EVS 4009 Honours Research Project

Body size predicts the likelihood of harbouring ectoparasites among channel catfish (*Ictalurus punctatus*) in Lac des Chats and its tributaries

By: Allison Drake
7794826

Supervisor: Gabriel Blouin-Demers
April 23, 2019

University of Ottawa
Department of Biology

Abstract

Determining the factors that affect parasite presence is integral to parasitology. In fishes, body size influences parasite load; however, it remains ambiguous whether increased parasite presence is due to increased exposure time to ectoparasites and their vectors (a function of age) or to greater surface area available for attachment (a function of size). Disentangling the effects of each can be problematic since older fish are generally larger. I examined whether age and/or size could predict the likelihood of *Myzobdella lugubris* leech ectoparasite presence among channel catfish (*Ictalurus punctatus*) in Lac des Chats, Ottawa River, and its tributaries. The high correlation between otolith mass (used as a proxy for age) and fish mass (from which surface area was calculated) did not allow me to statistically isolate the effects of age from the effects of size. Logistic regression revealed that surface area was an important predictor of the likelihood of a fish being parasitized by leeches. The logit curve indicated that an increase of 500 cm^2 in surface area resulted, on average, in a 30% increase in the probability of being infected by a leech. These results highlight the importance of separating interrelated host traits that affect intraspecific variation in parasite presence.

Key Words: channel catfish, ectoparasite, leech, age, body size

Introduction

Determinants of parasite presence are an integral dimension of parasitology. Parasites are omnipresent and can affect the behaviour, physiology, survival, and fitness of the host species. Alterations in habitat selection, foraging efficiency, predator-prey relationships, competitive ability, and mate choice have been observed in infected host fishes (Barber et al. 2000). Ultimately, parasites can cause reduced host growth and reproduction rates, shorter lifespans, and mortality (Ramdane et al. 2013; Tavares-Dias et al. 2015).

I examine the influence of host age and size on the likelihood of ectoparasite presence, which can be explained by two hypotheses. The first hypothesis stipulates that hosts accumulate parasites as they grow older because the likelihood of parasite acquisition increases over time. Exposure time can only be examined as a predictor of ectoparasite presence provided that hosts do not demonstrate acquired immunity (Jones 2001; Raffel et al. 2009). Hanek and Fernando (1978) found that parasite abundance increased with fish age among pumpkinseed (*Lepomis gibbosus*). Many other studies also found that infection was cumulative with fish age (Lo et al. 1998; Espínola-Novelo et al. 2015; Dugarov and Pronin 2017). The second hypothesis is related to the theory of island biogeography (MacArthur and Wilson 1967), and maintains that larger hosts have more space on which parasites can settle. Therefore, parasitic infections usually show an increase in intensity with an increase in host size due to the larger surface area available for attachment (Dogiel et al. 1958). Tucker et al. (2002) found that larger Atlantic salmon (*Salmo salar*) harboured higher mean numbers of parasites, while Lo et al. (1998) found that host body length showed a positive relationship with parasite abundance in reef fishes.

The channel catfish (*Ictalurus punctatus* Rafinesque, 1818) (Ictaluridae, Siluriformes) is the largest catfish species native to Canada and an abundant opportunist feeder that inhabits warmwater lakes and streams (Holm et al. 2010). This species is a significant predator with a disproportionately large ecological impact (Townsend and Winterbourn 1992) since it is an omnivorous feeder in the benthic area, water column, and water surface. The high tolerance of channel catfish to diverse water parameters enables it to inhabit many water bodies, with a range extending throughout eastern North America from the Great Lakes-St. Lawrence Basin in Canada to northern Mexico (U.S. Fish and Wildlife Service n.d.). Moreover, the channel catfish is recreationally important as a sport fish and economically valuable since it is the most extensively cultured food fish in North America (Peterson et al. 2014).

The leech *Myzobdella lugubris* Leidy, 1851 (Hirudinidae, Piscicolidae) is an opportunistic, widely-distributed sanguivorous ectoparasite commonly found on catfishes, sunfishes, and perches (Sawyer et al. 1975). Leeches are found attached to a substrate or swimming freely, and respond to changes in illumination, vibrations, chemical stimuli, and temperature differences as hosts approach (Thorp and Rogers 2014). *M. lugubris* is parasitic on skin and fin surfaces of the host for most of the year before detaching to deposit cocoons (Daniels and Sawyer 1975). I examine whether exposure time can predict the probability of parasite presence using a one-year time scale due to annual parasite recolonization.

Variation in growth rate can result in a range of body sizes for individuals of a particular age (Halliday and Verrell 1988). Therefore, it is essential to use a direct measure of age, instead of size as a proxy for age. Channel catfish age can be determined using inner ear bones; calcified structures for sound reception and balance. All teleosts have three sets of otoliths; sagittae, lapilli and asterisci. Sagittae are largest in most bony fishes, except Siluriformes and Cypriniformes (Jawad et al. 2011). Often, fisheries scientists declare that they are using channel catfish sagittae when in fact they are using the larger lapilli (Long and Stewart 2010). In this study, lapillar otolith mass is used as a proxy for fish age because mass increases over time as layers of calcium carbonate are continually deposited (Dub et al. 2013). Fish grow faster in the summer and otolith layers grow larger and wider apart, resulting in a notable increase in mass. Fish ageing using otolith mass offers a rapid, objective and less labour-intensive option than using thin-sectioned otoliths. Yet, this method remains underutilized, especially among researchers studying freshwater fishes (Lepak et al. 2012).

Disentangling the effect of size and age in predicting the likelihood of ectoparasite presence on channel catfish can be problematic since older fish are generally larger in size. The inherent difficulty of differentiating the influence of intertwined traits could explain the scarcity of intraspecific studies that include fish size, age and parasite abundance, as noted by Lo et al. (1998). My aim was to determine if the likelihood of ectoparasite presence in channel catfish (*Ictalurus punctatus*) in Lac des Chats and two tributaries could be predicted by age and/or body size. I expected a higher likelihood of ectoparasite presence among larger individuals with greater surface area for attachment, and older individuals that have been exposed to parasites and their vectors for a longer time period. To the best of my knowledge, this is the first study to distinguish between the effects of age and size on parasite presence in fish.

Methods

Study site

Sampling took place in Lac des Chats, a ~40-km stretch of the Ottawa River between Portage-du-Fort, Québec and Chats Falls Generating Station, and two of its tributaries; the Madawaska River and Mississippi River. Lac des Chats draws its name from the historical abundance of channel catfish observed in the area. All work was completed on the Ontario side of the Ottawa river. Seven sites were sampled; five in the main channel, and one in each tributary (Figures 1 and 2). Channel catfish were obtained from the beginning of June until the end of August 2018. This research was conducted with a Ministry of Natural Resources and Forestry licence (#1089849) and approved by the University of Ottawa's Animal Care Committee in accordance with the Canadian Council on Animal Care (protocol #BL-3015).

Field measurements

I sampled in the morning (0800) and at dusk (1830), when fish are most active. I caught 162 channel catfish using fishing rods with lead weights and treble hooks, using worms as bait. At every site, the total length of each fish was measured and recorded to obtain individuals of varying body sizes. If the site size quota was already met, catfish were returned to the river unharmed. I euthanized the retained fish in a large container of water diluted with clove oil that had a concentration of at least 150 mg/l, with additional drops added as necessary (Neiffer and Stamper 2009; Leary 2013). Once opercular function had ceased for 10 minutes, the weight of each individual was taken using a Pesola spring scale. Ectoparasite presence or absence was then recorded (Figure 3). The channel catfish were frozen within hours of euthanasia.

Otoliths

I dissected the catfish to obtain the left and right lapillar otoliths (Buckmeier et al. 2002) (Figures 4 and 5). The otoliths were rinsed with water to remove any attached material and dried. Otolith mass was measured using a Denver Instrument analytical balance.

Surface area

I calculated channel catfish surface area using the formula $S = 11.2M^{0.65}$, where S is surface area and M is fish mass (O'Shea et al. 2006). The calculated surface area includes body and fin surface area, but excludes gill surface area. I used the formula for Atlantic cod (*Gadus morhua*) since this species is most similar in body form to *Ictalurus punctatus* (Figure 6). The other five fishes studied by these researchers; saithe (*Pollachius virens*), halibut *(Hippoglossus hippoglossus*), and three salmonid species, do not resemble channel catfish.

Statistical analyses

Prior to determining if age (using otolith mass as a proxy) could predict the likelihood of ectoparasite presence, I calculated the correlation between otolith mass and fish mass, which is incorporated into surface area in the size hypothesis. If these two variables displayed high correlation, then otolith mass would offer no new information that could predict the likelihood of parasitism. However, if fish mass and otolith mass showed little correlation, then otolith mass could provide distinct information to explain the likelihood of ectoparasite presence. I also calculated a correlation confirming that surface area and otolith mass have the same relationship as fish mass and otolith mass. To determine if fish size could predict the likelihood of a fish being parasitized, I ran a binary logistic regression comparing surface area and the likelihood of ectoparasite presence. Utilizing presence-absence data was necessary because 39 of 162 channel catfish did not harbour ectoparasites. Statistical analyses were performed in JMP 13 from SAS, with an alpha value of 0.05.

Results

The high correlation between fish mass and otolith mass ($r = 0.91$), and surface area and otolith mass ($r = 0.92$) did not allow me to statistically disentangle the effects of age from the effects of size. (Figure 7). Surface area was found to be an important predictor of the likelihood of a fish being parasitized by leeches ($p = 0.0027$). The logit curved indicated that an increase of 500 cm^2 in surface area resulted, on average, in a 30% increase in the probability of being infected by a leech, as can be seen between 300 cm^2 and 800 cm^2 (Figure 8).

Discussion

I attempted to test two competing hypotheses to determine if age and/or body size could predict the likelihood of channel catfish harbouring leech ectoparasites. The high degree of correlation between otolith mass and fish mass did not allow me to statistically isolate the effect of age from the effect of size.

However, I found support for the hypothesis that larger individuals have a greater likelihood of ectoparasite presence due to increased surface area available for attachment. As predicted, larger individuals had a greater likelihood of harbouring at least one leech than smaller fish. Theoretically, I could have chosen to test either the age or size hypothesis because otolith mass and fish mass present the same information. I chose to test the size rather than the age hypothesis because body size is more commonly addressed in literature. In addition, the age hypothesis, which is more representative of exposure time because of the smaller timescale in this study, is weaker than the body size hypothesis. This is due to the short lifespan (maximum of a few years) and annual reproductive cycle of leeches that prevents ectoparasite accumulation over multiple years.

The cyclic life history of leech ectoparasites means that all hosts should have entered the active season with none or very few leeches. Daniels and Sawyer (1975) found that the reproductive cycle of *Myzobdella lugubris* was driven by water temperature, with leech abundance on white bullhead (*Ameiurus catus*) increasing during the winter and declining in the spring as the leeches detached to reproduce. Although absolute water temperatures differ between South Carolina; the chosen study area, and Ontario, the relative seasonal temperature pattern is identical. I expected leech abundance on channel catfish to have reached an annual minimum at the beginning of the sampling season in June, which enabled the age hypothesis to be tested as ectoparasites accumulated throughout the months that followed.

Additionally, I examined channel catfish of varying ages, including very young individuals that may have been born that season. Channel catfish in the Ottawa River generally spawn from late June to early July, although timing can vary with water temperature (Smith 1974). Analyzing parasite presence in juveniles compared to older individuals allowed the exposure time mechanism of the age hypothesis to be tested within a one-year timescale.

My results are consistent with other studies of fish. George-Nascimiento and Oliva (2015) noted that in 38 different fish species, individuals with greater total lengths had a higher prevalence of parasitism. Poulin et al. (1991) found that size directly influenced ectoparasite colonization for copepods of brook trout (*Salvelinus fontinalis*), while Tucker et al. (2002) found that larger Atlantic salmon harboured higher parasite abundance. Similar to my study results, Lo et al. (1998) were unable to differentiate size and age effects on parasite prevalence. Teasing apart highly-correlated traits such as otolith mass, fish mass, fish length, and surface area renders study questions of this nature extremely challenging.

Other factors including fish traits could explain the observed phenomenon. Kearn (1967) discovered that monogenean skin parasite larvae were attracted to the mucus produced by common sole (*Solea solea*). Larger fish have more epidermis and can secrete more mucus, thereby increasing parasite attraction. Furthermore, Bovet (1967) suggested that larger fish have a higher ventilation volume through their gills, which physically draws parasites to the fish and increases attachment likelihood. These physical stimuli may provide alternate explanations for my results.

My results suggest that larger channel catfish may be disproportionately affected by any adverse effects of ectoparasites. Rábago-Castro et al. (2014) found that channel catfish infected with a gill monogenean parasite had a significantly lower mean weight and growth rate than non-infected individuals. Parasites can increase the chances of fish mortality by depriving the host of vital nutrients, facilitating pathogen entry at lesion sites, and serving as pathogen vectors (Thorp and Rogers 2014). *Myzobdella lugubris* was found to contain Viral Hemorrhagic Septicemia virus, which caused widespread fish mortality in the Great Lakes-St. Lawrence Basin (Faisal and Schulz 2009; Faisal et al. 2012). Alternatively, larger fish may be better able to withstand an infection than smaller fish with the same number of ectoparasites. Smaller fish tended to be most susceptible to damage even though they harboured lower absolute numbers of the ectoparasite *Lepeophtheirus salmonis* (Tucker et al. 2002). These two possibilities imply two opposing selective pressures, which could shape population dynamics (Ramdane et al. 2013) and result in evolutionary ecology changes over longer time scales (Barber et al. 2000).

Future research directions should include the study of endoparasites, which accumulate every year without recolonization. This may elucidate the link between exposure time and the likelihood of parasite presence. Furthermore, fish sex should be incorporated into similar analyses, which would yield insight into sex-specific mechanisms that may affect the likelihood of parasite presence. In species such as lizards, testosterone has been found to be immunosuppressive, with males harbouring greater parasite abundance than females (Salvador et al. 1996).

This study provided insight into whether the likelihood of ectoparasite presence in channel catfish in Lac des Chats and two of its tributaries could be predicted by age and/or body size. Many researchers have suggested that parasite load increases with fish age due to longer exposure time to parasites and their vectors. My results showed that larger channel catfish with greater surface area for attachment had a higher likelihood of being parasitized by at least one *Myzobdella lugubris* leech. These results highlight the importance of separating entwined host traits that affect intraspecific variation in the likelihood of parasite presence.

Acknowledgements

I would like to thank my supervisor, Gabriel Blouin-Demers. I am grateful for field and laboratory assistance from F. Janzen, S. Karau, and S. Tessier. This research was funded by a Natural Sciences and Engineering Research Council of Canada (NSERC) grant to G.B.D. Funds were utilized for the boat, gasoline and other field equipment.

References

Barber, I., Hoare, D., and Krause, J. 2000. Effects of parasites on fish behaviour: a review and evolutionary perspective. Review in Fish Biology and Fisheries, 10(2): 131-165.

Bovet, J. 1967. Contribution à la morphologie et à la biologie de *Diplozoon paradoxum* v. Nordmann, 1832. Bulletin de la société neuchâteloise des sciences naturelles, 90: 63-159.

Buckmeier, D.L., Irwin, E.R., Betsill, R.K., and Prentice, J.A. 2002. Validity of otoliths and pectoral spines for estimating ages of channel catfish. North American Journal of Fisheries Management, 22(3): 934-942.

Daniels, B.A. and Sawyer, R.T. 1975. The biology of the leech Myzobdella lugubris infesting blue crabs and catfish. The Biological Bulletin, 148(2):193-198.

Doering-Arjes, P., Cardinale, M., and Mosegaard, H. 2008. Estimating population age structure using otolith morphometrics: a test with known-age Atlantic cod (*Gadus morhua*) individuals. Canadian Journal of Fisheries and Aquatic Sciences, 65(11): 2342-2350.

Dogiel, V.A., Petrushevski, G.K., and Yu, I. 1958. Parasitology of fishes. Leningrad University Press, Leningrad (translated by Kabata, Z. Oliver & Boyd, London). 384 p.

Dub, J.D., Redman, R.A., Wahl, D.H., and Czesny, S.J. 2013. Utilizing random forest analysis with otolith mass and total fish length to obtain rapid and objective estimates of fish age. Canadian Journal of Fisheries and Aquatic Sciences, 70(9): 1396-1401.

Dugarov, Z.N. and Pronin, N.M. 2017. Faunal diversity and dynamics of species richness and dominance of parasite communities in age series of the perch (*Perca fluviatilis)*. Russian Journal of Ecology, 48(1): 38-44.

Espínola-Novelo, J.F., González-Salas, C., Guillén-Hernández, S., and MacKenzie, K. 2015. Metazoan parasite infracommunities of Mycteroperca bonaci (Poey, 1960) (Pisces: Epinephelidae) in reef and coastal environments off the coast of Yucatan, Mexico. Acta Parasitologica, 60(3): 476-484.

Faisal, M. and Schulz, C.A. 2009. Detection of Viral Hemorrhagic Septicemia virus (VHSV) from the leech *Myzobdella lugubris* Leidy, 1851. Parasites and Vectors, 2(1): 45-48.

Faisal, M., Shavalier, M., Kim, R.K., Millard, E.V., Gunn, M.R., Winters, A.D. et al. 2012. Spread of emerging Viral Hemorrhagic Septicemia virus strain, Genotype IVb, in Michigan, USA. Viruses, 4(5): 734-760.

Fish Identification. (n.d.). Channel Catfish (*Ictalurus punctatus)*. Retrieved March 15, 2019, from http://identifyfish.blogspot.com/2010/11/channel-catfish-ictalurus-punctatus.html

George-Nascimiento, M. and Oliva, M. 2015. Fish population studies using parasites from the Southeastern Pacific Ocean: considering host population changes and species body size as sources of variability of parasite communities. Parasitology, 142(1): 25-35.

Halliday, T. and Verrell, P. 1988. Body size and age in amphibians and reptiles. Journal of Herpetology, 22(3): 253-265.

Hanek, G. and Fernando, C.H. 1978. The role of season, habitat, host age and sex on gill parasites of Lepomis gibbosus (L). Canadian Journal of Zoology, 56(6): 1247-1250.

Haxton, T. 1999. Nearshore community index netting of Lac des Chats (Ottawa River). Ontario Ministry of Natural Resources, Pembroke, Ontario. 19 p.

Holm, E., Mandrak, N.E., and Burridge, M.E. 2010. The ROM field guide to freshwater fishes of Ontario. Royal Ontario Museum, Toronto, Ontario. 462 p.

Jawad, L.A., Ambuali, A., Al-Mamry, J.M., and Al-Busaidi, H.K. 2011. Relationships between fish length and otolith length, width and weight of the Indian Mackerel Rastrelliger kanagurta (Cuvier, 1817) collected from the Sea of Oman. Croatian Journal of Fisheries, 69(2): 51-61.

JMP®, Version 13. SAS Institute Inc., Cary, NC, 1989-2019.

Jones, S.R.M. 2001. The occurrence and mechanisms of innate immunity against parasites in fish. Developmental and Comparative Immunology, 25(8-9): 841-852.

Kearn, G.C. 1967. Experiments on host-finding and host-specificity in the monogenean skin parasite Entobdella soleae. Parasitology, 57(3): 585-605.

Leary, S. 2013. AVMA guidelines for the euthanasia of animals: 2013 Edition. Journal of the American Veterinary Medical Association, 1-102.

Lepak, J.M., Cathcart, C.N., and Hooten, M.B. 2012. Otolith mass as a predictor of age in kokanee salmon (Oncorhynchus nerka) from four Colorado reservoirs. Canadian Journal of Fisheries and Aquatic Sciences, 69(10): 1569-1575.

Lo, C.M., Morand, S., and Galzin, R. 1998. Parasite diversity/host age and size relationship in coral-reef fishes from French Polynesia. International Journal of Parasitology, 28(11):1695-1708.

Long, J.M. and Stewart, D.R. 2010. Verification of otolith identity used by fisheries scientists for aging channel catfish. Transactions of the American Fisheries Society, 139(6): 1775-1779.

MacArthur, R.H. and Wilson, E.O. 1967. The Theory of Island Biogeography. Princeton University Press, Princeton, New Jersey. 215 p.

Matić-Skoko, S., Ferri, J., Škeljo, F., Bartulović, V., Glavić, K., and Glamuzina, B. 2011. Age, growth and validation of otolith morphometrics as predictors of age in the forkbeard, Phycis phycis (Gadidae). Fisheries Research, 112(1): 52-58.

Neiffer, D.L. and Stamper, M.A. 2009. Fish sedation, anesthesia, analgesia, and euthanasia: Considerations, methods, and types of drugs. Institute for Laboratory Animal Research Journal, 50(4): 343-360.

NOAA Fisheries. (n.d.). Atlantic Cod. Retrieved March 15, 2019, from https://www.fisheries.noaa.gov/species/atlantic-cod

O'Shea, B., Mordue-Luntz, A.J., Fryer, R.J., Pert, C.C., and Bricknell, I.R. 2006. Determination of the surface area of a fish. Journal of Fish Diseases, 29(7): 437-440.

Peterson, B.C., Bosworth, B.G., Li, M.H., Beltran, R., and Santos, G.A. 2014. Assessment of a phytogenic feed additive (Digestarom P.E.P. MGE) on growth performance, processing yield, fillet composition, and survival of channel catfish. Journal of the World Aquaculture Society, 45(2): 206-212.

Poulin, R., Curis, M.A., and Rau, M.E. 1991. Size, behaviour, and acquisition of ectoparasitic copepods by brook trout, Salvelinus fontinalis. Oikos, 61(2): 169-174.

Rábago-Castro, J.L., Sánchez-Martínez, J.G., Perez-Castañeda, R., Vázquez-Sauceda, M., and Ruiz-Orozco, G. 2014. Chronic effects of a monogenean *Ligictaluridus floridanus* (Ancyrocephalidae) infection on channel catfish (*Ictalurus punctatus*) growth performance. Acta Veterinaria Brno, 83(2): 83-87.

Raffel, T.R., Legros, R.P., Love, B.C., Rohr, J.R., and Hudson, P.J. 2009. Parasite age-intensity relationships in red-spotted newts: Does immune memory influence salamander disease dynamics? International Journal for Parasitology, 39(2): 231-241.

Ramdane, Z., Trilles, J-P., Mahe, K., and Amara, R. 2013. Metazoan ectoparasites of two teleost fish, *Boops boops* (L.) and *Mullus barbatus barbatus* L. from Algerian coast: diversity, parasitological index and impact of parasitism. Cybium, International Journal of Ichthyology, 37(1-2): 59-66.

Salvador, A., Veiga, J.P., Martin, J., Abelenda, M., and Puertac, M. 1996. The cost of producing a sexual signal: testosterone increases the susceptibility of male lizards to ectoparasitic infestation. Behavioral Ecology, 7(2): 145-150.

Sawyer, R.T., Lawler, A.R., and Oversrteet, R.M. 1975. Marine leeches of the eastern United States and the Gulf of Mexico with a key to the species. Journal of Natural History, 9(6): 633-667.

Smith, N.W. 1974. Age, growth, food, fecundity, maturation and local distribution of channel catfish (Ictalurus punctatus) in the Ottawa River near Ottawa and Hull, Canada. Thesis, University of Ottawa, Ottawa, Ontario. 120 p.

Tavares-Dias, M., Dias-Júnior, M.B.F., Florentino, A.C., Silva, L.M.A., and da Cunha, A.C. 2015. Distribution pattern of crustacean ectoparasites of freshwater fish from Brazil. Brazilian Journal of Veterinary Parasitology, 24(2): 136-147.

Thorp, J.H. and Rogers, D.C. (eds.) 2014. Thorp and Covich's Freshwater Invertebrates: Ecology and General Biology (4th ed., Vol. 1). Academic Press, San Diego, California. 1148 p.

Townsend, C.R. and Winterbourn, M.J. 1992. Assessment of the environmental risk posed by an exotic fish: The proposed introduction of channel catfish (Ictalurus punctatus) to New Zealand. Conservation Biology, 6(2): 273-282.

Tucker, C.S., Sommerville, C., and Wootten, R. 2002. Does size really matter? Effects of fish surface area on the settlement and initial survival of Lepeophtheirus salmonis, an ectoparasite of Atlantic salmon Salmo salar. Diseases of Aquatic Organisms, 49(2): 145-152.

U.S. Fish and Wildlife Service. (n.d.). Channel catfish. Retrieved March 6, 2019, from https://www.fws.gov/fisheries/freshwater-fish-of-america/channel_catfish.html

Appendix

Table 1. Location of study sites in Lac des Chats, Ottawa River and the Mississippi and Madawaska River tributaries in DMS latitude and longitude coordinates.

Site	Area	North	West
1	Mississippi R.	45^{o}25'47.0"	76^{o}15'40.0"
2	Lac des Chats	45^{o}27'46.4"	76^{o}23'12.7"
3	Lac des Chats	45^{o}30'47.6"	76^{o}30'17.2"
4	Lac des Chats	45^{o}29'48.0"	76^{o}26'47.0"
5	Lac des Chats	45^{o}31'08.0"	76^{o}32'22.0"
6	Lac des Chats	45^{o}26'51.0"	76^{o}19'4.2"
7	Madawaska R.	45^{o}26'32.9"	76^{o}20'54.9"

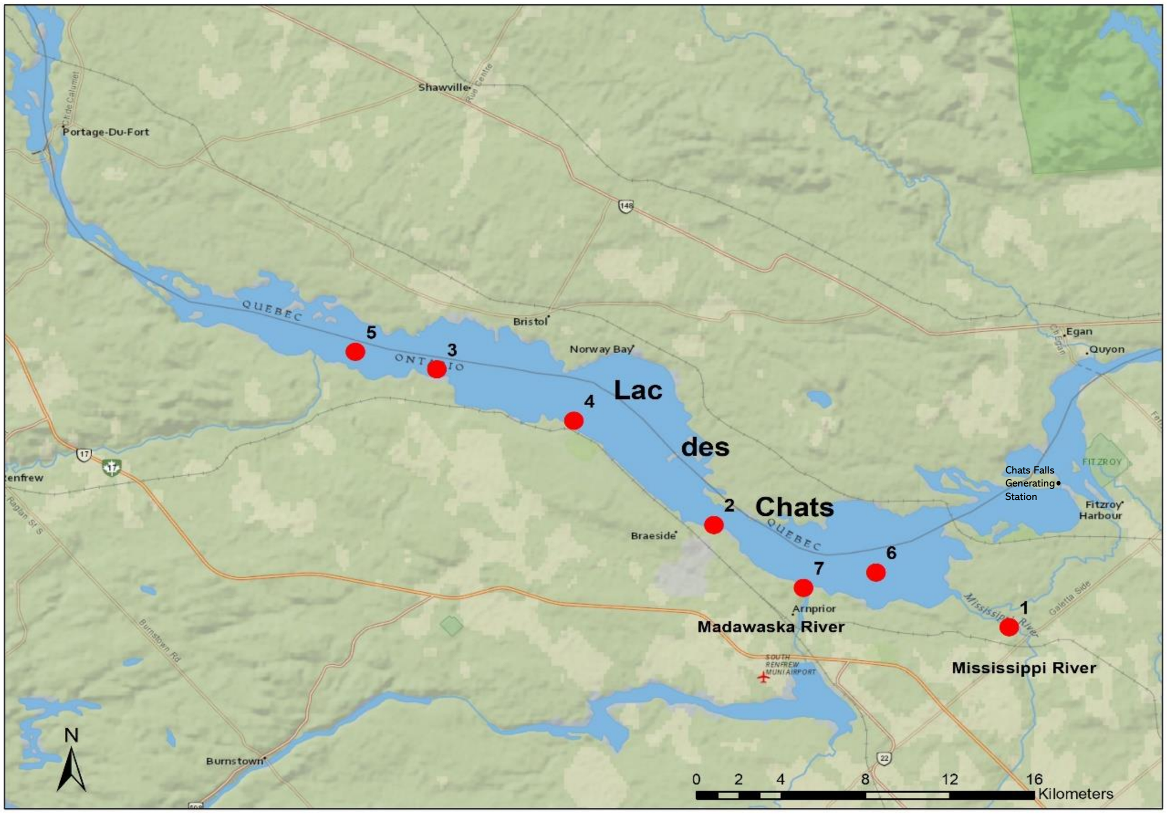


Figure 1. Location of seven sampling sites in Lac des Chats and two tributaries; the Mississippi River and Madawaska River. Note Portage-du-Fort, QC, and Chats Falls Generating Station, which delineate the ~40-km stretch.

Figure 2. Sampling site 4 in Lac des Chats, Ottawa River. This site's features are representative of the five main channel sites.

Figure 3. *Myzobdella lugubris* Leidy, 1851.

Figure 4. Size comparison of a lapillar otolith pair with my hand.

Figure 5. Lapillar otolith pairs from 162 channel catfish.

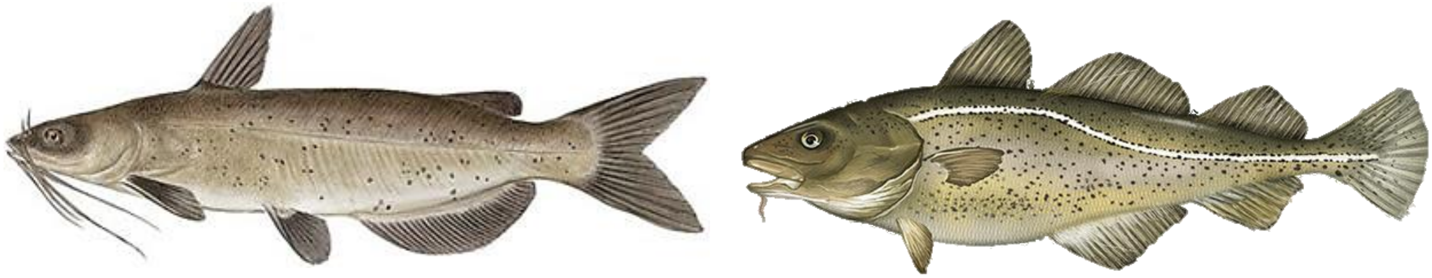


Figure 6. Channel catfish (left) shares a similar body form with Atlantic cod (right) (Fish Identification n.d., NOAA Fisheries n.d., respectively).

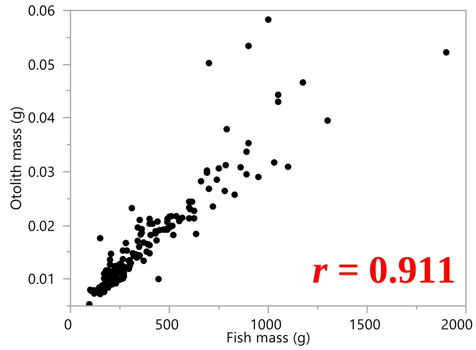
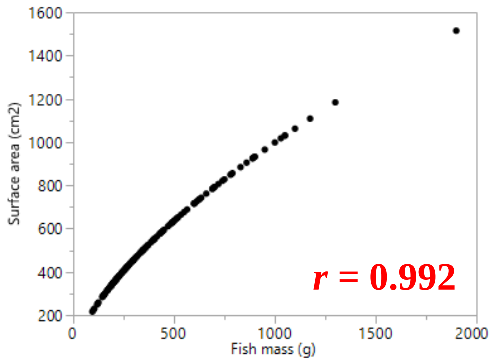
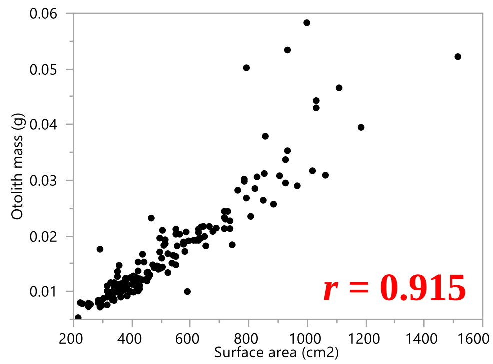
	Fish mass	Otolith mass
Otolith mass		
Surface area		

Figure 7. Correlation matrix with the variables fish mass, otolith mass and surface area, and the corresponding coefficients of correlation. All variable sets are highly correlated.

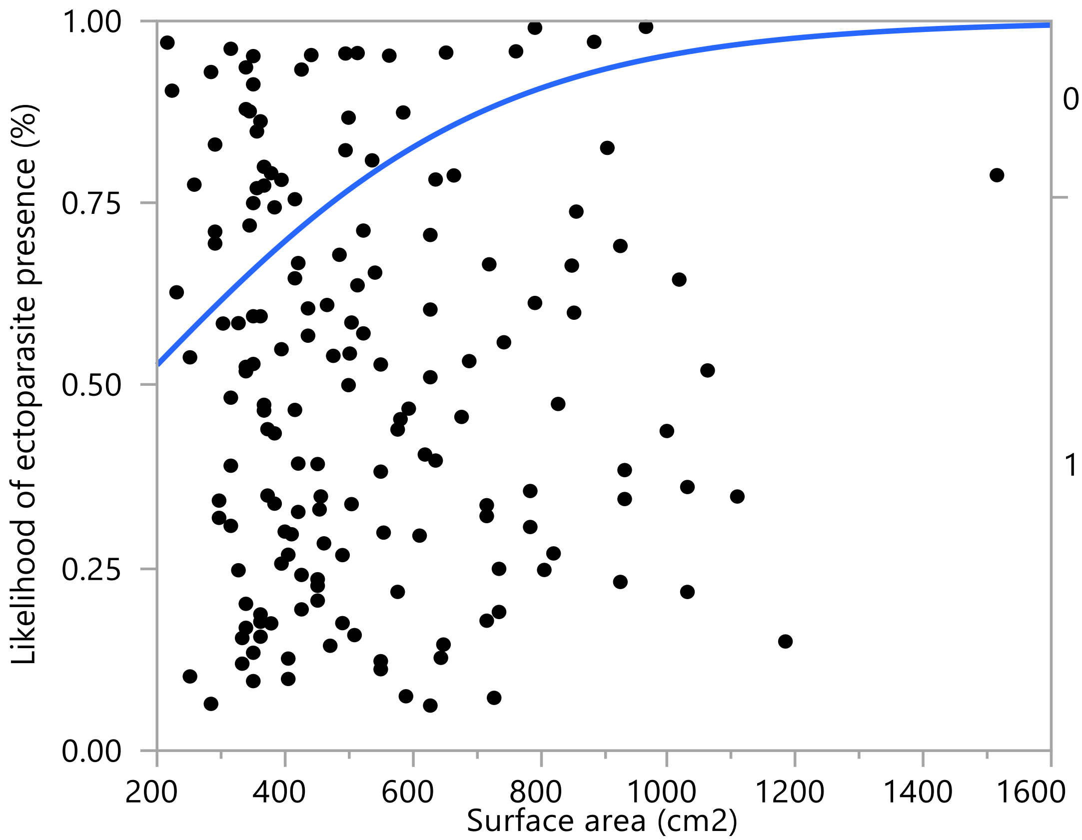


Figure 8. Logit curve indicating that an increase of approximately 500 cm^2 in surface area results in a 30% increase in the probability of a channel catfish being infected with at least one leech ectoparasite.