted by the OMNR suggest that suitable substrate exists. It is not expected that temperature will limit survival of round goby in Lake Simcoe, as they are currently found further north from Lake Simcoe (Figure 2). Food resources used by round goby in their Canadian introduced range are found in Lake Simcoe. Expert opinion has also suggested that there are no unique predators within Lake Simcoe to which round goby have not been exposed to in other areas of Ontario.

3.4. Impact (arrives but does not survive) **- I_2=1; reasonably certain**

If individual round goby are temporarily present (less than a year) in Lake Simcoe, the impact on the biological resources of Lake Simcoe would be minimal. Documented impacts from other areas of introduction occur over a longer time scale with increasing round goby populations, and this increase would not be expected to occur in less than a year.

3.5. Establishment – p_3=0.95; reasonably certain

Preliminary mapping of the nearshore habitat of Lake Simcoe indicates that there is enough spawning habitat available for round goby. Highly preferred substrate for spawning is found in 407,500 m^2 in the nearshore area of Lake Simcoe (Figure 11). The amount of area available in Lake Simcoe within the preferred spawning depth of round goby is estimated at 268,852,500 m^2 (Figure 12).

3.6. Impact (arrives, survives, but does not establish) **- I_3=100; reasonably certain**

Assumes individuals survive over time, but do not reproduce in the lake. The maximum life span of round goby in Ontario is approximately four years (McInnis and Corkum 2000). It can be assumed that competition for space and prey items would impact the native fishes in Lake Simcoe during the life span of round goby. Without successful reproduction, the impact will be limited to the magnitude of the initial inoculation or repeated introductions.

3.7. Spread – p_4=0.87; reasonably certain

Given existing data on round goby habitat preference, the spatial distribution of round goby can be expected to extend throughout the lake, as enough appropriate habitat exists in Lake Simcoe for round goby.

3.8. Impact (arrives, survives, establishes in a localized area) - **I_4=100; reasonably certain**

Assumes localized, established populations, associated with localized impacts from competition for habitat, spawning habitat and prey with native species.

3.9. Impact (arrives, survives, establishes and spreads) – **I_5=1000; reasonably certain**

Assumes established populations of round goby will be found throughout Lake Simcoe. The amount of nearshore habitat in Lake Simcoe containing the preferred substrate of round goby adults and juveniles is estimated at 4,410,000m^2 and 5,172,500m^2, respectively (Figures 13,14). The amount of nearshore habitat in Lake Simcoe containing the less preferred substrate of round goby adults and juveniles is 3,105,000m^2 and 220,000m^2, respectively (Figures 13,14). Therefore, the total amount of nearshore habitat within Lake Simcoe at high risk (highly preferred by round goby) is 9,860,000m^2, and medium risk (less preferred) is 3,292,500m^2 (Figure 15). Lake Simcoe native fish species expected to be impacted are: lake whitefish, lake trout, smallmouth bass, benthic darters and mottled and slimy sculpins.

4.0. Results

The results of this case study indicate that the biological resources of Lake Simcoe are at risk from round goby. Total Biological Risk, as identified using QBRAT, is R_B=793.3, with a lower limit of 279.5 and an upper limit of 1183.0 (Appendix B). Using this range and placing it into the $\log_{10}$ scale used to categorize risk (Figure 16), the risk falls between medium and high, with a skew towards medium risk (Appendix B). However, applying the precautionary approach would suggest that the overall biological risk to Lake Simcoe from round goby be categorized as high – a critical impact, will require proper management or adaptation (Figure 16).

The impact of widespread populations (I_5) of round goby in Lake Simcoe has the greatest sensitivity (Appendix B) and, it is assumed, this component is the driver of the final conclusion of high risk. Therefore, research should be directed toward predicting and understanding the potential for widespread distribution of round goby in Lake Simcoe. As the risk substantially increases with the potential for widespread distribution of round goby in Lake Simcoe (Appendix B), this is where we suggest management efforts to slow, or decrease, spread of round goby be directed to reduce overall risk to the biological resources of Lake Simcoe. These efforts could include public outreach and education to decrease the potential for spread through intentional or unintentional means by the public, as well as monitoring of the fish community, including small fishes.

5.0. Recommendations for QBRAT

1. The optional management costs input boxes in the QBRAT flow diagram may be less misleading if there was the ability to hide the input boxes if the risk assessor has chosen not to include risk management in the assessment. The potential for misinterpreting a non-answer with an answer of zero exists with the current display.

2. The current implementation of QBRAT assumes that the specified impacts fall along a continuous scale. However, as exemplified by this case study, it is not always possible to specify impacts on a continuous scale and impact may instead be specified categorically. In this case, two options are available. One is to not input impacts into QBRAT, instead using the tool to only specify and evaluate the probability of introduction. This would be accomplished by inputting a zero for the first three impacts (impacts of non-arrival (I_1), non-survival (I_2) and non-establishment (I_3)) and specifying a one for the impacts associated with either a local (I_4) or widespread (I_5) population. Once the probability of introduction is evaluated via QBRAT, it would then need to be associated with the potential categorical impact. The limitation of this approach is that impacts and uncertainty about the impacts are not evaluated with the probabilities of the impact occurring.

   The second option would be to specify ranks for the categories. This was the option employed in this case study. A logarithmic scale was used as it provided results consistent with other approaches used for risk assessment. However, this approach is still not fully satisfactory as QBRAT treats these categorical ranks as if they were a continuous variable.

If categorical impacts are to be used, and we suspect that they will be used commonly, then it may be worth considering a revision to QBRAT allowing for impacts to be specified categorically. This would also require that the Monte Carlo simulations be modified so that each simulation randomly draws an impact from the specified potential categories, instead of from a distribution of ranks that may not encompass the true range of potential impacts.

3. The current specification of uncertainty distributions is limited to two symmetric distributions (uniform and normal) and one asymmetric distribution (log-normal). The log-normal distribution describes a situation where most of the occurrence (of a probability or impact) is centered on a low value with a small frequency of high values (i.e. it has a positive skew). It may be worth considering an asymmetric distribution which is negatively skewed so that the situation of a high value with a low frequency of low values can be included.

4. The ability to identify areas for further research to decrease risk is a valuable aspect of QBRAT.

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Table 1. Unique identifying values assigned to the presence or absence values in each substrate raster (from McNiece and Borwick, unpubl data).

Substrate Type	Unique Reclassified Value	
	Presence	Absence
Rock	1	0
Boulder	10	0
Rubble	100	0
Gravel	1000	0
Sand	10000	0
Silt	100000	0
Clay	1000000	0
Muck	10000000	0
Detritus	100000000	0

Figure 1. Round goby (*Neogobius melanostomus*). Photo by D. Jude.

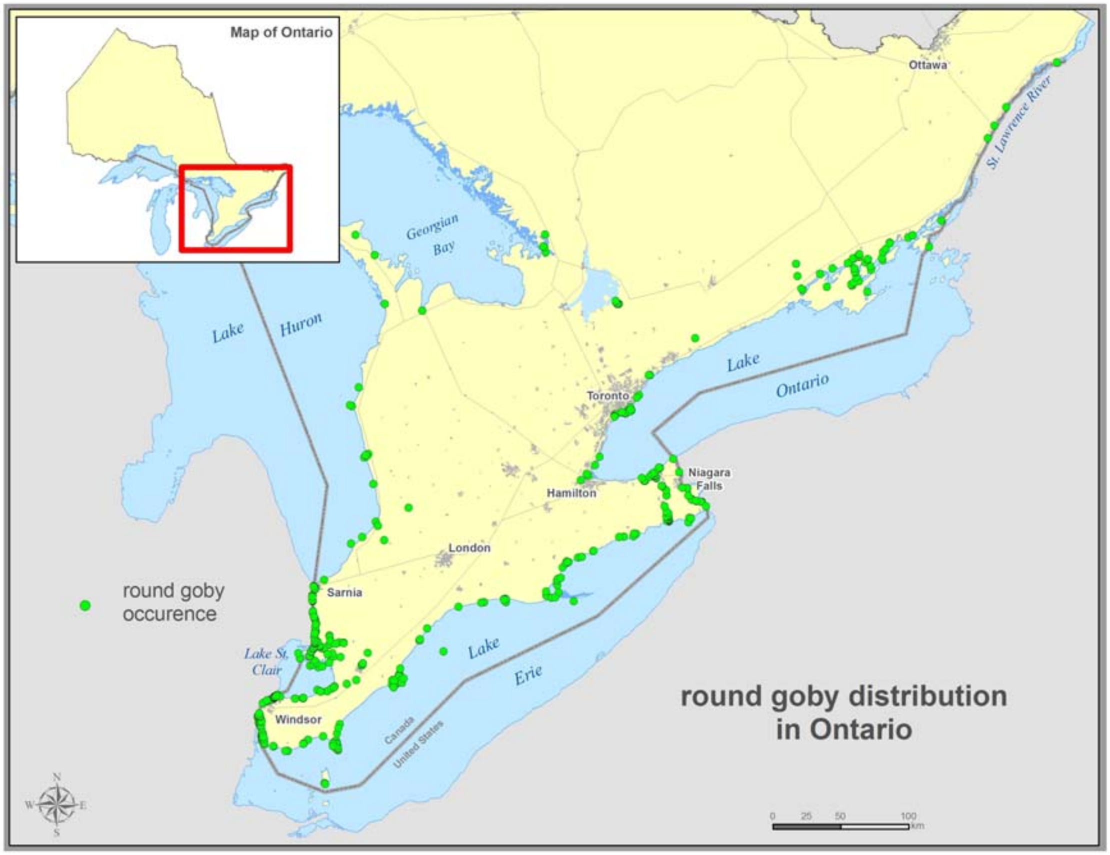


Figure 2. Distribution of round goby in Ontario (data from Mandrak unpub. data, and Ontario Federation of Anglers and Hunters).

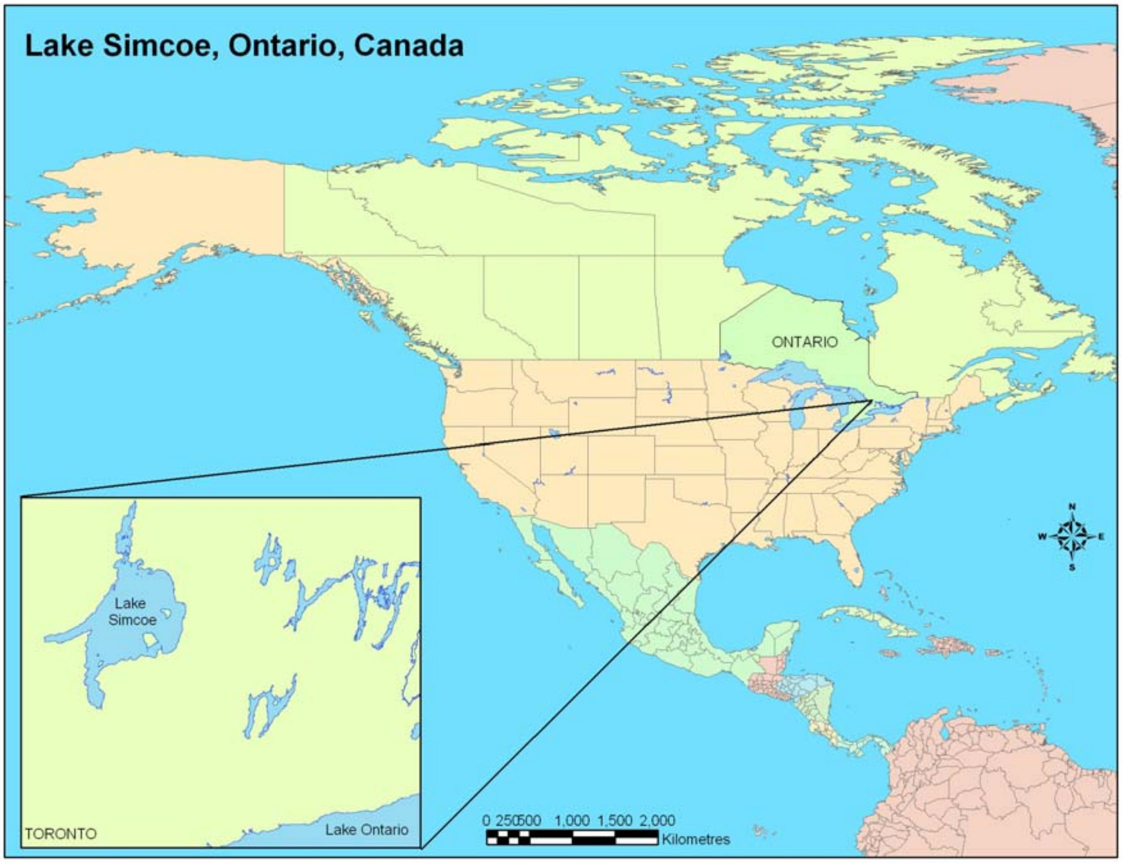


Figure 3. Location of Lake Simcoe, Ontario (map provided by J. McNiece, OMNR).

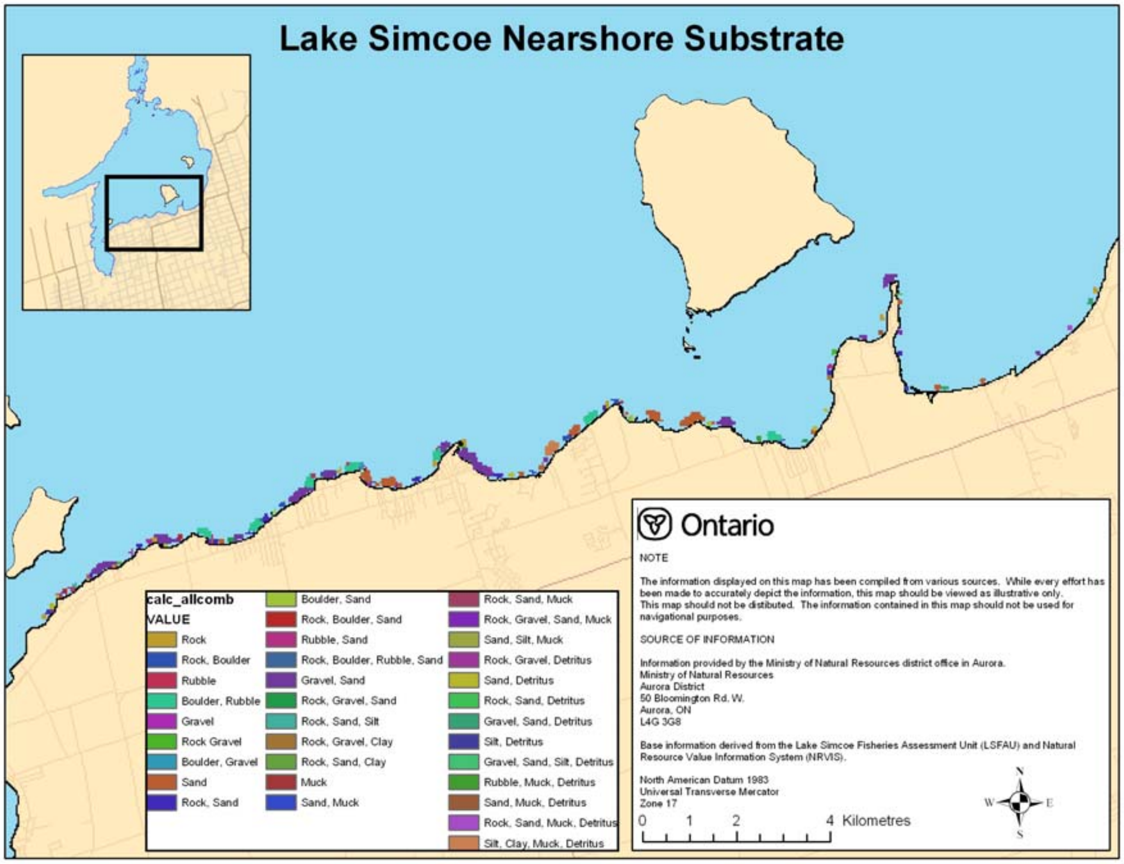


Figure 4. Nearshore substrate mapping of Lake Simcoe test site (McNiece and Borwick, unpubl. data).

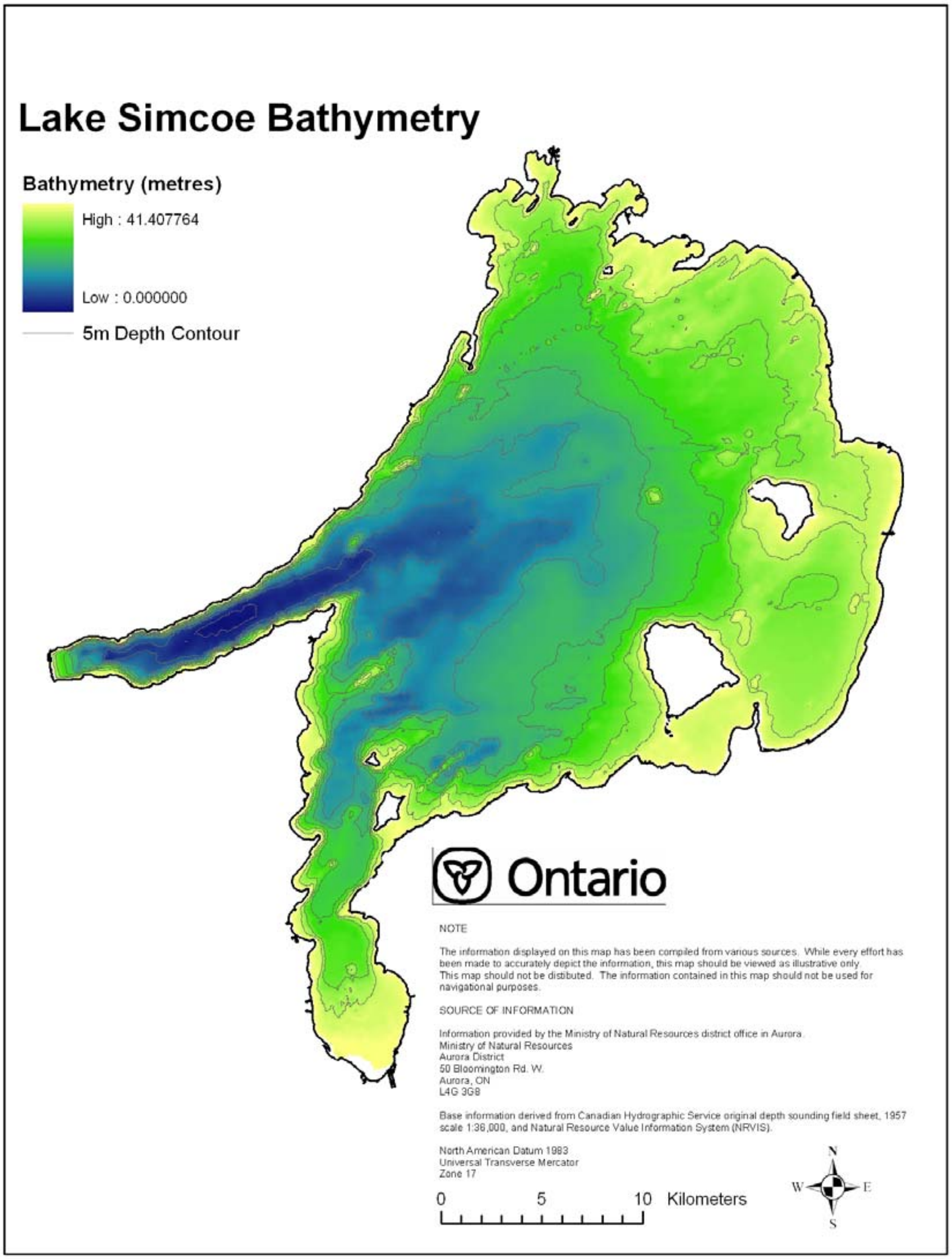


Figure 5. Bathymetry of Lake Simcoe (McNiece and Borwick, unpubl. data).

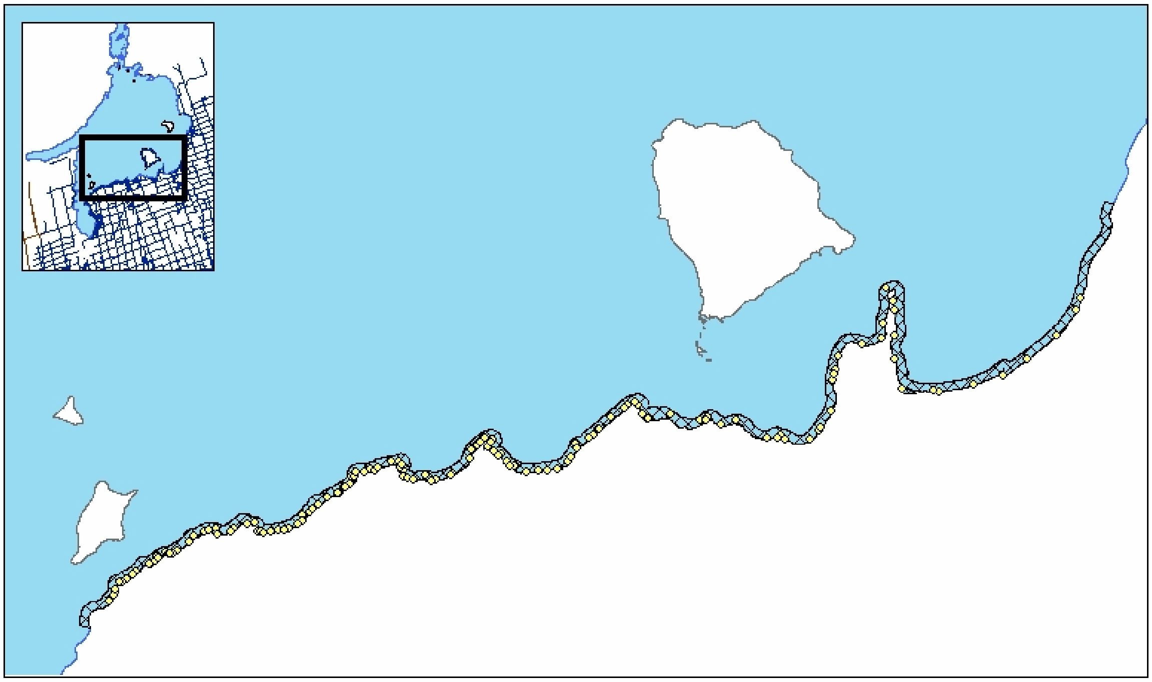


Figure 6. Lake Simcoe nearshore habitat mapping test area (shaded) from Island Grove, east to Cedarhurst Beach. Points represent spatially referenced sites where littoral and NSCIN data is readily available (McNiece and Borwick, unpubl. data).

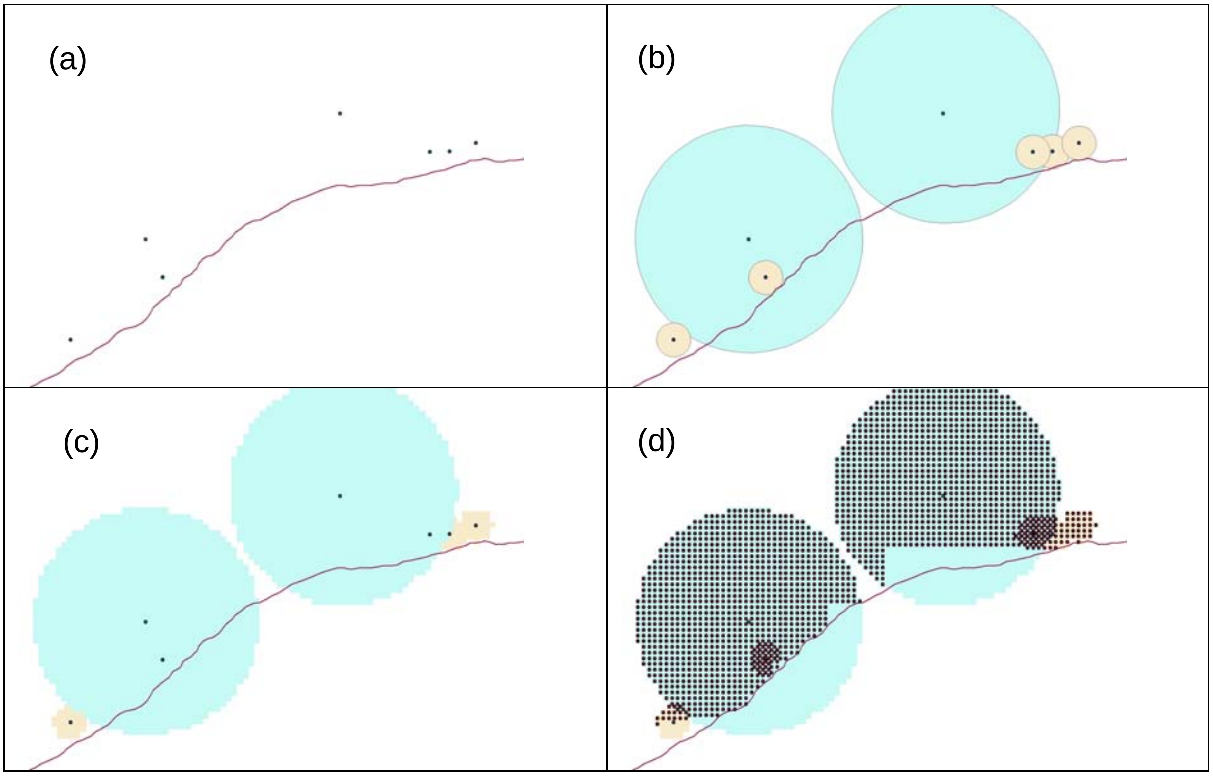
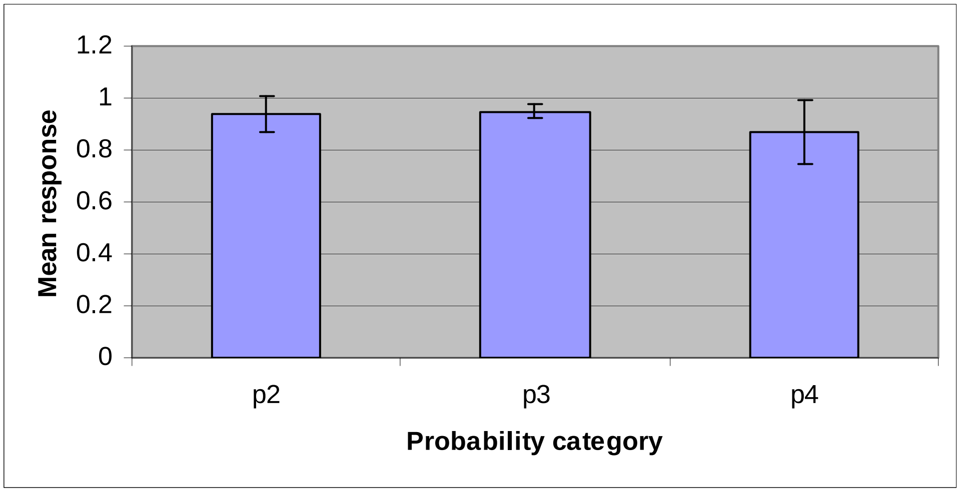
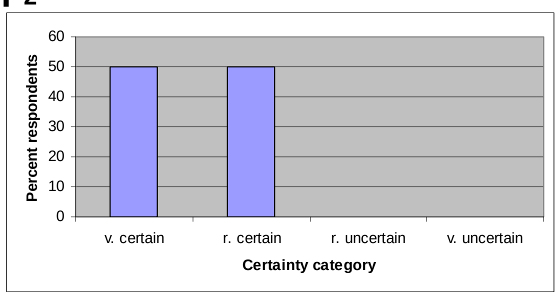


Figure 7. Images of the process involved in converting the littoral data to: (a) polygons representing the sampled area; (b) 5m resolution rasters of the sample polygon; and (c-d) point coverage of the sample polygon at 5m intervals (McNiece and Borwick, unpubl. data).

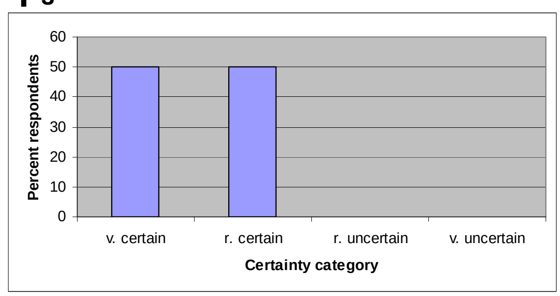
Probabilities



$\mathbf{p_2}$



$\mathbf{p_3}$



$\mathbf{p_4}$

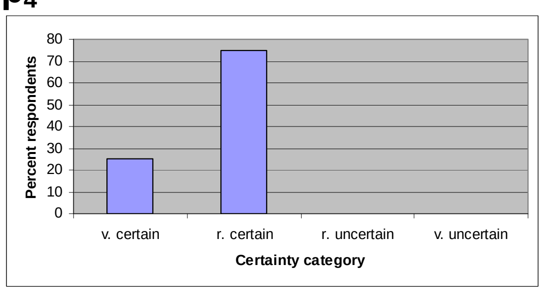


Figure 8. Results of responses assigning probabilities and associated certainties.

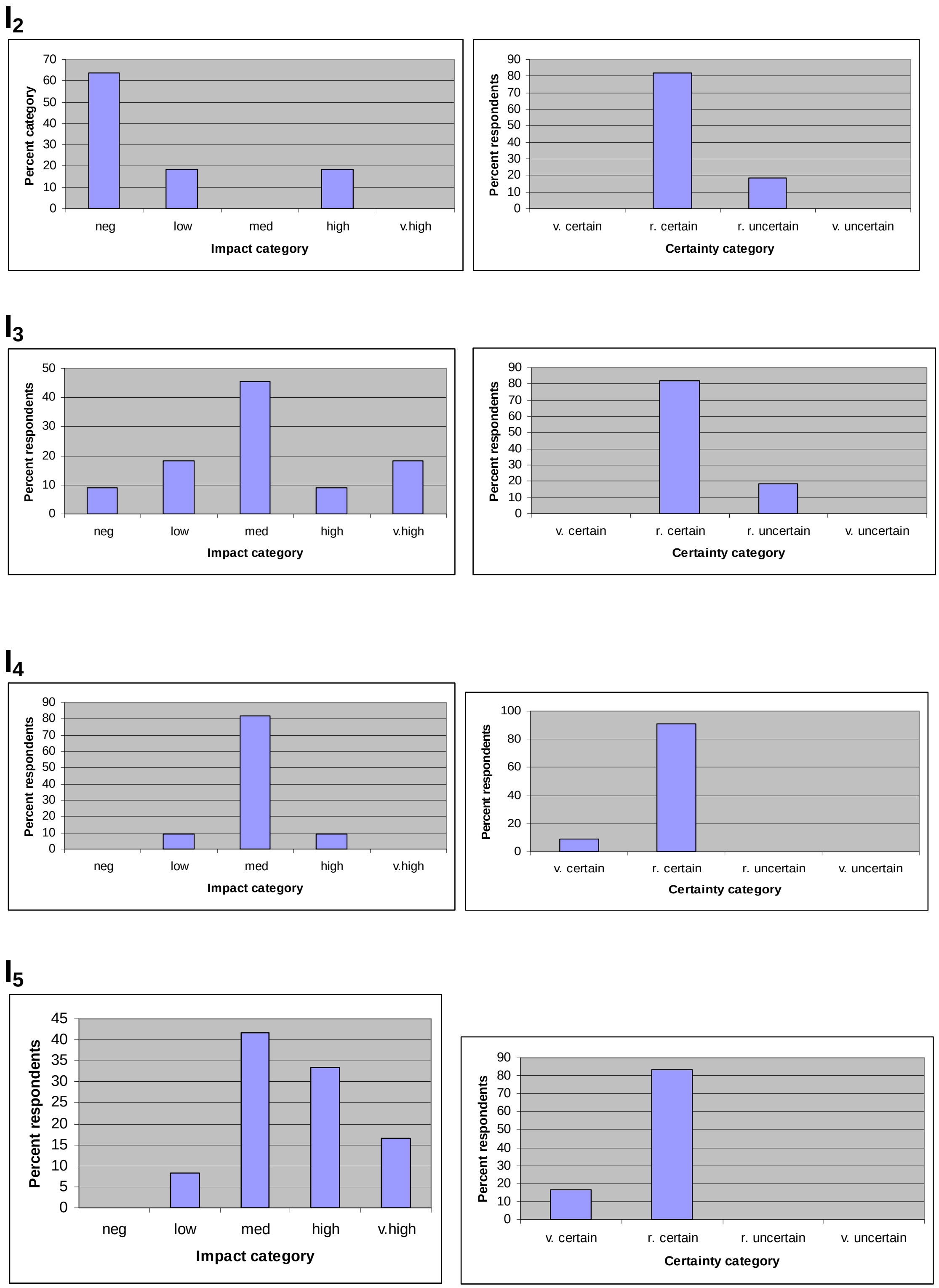


Figure 9. Results of responses categorizing impacts and associated certainties.

Semi-Quantitative Impacts, potential scales:

Impact	Linear 1	Linear 10	Log 10	Log e
Negligible	1	10	1	1
Low	2	20	10	3
Medium	3	30	100	7
High	4	40	1,000	20
Very High	5	50	10,000	55

Figure 10a. Potential scales for assigning impact.

Grass Carp Risk Assessment; test case:

p(survival)	High, very certain
p(repro)	High, reasonably certain
p(spread)	High, reasonably cetain
I(widespread)	High, very certain
Final Risk Est.	High, very certain

Mandrak & Cudmore. 2004. CSAS Res Doc 2004/103.

Figure 10b. Text results of grass carp risk assessment.

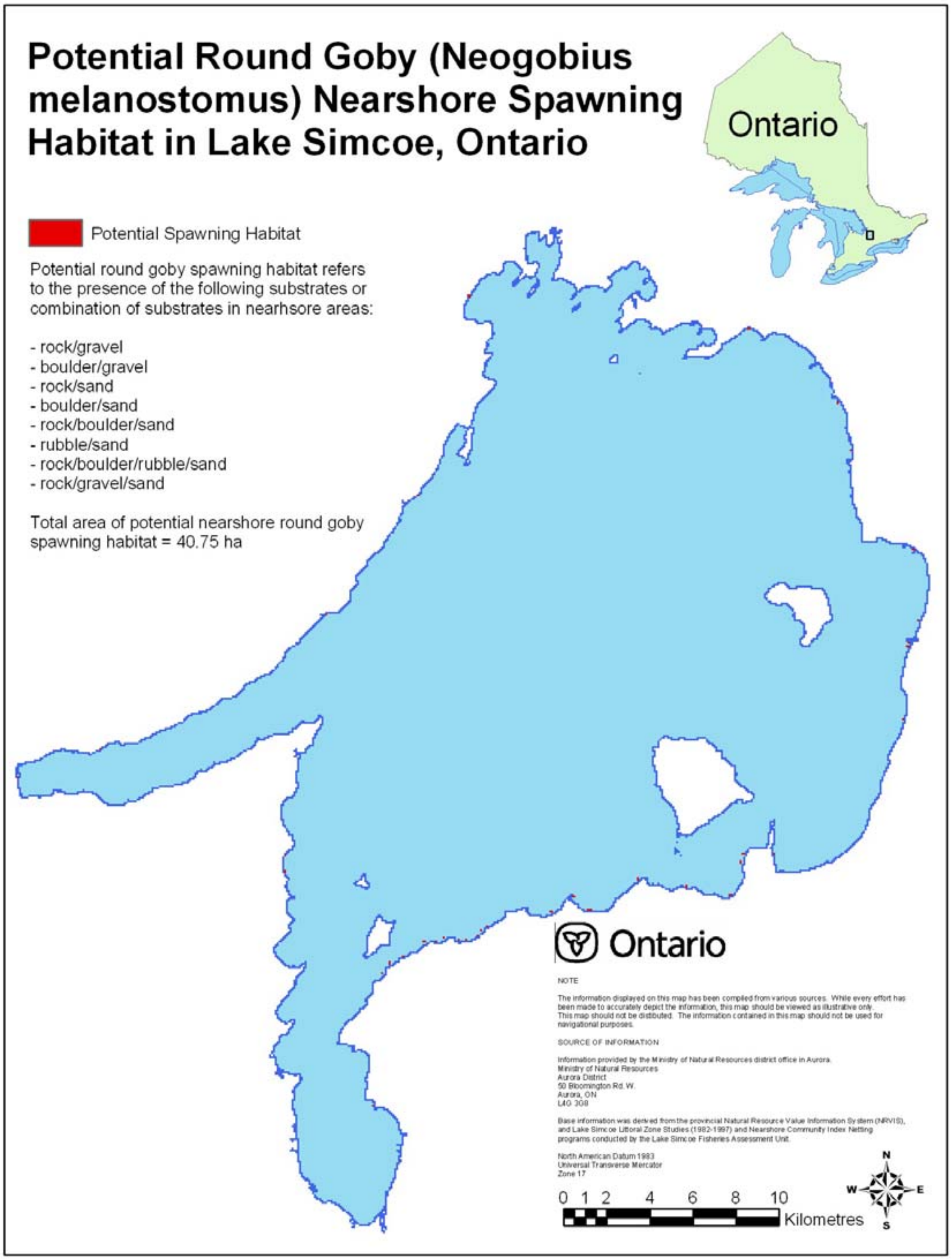


Figure 11. Potential nearshore round goby spawning habitat in Lake Simcoe (McNiece and Borwick, unpubl. data).

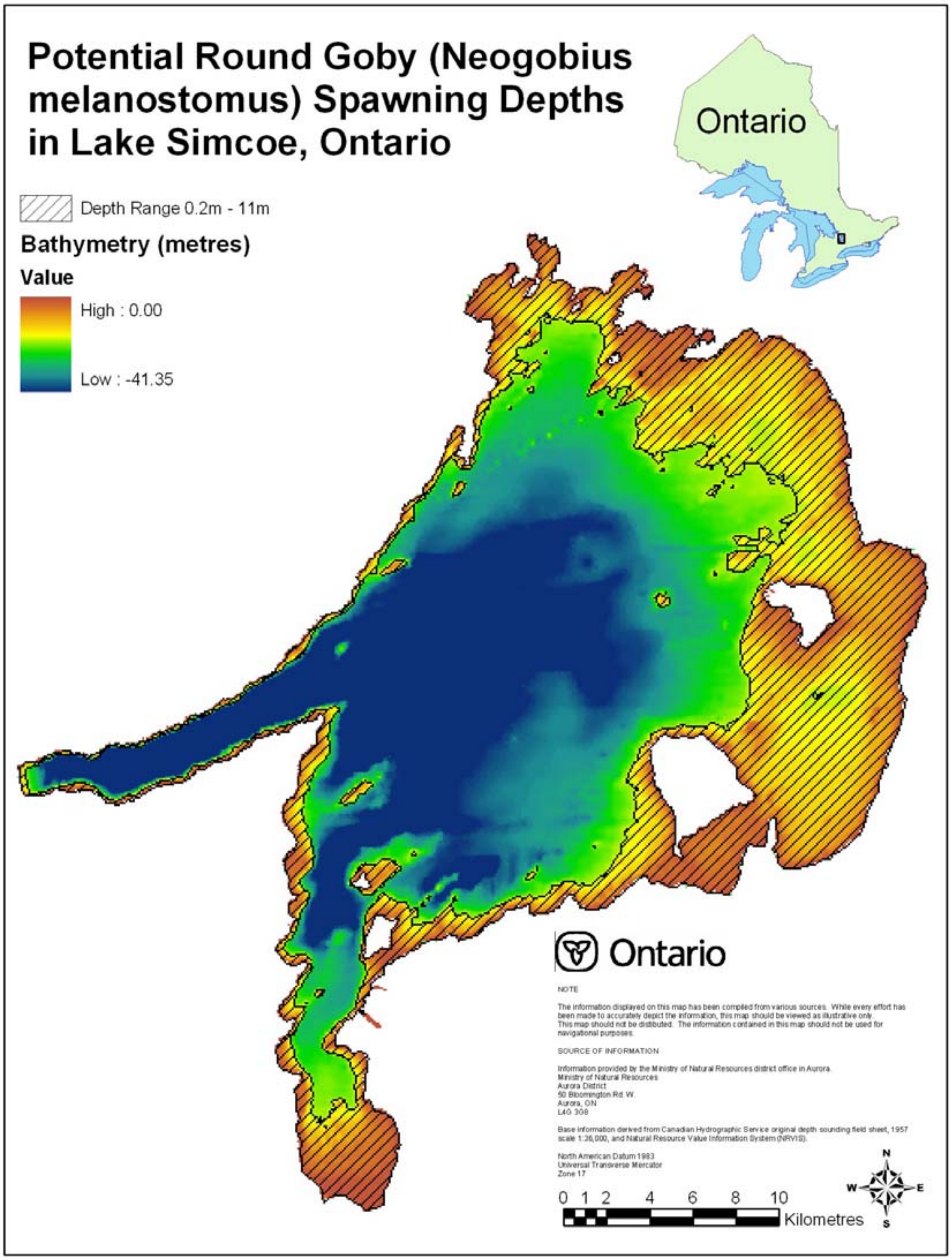


Figure 12. Potential round goby spawning depths in Lake Simcoe (McNiece and Borwick, unpubl. data).

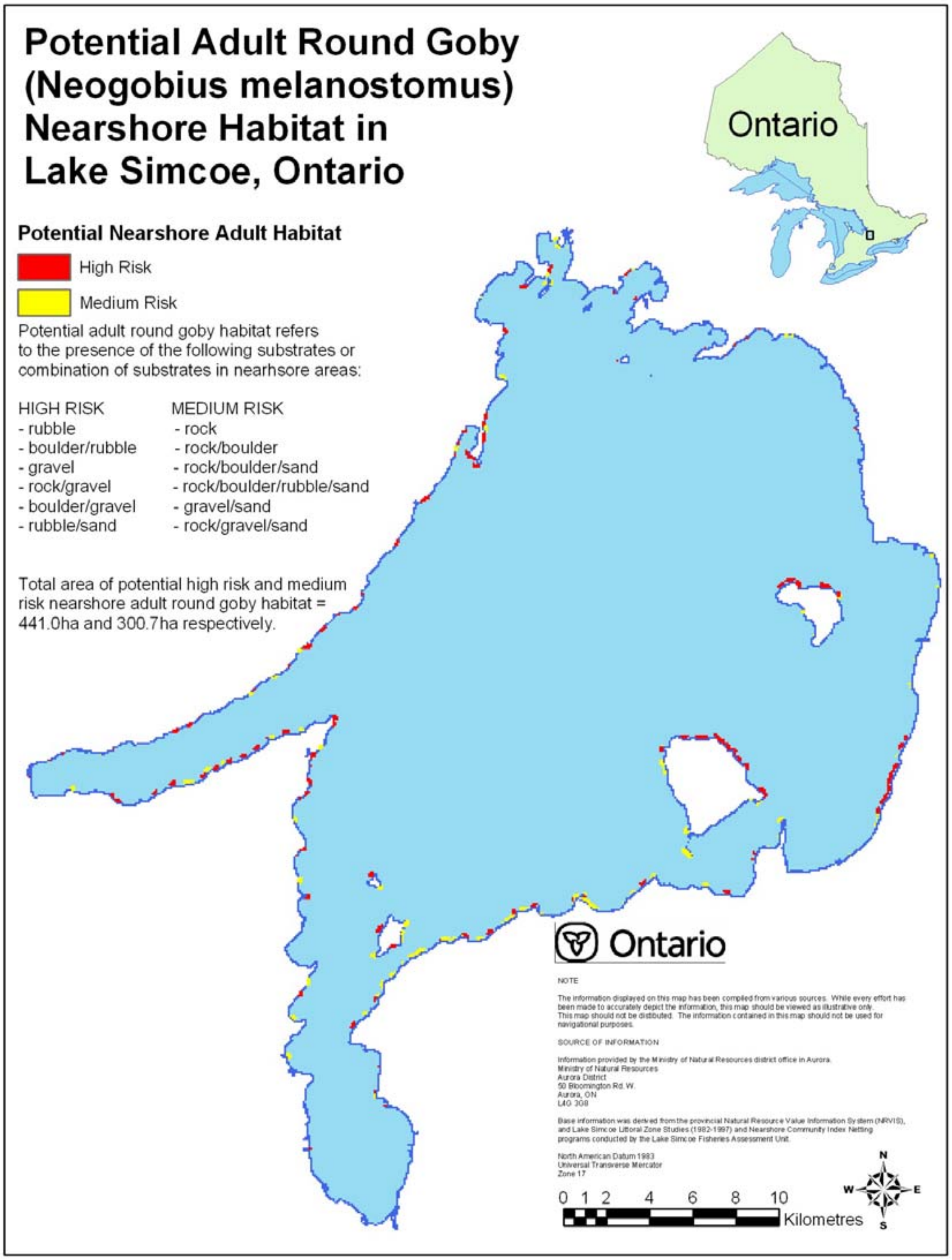


Figure 13. Potential high and medium risk nearshore adult round goby habitat in Lake Simcoe (McNiece and Borwick, unpubl. data).

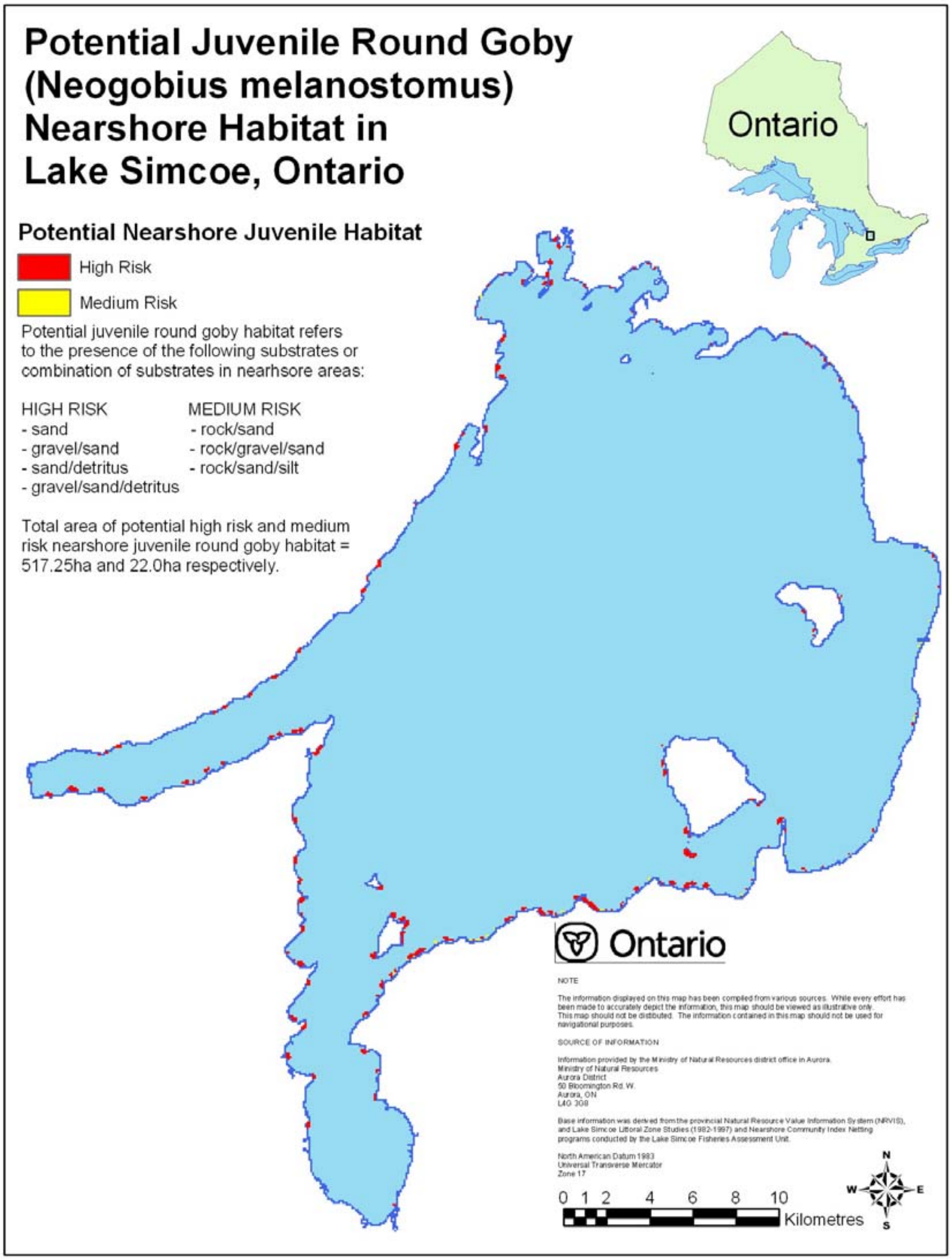


Figure 14. Potential high and medium risk nearshore juvenile round goby habitat in Lake Simcoe (McNiece and Borwick, unpubl. data).

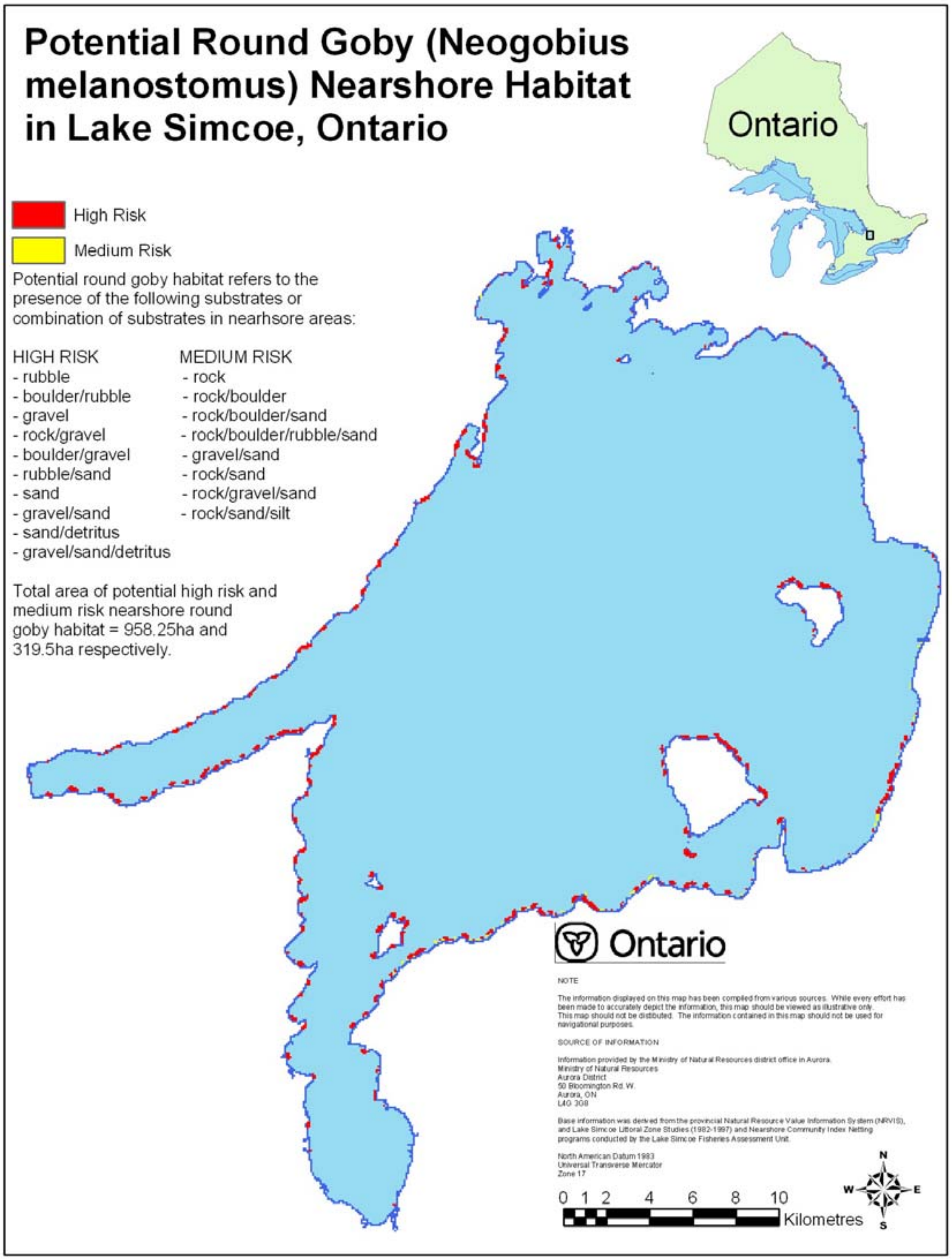


Figure 15. Potential high and medium risk nearshore total (combined adult and juvenile) round goby habitat in Lake Simcoe (McNiece and Borwick, unpubl. data).

Rank	Impact	Description
1	Negligible	No measurable impacts. Consequences can be absorbed through normal activity.
10	Low	A measurable impact. May require effort to minimize.
100	Medium	A significant impact. Can be managed under normal circumstances.
1,000	High	A critical impact. Will require proper management or adaptation.
10,000	Very High	A catastrophe. May not be manageable.

Figure 16. Impact categories and associated descriptions (from DFO 2003) using $\log_{10}$ scale.

Appendix A. Expert opinion online questionnaire (English version) [www.surveymonkey.com/rgoby_LSimcoe]

Introduction, page 1:
As part of a research project funded by Fisheries and Oceans Canada, a Quantitative Biological Risk Assessment Tool (QBRAT) has been developed as a tool for conducting risk assessments of aquatic invasive species. Several case studies involving different taxa groups from across Canada are being conducted in order to evaluate QBRAT. One of these case studies is looking at the risk of round goby (*Neogobius melanostomus*) invasion to Lake Simcoe, Ontario. To round out the case study, the case study leader would like to include as part of the methodology a determination of probability and associated level of certainty using expert opinion. You are being asked to complete this very brief online questionnaire in order for the case study leader to compile the results as expert opinion to feed into QBRAT.

Introduction, page 2:
Lake Simcoe is the largest inland lake (722 km^2) in southern Ontario and is the most intensively fished inland lake in Ontario with a yellow perch, lake trout and lake whitefish fishery. It supports a recreational fishery valued at $200 million annually and supports approximately 15% of Ontario's angling effort.

In August 2004, round gobies were found approximately 4 km upstream from Lake Simcoe in Pefferlaw Brook, likely as a result of the bait industry. As of summer 2006, despite eradication efforts, a few individuals of round goby have been found in Lake Simcoe.

For more information on round goby biology, please see:
http://filaman.ifm-geomar.de/Summary/SpeciesSummary.php?id=12019

Q.1a. What is the probability that round goby will survive in Lake Simcoe?

Rank	**Likelihood**	**Description**
0.05	Rare	Event may occur only in exceptional circumstances
0.2	Unlikely	Event could occur at some time
0.5	Moderate	Event should occur at some time
0.75	Likely	Event will probably occur at some time
0.95	Almost Certain	Event is expected to occur in most circumstances

The above table is a guideline only; respondent can enter any value between 0-1.

Q.1b. What is the level of confidence associated with your probability of survival?

Radio buttons (choose one):
- o Very certain (+/- 10% - specific scientific basis)
- o Reasonably certain (+/- 40 % - extrapolation/literature based)
- o Reasonably uncertain (+/- 70% - expert opinion)
- o Very uncertain (+/- 100% - best guess)

Optional comment space

Q. 2a. What impact will there be on the biological resources of Lake Simcoe should round goby be temporarily present (i.e. not survive one year)?

Radio buttons (choose one):
- o Negligible (no measurable impacts. Consequences can be absorbed through normal activity)
- o Low (a measurable impact. May require effort to minimize)
- o Medium (a significant impact. Can be managed under normal circumstances)
- o High (a critical impact. Will require strong management or adaptation)
- o Very high (a catastrophe. May not be manageable)

Q. 2b. What is the level of confidence associated with this impact?

Radio buttons (choose one):
- o Very certain (+/- 10% - specific scientific basis)
- o Reasonably certain (+/- 40 % - extrapolation/literature based)
- o Reasonably uncertain (+/- 70% - expert opinion)
- o Very uncertain (+/- 100% - best guess)

Optional comment space

Q. 3a. If round goby prove capable of surviving in Lake Simcoe, what is the probability that round goby will establish (i.e. successfully reproduce) in Lake Simcoe?

Rank	**Likelihood**	**Description**
0.05	Rare	Event may occur only in exceptional circumstances
0.2	Unlikely	Event could occur at some time
0.5	Moderate	Event should occur at some time
0.75	Likely	Event will probably occur at some time
0.95	Almost Certain	Event is expected to occur in most circumstances

The above table is a guideline only; respondent can enter any value between 0-1.

Q. 3b. What is the level of confidence associated with your probability of establishment?

Radio buttons (choose one):
- o Very certain (+/- 10% - specific scientific basis)
- o Reasonably certain (+/- 40 % - extrapolation/literature based)
- o Reasonably uncertain (+/- 70% - expert opinion)
- o Very uncertain (+/- 100% - best guess)

Optional comment space

Q. 4a. What impact will there be on the biological resources of Lake Simcoe should round goby survive in Lake Simcoe, but not become established?

Radio buttons (choose one):

- o Negligible (no measurable impacts. Consequences can be absorbed through normal activity)
- o Low (a measurable impact. May require effort to minimize)
- o Medium (a significant impact. Can be managed under normal circumstances)
- o High (a critical impact. Will require strong management or adaptation)
- o Very high (a catastrophe. May not be manageable)

Q. 4b. What is the level of confidence associated with this impact?

Radio buttons (choose one):

- o Very certain (+/- 10% - specific scientific basis)
- o Reasonably certain (+/- 40 % - extrapolation/literature based)
- o Reasonably uncertain (+/- 70% - expert opinion)
- o Very uncertain (+/- 100% - best guess)

Optional comment space

Q. 5a. What is the probability that if round goby can survive and successfully establish a population they will remain in a localized area within Lake Simcoe (e.g. nearshore areas only)?

Rank	Likelihood	Description
0.05	Rare	Event may occur only in exceptional circumstances
0.2	Unlikely	Event could occur at some time
0.5	Moderate	Event should occur at some time
0.75	Likely	Event will probably occur at some time
0.95	Almost Certain	Event is expected to occur in most circumstances

The above table is a guideline only; respondent can enter any value between 0-1.

Q. 5b. What is the level of confidence associated with your answer?

Radio buttons (choose one):

- o Very certain (+/- 10% - specific scientific basis)
- o Reasonably certain (+/- 40 % - extrapolation/literature based)
- o Reasonably uncertain (+/- 70% - expert opinion)
- o Very uncertain (+/- 100% - best guess)

Optional comment space

Q. 6a. What impact will there be on the biological resources of Lake Simcoe should round goby establish in Lake Simcoe, but not become widespread throughout the lake?

Radio buttons (choose one):

- o Negligible (no measurable impacts. Consequences can be absorbed through normal activity)

- Low (a measurable impact. May require effort to minimize)
- Medium (a significant impact. Can be managed under normal circumstances)
- High (a critical impact. Will require strong management or adaptation)
- Very high (a catastrophe. May not be manageable)

Q. 6b. What is the level of confidence associated with this impact?

Radio buttons (choose one):

- Very certain (+/- 10% - specific scientific basis)
- Reasonably certain (+/- 40 % - extrapolation/literature based)
- Reasonably uncertain (+/- 70% - expert opinion)
- Very uncertain (+/- 100% - best guess)

Optional comment space

Q. 7a. If round goby survive and establish in Lake Simcoe, what is the probability that round goby will become widespread throughout Lake Simcoe?

Rank	Likelihood	Description
0.05	Rare	Event may occur only in exceptional circumstances
0.2	Unlikely	Event could occur at some time
0.5	Moderate	Event should occur at some time
0.75	Likely	Event will probably occur at some time
0.95	Almost Certain	Event is expected to occur in most circumstances

The above table is a guideline only; respondent can enter any value between 0-1.

Q. 7b. What is the level of confidence associated with this impact?

Radio buttons (choose one):

- Very certain (+/- 10% - specific scientific basis)
- Reasonably certain (+/- 40 % - extrapolation/literature based)
- Reasonably uncertain (+/- 70% - expert opinion)
- Very uncertain (+/- 100% - best guess)

Optional comment space

Q. 8a. What impact will there be on the biological resources of Lake Simcoe should round goby become widespread throughout the lake?

Radio buttons (choose one):

- Negligible (no measurable impacts. Consequences can be absorbed through normal activity)
- Low (a measurable impact. May require effort to minimize)
- Medium (a significant impact. Can be managed under normal circumstances)
- High (a critical impact. Will require strong management or adaptation)
- Very high (a catastrophe. May not be manageable)

Q. 8b. What is the level of confidence associated with this impact?

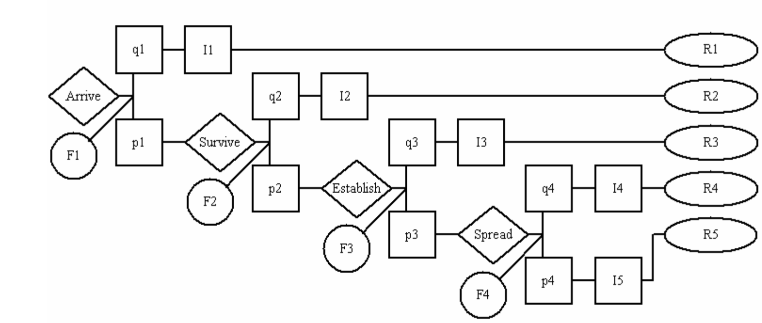
Radio buttons (choose one):

- o Very certain (+/- 10% - specific scientific basis)
- o Reasonably certain (+/- 40 % - extrapolation/literature based)
- o Reasonably uncertain (+/- 70% - expert opinion)
- o Very uncertain (+/- 100% - best guess)

Optional comment space

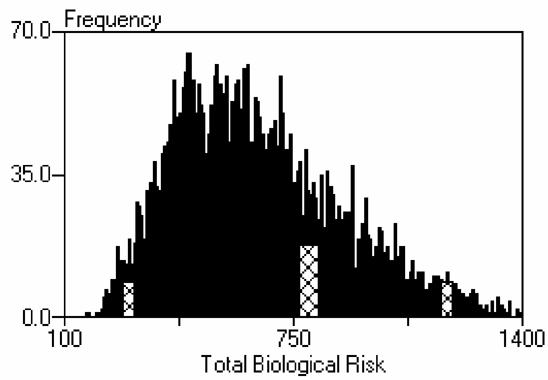
Optional name:

Appendix B: QBRAT results report.

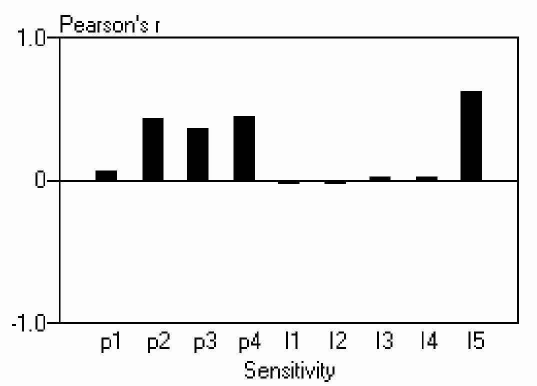


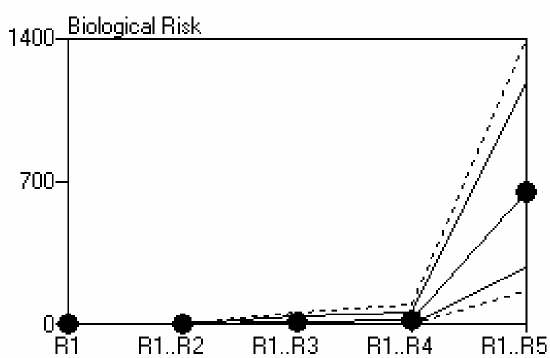
Species:	Round Goby
Location:	Lake Simcoe
Date:	22-Nov-2006

Monte Carlo Simulation Results: Biological Risks [PRNG=VB]



Probabilities	Calculated Risks
p1 = 1.00 (0.05774,U)	R1 = 0
p2 = 0.94 (0.2171,U)	R2 = 0.06
p3 = 0.95 (0.2194,U)	R3 = 4.7
p4 = 0.87 (0.2009,U)	R4 = 11.61
	R5 = 776.9
	Rb = 793.3
Impacts	Simulation Stats
I1 = 0 (0,U)	N = 5000
I2 = 1 (0.2309,U)	Mean = 647.9
I3 = 100 (23.09,U)	SD = 48760
I4 = 100 (23.09,U)	
I5 = 1000 (230.9,U)	
Sensitivities	
p1 = 0.066	
p2 = 0.427	
p3 = 0.356	
p4 = 0.437	
I1 = -0.020	
I2 = -0.014	
I3 = 0.021	
I4 = 0.025	
I5 = 0.617	





Cumulative Risk (CI = 95 %) [Sx = Sum R1 to Rx]

	Mean	Min	Max	Lower CI	Upper CI
S1	0	0	0	0	0
S2	0.1224	0	0.583	0	0.4662
S3	10.47	0	58.72	0	42.44
S4	22.73	0	94.52	0	59.17
S5	647.9	160.7	1398	279.5	1183