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SAMPLING EFFORT TO DETECT ASIAN CARPS DURING RESPONSE ACTIVITIES IN THE GREAT LAKES BASIN

Coordinated response effort in the Toronto Islands, July 2015 following the detection of a Grass Carp.

Figure 1. DFO's Asian Carp Program Early Detection Surveillance sites in the Great Lakes basin.

Context:

*Asian carps (Bighead Carp [*Hypophthalmichthys nobilis*], Silver Carp [*H. molitrix*], Grass Carp [*Ctenopharyngodon idella*], and Black Carp [*Mylopharyngodon piceus*]) were introduced in the southern U.S. in the late 1960's and have since spread throughout the Mississippi River basin causing significant losses to biodiversity and ecosystem services. These species are nearing the Great Lakes basin and are anticipated to pose significant ecological and socio-economic threats, should they arrive. In response to these threats, DFO developed the Asian Carp Program in 2012. The Asian Carp Program conducts extensive early detection surveillance around the Great Lakes basin and implements a response plan based on the Incident Command System (ICS) following the verified capture of an Asian carp in Canadian waters. When on-water response operations are conducted, the response plan directs intensive, targeted sampling using traditional gears around the location of capture. Sampling efforts are scaled up or down depending on the fertility, number, species, or life stage of captured individuals. The sampling effort (duration, intensity) and search area are determined at the discretion of the ICS team. Science advice was requested to identify best practices for allocating sampling effort during responses. The goal of this science advisory meeting was to identify the relationship between sampling effort (time, intensity, search area) and the probability of detecting Asian carps should they be present in the search area.*

This Science Advisory Report is from the January 13–15, 2021 regional peer review meeting on Sampling effort to detect Asian carps during response activities in the Great Lakes basin. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

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SUMMARY

- Response programs are designed to remove newly discovered, high priority aquatic invasive species from the wild. Advice is needed regarding sampling effort required to detect and remove Asian carps during response activities in the Great Lakes basin.
- Simulation models were developed to examine the relationship between fish abundance, the probability of capture, and sampling effort for detection and local removal under different sampling schemes (systematic, random, repeat, and informed sampling), response area sizes, and assumed fish behaviours (avoidance, aggregation, no emigration).
- The range in relative effort required for detection and local removal was strongly influenced by the probability of capture, which is poorly known for most gears and environmental conditions.
    - Under the base simulation, the relative effort required for detection ranged from 0.07 to 13.48 complete passes of a response area, while relative effort for local removal ranged from 0.72 to 69.55 complete passes. For a modelled 75 ha response area, an electrofishing boat crew could require 5.8–1,120.7 sampling hours for detection, while local removal could require 59.9–5,782.1 sampling hours.
- Lower effort for detection was needed when the probability of capture was high, there was a higher abundance of Asian carps, and to a lesser degree if fish did not aggregate. Lower effort for local removal was needed when the probability of capture was high and there were fewer Asian carps. Total effort for detection and local removal was proportional to the size of the response area.
- Informed sampling, which involves only sampling habitats preferred by Asian carps, had the greatest decrease in effort for detection and local removal compared to the base model. The influence of informed sampling increased with higher habitat specificity and the ability of field crews to target such areas. Repeat sampling, when a fish was detected, reduced the effort for local removal when fish were aggregated, while random sampling generally increased effort for detection and local removal.
- Using information on species ecology and local habitat characteristics, field crews can use these results in real time to evaluate the likelihood that fish remain in the response area given the number of detections and assumptions about the probability of capture.
- General conclusions of this work can be applied to response efforts targeting other aquatic invasive species, but will require knowledge of the probability of capture of gears employed.

INTRODUCTION

An early detection and response program in the Canadian waters of the Great Lakes has been implemented by Fisheries and Oceans Canada (DFO)'s Asian Carp Program to prevent the potential invasion of Asian carp species (Grass Carp [*Ctenopharyngodon idella*], Bighead Carp [*Hypophthalmichthys nobilis*], Silver Carp [*H. molitrix*], and Black Carp [*Mylopharyngodon piceus*]). These four species pose moderate to high invasion risk to the lower Great Lakes and can enter the basin through several natural or human-mediated pathways (Cudmore et al. 2011, 2017, Drake et al. in prep.[1]). None of the Asian carps have established within the Canadian

[1]Drake, D.A.R., Baerwaldt, K., Dettmers, J.M., Nico, L.G., and Chapman, D.C. In preparation. Ecological Risk Assessment of Black Carp (*Mylopharyngodon piceus*) for the Great Lakes Basin. DFO Can. Sci. Advis. Sec. Res. Doc.

waters of the Great Lakes, but reproduction by Grass Carp has occurred within U.S. waters of the Lake Erie basin (Chapman et al. 2013, Embke et al. 2016).

The DFO early detection and response program is designed to detect and capture Asian carps to prevent establishment in Canadian waters (Marson et al. 2018). The response program includes the deployment of strike teams (hereafter referred to as “field crews”) following the detection of Asian carps. Detections have occurred through DFO’s early detection program (Figure 1; see Marson et al. 2018 for a description of surveillance sites), other agencies, or through commercial fishery or citizen means (Colm et al. 2018). The goal of field crew deployment is to capture and remove any remaining Asian carps at the point of initial detection. The magnitude of response (i.e., number of field crews and search effort) depends on the species, ploidy (triploid vs. diploid), and life stage of the detected individual(s), which can lead to varying time lags between initial detection and response activity. Once deployed, field crews survey the area where the original detection occurred using multiple sampling gears (primarily boat electrofishing and trammel nets). Boat electrofishing is often completed in a systematic approach within the response area with an emphasis on suitable Asian carp habitat, while trammel nets are often set concurrently in these areas. If additional Asian carps are detected during this initial survey, additional field crews may be deployed. If no additional Asian carps are detected, the response effort will conclude after a period of time that is currently based on professional judgement. Since the inception of the early detection and response program in 2013, 11 responses with field crews have been conducted, with 13 Grass Carp captured by field crews (DFO unpublished data). The majority of responses resulted in no subsequent detections following the initial detection; however, responses near the Toronto Islands in Lake Ontario, resulted in the capture of one Grass Carp in July 2015 and two Grass Carp in September 2015. In addition, 10 Grass Carp were captured in Lake Gibson (Thorold, Ontario) in June 2016.

Understanding the efficacy of response (i.e., the probability of detecting and removing Asian carps, if present) requires an understanding of the relationships between probability of capture and fishing effort needed for detection and local removal. The objectives of the analysis were to determine: 1) the sampling effort required to capture a single individual (i.e., detection) and capture all locally present Asian carps (i.e., local removal) across abundances likely to be encountered by field crews; and, 2) how response area, sampling scheme (systematic, random, informed, and repeat sampling), fish aggregations, and fish avoidance within the response area influence these estimates.

ANALYSIS

Simulation models were used to calculate the effort required to detect and locally remove Asian carps within the response area. Effort was evaluated across different fish abundances and probabilities of capture and to calculate the effect of different sampling schemes, sizes of the response area, and estimates of fish aggregations or avoidance of the field crew within the fished area. The base model was based on 173 x 173 square matrix to represent a ~ 75 ha response area with each grid cell (hereby referred to as a site) as 0.0025 ha (25 m^2). Multiple fish abundances within the response area were used (i.e., 1, 3, 5, 7, 10, 15, 20, and 25 fish) to determine how effort for detection and local removal may vary across fish abundance. Fish were randomly assigned to sites throughout the response area matrix where they would remain during the simulation; however, the probability that a fish would be assigned to an occupied site was based on the aggregation rate. Five aggregation rates were used (i.e., 0.00, 0.25, 0.50, 0.75, 1.00), reflecting the probability that an individual fish would be assigned to a site inhabited by other fish, to determine how fish aggregations may influence detection and local removal. Sampling by field crews within the response area was completed using a systematic sampling approach, which involved the field crews moving (sampling) through the response area matrix row by row. When the field crews sampled an occupied site, the capture of an individual Asian carp was based on predetermined probability of capture values (from 0.05 to 1.00 with 0.05 increments). The model results for probability of capture values from 0.05 to 0.70 are presented, as this range was considered probable based on literature-derived catchability estimates (Smyth et al. 2022).

The simulation models were run for 5,000 iterations for each abundance, fish aggregation, and probability of capture value (hereby referred to as a scenario). For each iteration, the field crew would systematically sample each site throughout the response area until all 29,929 sites within the response area were sampled. Once a fish was captured, the number of sites sampled until capture was recorded and sampling continued until all fish were captured and removed from the response area. Effort needed for detection reflects the number of sites sampled until the first fish was captured in each iteration, while effort needed for local removal reflects the number of sites sampled until the last fish was captured for each iteration.

In addition to the base model, alternative sizes of the response area, sampling schemes (systematic, random, repeat, and informed sampling), and fish avoidance rates within the response area were incorporated to determine their influence on response efficacy. Alternative response area sizes were examined by calculating detection and local removal effort when the response area was ~ 37.50 ha (50% of base model response area) and ~18.75 ha (25% of base model response area). The random sampling scheme was examined by randomly sampling sites (with replacement) within a response area. The repeat sampling scheme considered a situation where field crews immediately resampled a site following the capture of a single fish. Multiple repeat sampling rates were considered (i.e., 3, 4, and 5 sampling events per site). The informed sampling scheme considered a situation where only a portion of the response area would be suitable for Asian carps and crews sampled within this reduced area of suitable habitat (also considered was the effect of sampling the entire response area when fish occupied only the reduced habitat area). Asian carps were randomly assigned to sites within 50% (37.50 ha) or 25% (18.75 ha) of the response area and crews either sampled the entire 75.00 ha response area (“large buffer”; indicative of field crews having lower confidence in selecting suitable habitat and thus, sampling the entire response area) or the reduced habitat areas (“small buffer”). Fish avoidance was modelled by incorporating multiple probabilities (i.e., 0.05, 0.25, 0.50, and 0.75) that fish may depart a site immediately prior to sampling and be randomly assigned to a different site within the response area.

Results

The effort required to detect the presence of Asian carps was influenced by both the probability of capture and fish abundance. Mean relative effort required for detection ranged from 0.07 to 13.48 passes of the total response area based on probabilities of capture from 0.05 to 0.70 (Figure 2). If sampling time per site was ~ 10 seconds (e.g., while boat electrofishing), 5.8–1,120.7 sampling hours would be required to detect an Asian carp within a 75-ha response area. As the probability of capture or fish abundance increased, the effort required for detection decreased in a nonlinear manner. Overall, relative effort required for detection did not vary across aggregation rates, except when abundance and aggregation rates were high. In this extreme scenario, all fish would occupy a single site within the response area.

The mean relative effort required for local removal was substantially greater than the effort required for detection and ranged from 0.72 to 69.55 passes based on probability of capture rates from 0.05 to 0.70 (Figure 3). If sampling time per site was ~10 seconds, 59.9–5,782.1 sampling hours would be required to locally remove Asian carps within a 75-ha response area. As the probability of capture increased or abundance decreased, the amount of effort required for local removal decreased in a nonlinear manner (Figure 3). Similar to detection, as the probability of capture or fish abundance increased, the effort required for local removal decreased in a nonlinear manner; however, mean relative effort required for local removal varied little across aggregation rates.

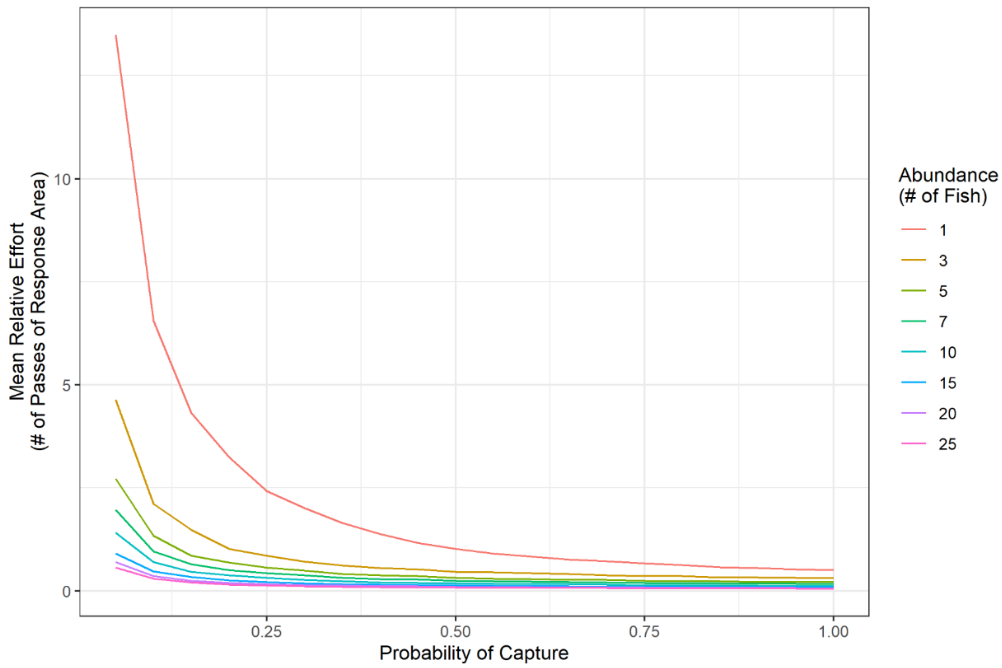

Figure 2. Mean relative effort required for detection of a single Asian carp in relation to the probability of capture and several fish abundances (i.e., 1, 3, 5, 7, 10, 15, 20, and 25 fish) given systematic sampling and an aggregation rate of 0.50.

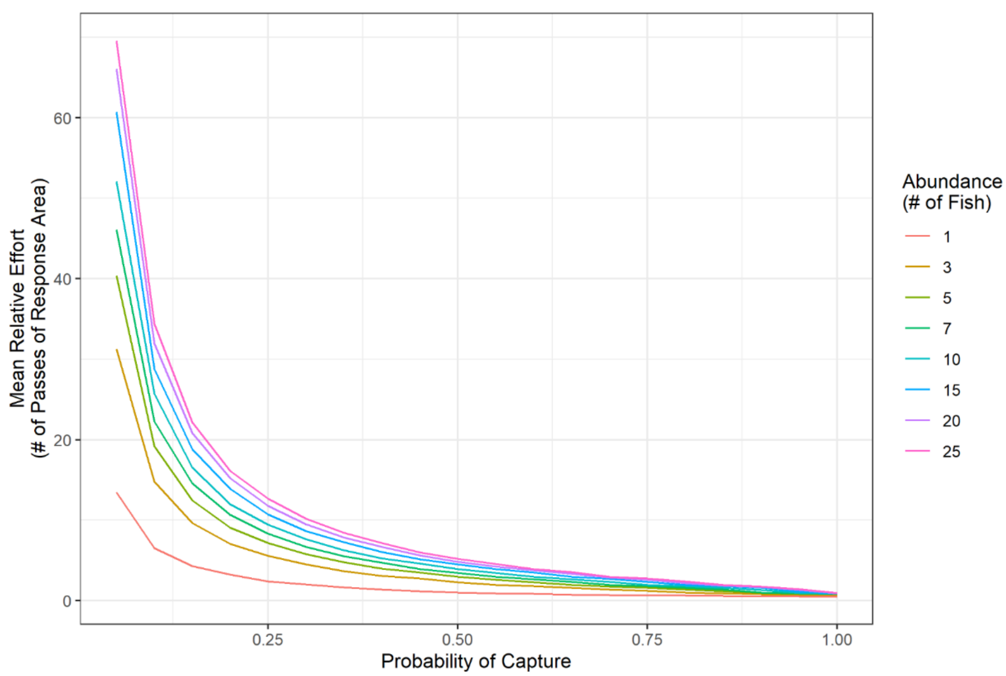

Figure 3. Mean relative effort required for local removal of Asian carps in relation to the probability of capture and several fish abundances (i.e., 1, 3, 5, 7, 10, 15, 20, and 25 fish), given systematic sampling and an aggregation rate of 0.50.

The effort required for local removal demonstrated that even five complete passes of the response area were insufficient to have a high probability of removal under many situations (Figure 4). A single pass was insufficient to achieve a high probability of local removal ($p = 0.80$) unless probability of capture was 1.00 for moderate to high abundances (i.e., > 5 fish) and 0.95 for low abundances (i.e., < 3 fish). To achieve a high probability of local removal ($p = 0.80$) within five passes, the probability of capture would need to be > 0.25 for low abundances (i.e., 1 fish) and > 0.55 for high abundances (i.e., 20 fish).

The effort required for detection and local removal for each of the alternative scenarios (response area size, sampling scheme, and fish avoidance rate) across probability of capture, fish abundance, and fish aggregation rates (in the case of repeat sampling) are presented in Smyth et al. (2022). Some of these results were compared against the base model to evaluate the influence of each alternative scenario on the effort for detection (Figure 5) and local removal (Figure 6). Informed sampling (i.e., small buffer) when fish occupied 50% of the base model response area consistently decreased detection and local removal effort by 50% relative to the base model. Although informed sampling resulted in the greatest change in effort required for detection relative to the base model, fish aggregation resulted in the greatest change in effort required for detection when abundance was 25 fish (Figure 5d). In addition, fish avoidance behaviour had a consistently negative effect on detection effort, resulting in substantial increases in effort (13%–34%) relative to the base model, particularly if the probability of capture was high (Figure 5). Informed sampling (i.e., small buffer) resulted in the greatest change in effort required for local removal except when abundance was 25 and probability of capture was 0.70, in which case random sampling resulted in the greatest change in effort (Figure 5d). Repeat sampling led to variable decreases (4%–38%) in effort while fish avoidance resulted in variable increases (16%–29%) in effort required for local removal, particularly when probability of capture was high (Figure 6).

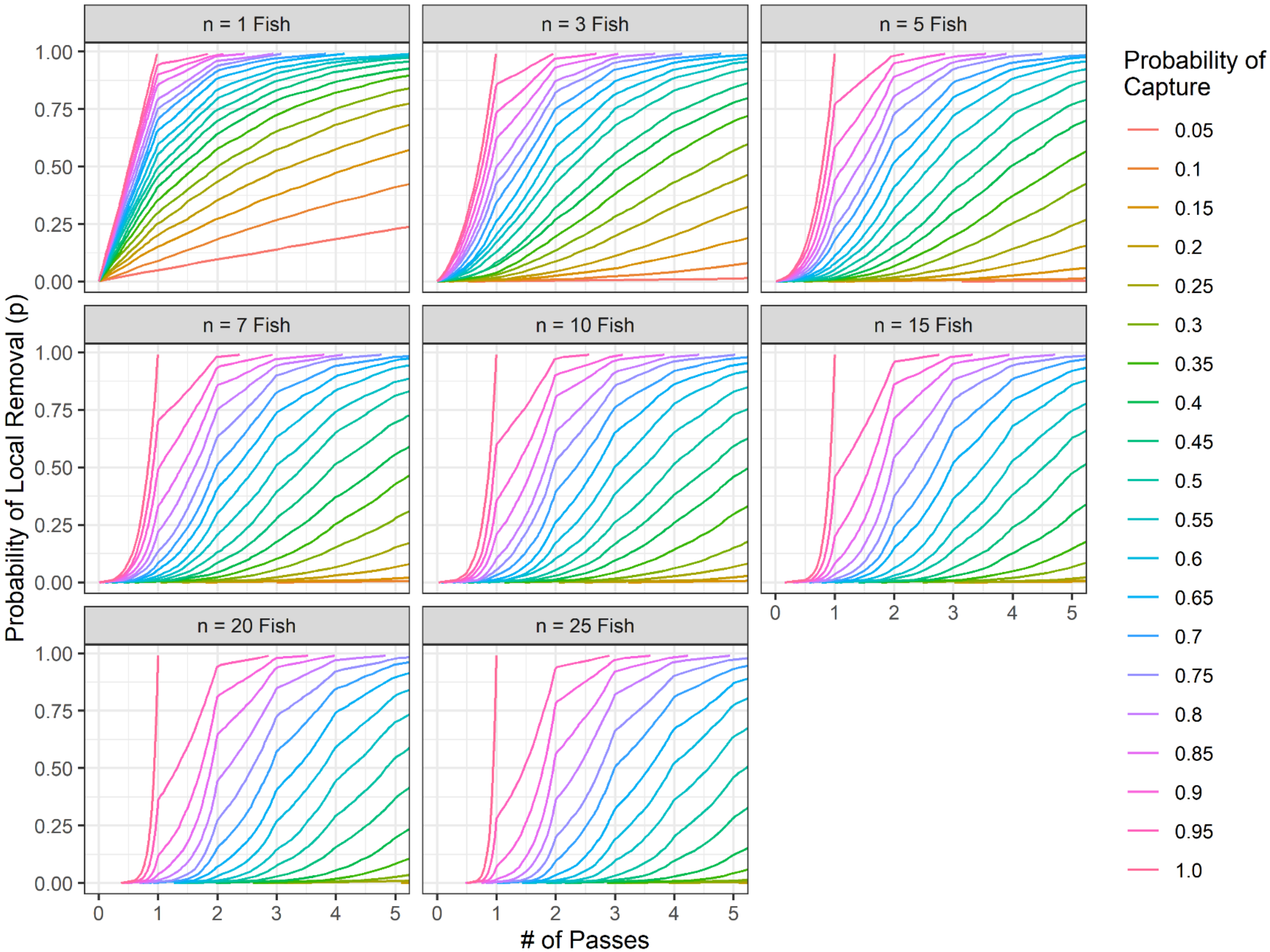

Figure 4. Probability of locally removing n Asian carps within the response area (indicated at the top of each panel) with an aggregation rate of 0.50. The lines within the graphs represent probability of capture values ranging from 0.05 to 1.00.

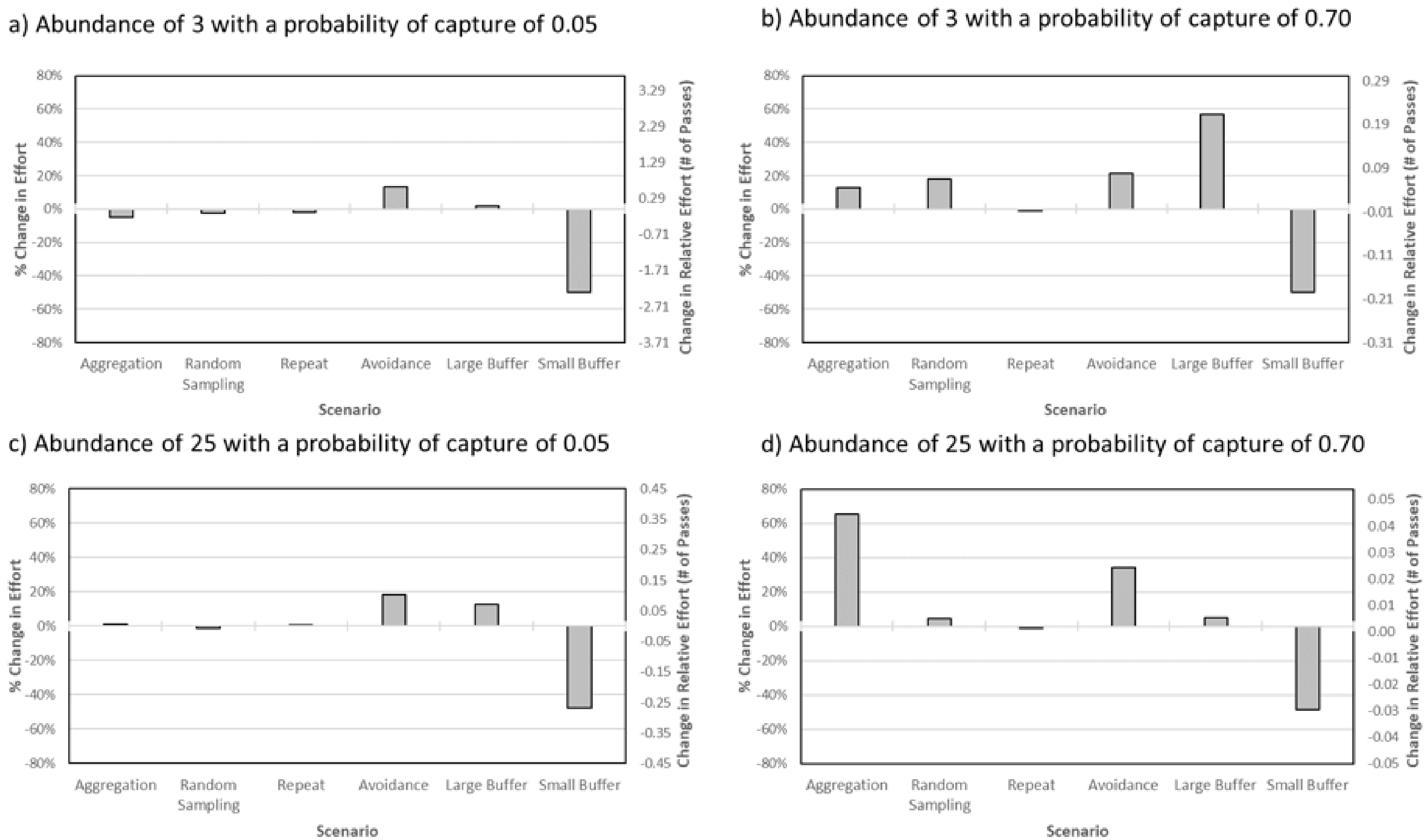

Figure 5. The percent change in effort (relative to base model results) for the detection of Asian carps when: fish aggregations of 0.75 occurred (aggregation), random sampling was implemented (random sampling), repeat sampling occurred with three samples per site (repeat), fish exhibited avoidance behavior with a rate of 0.25 (avoidance), crews sampled the entire 75 ha sampling area but only 50% of the response area was suitable for Asian carp (large buffer), and when crews were informed and only sampled the suitable area for Asian carp that composed 50% of the response area (small buffer). The scenarios were compared to base model conditions that differed for each panel, with fish aggregations of 0.50 when abundance was 3 fish and a) probability of capture was 0.05 and b) 0.70; and, when abundance was 25 fish and a c) probability of capture was 0.05 and d) 0.70.

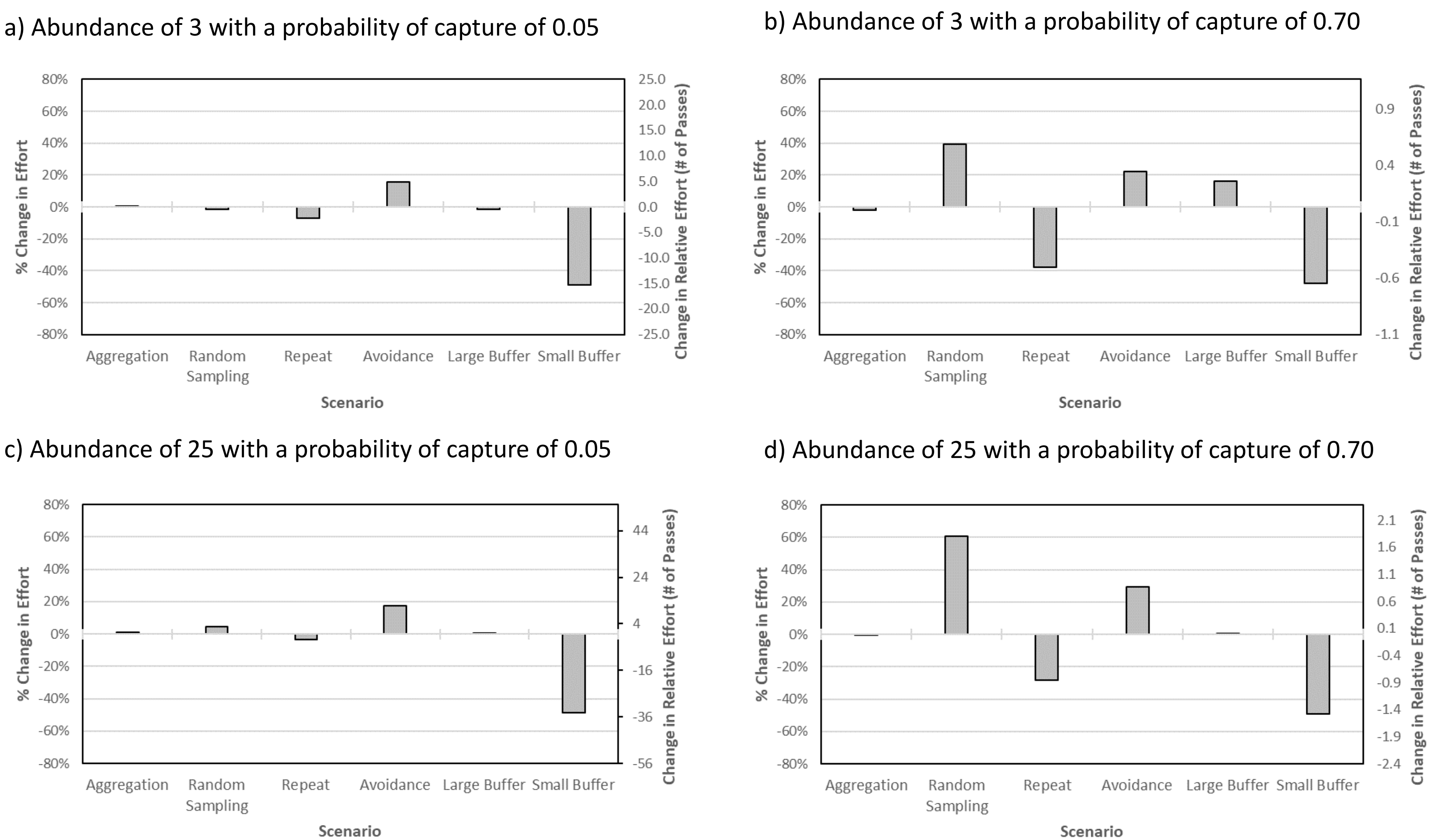

Figure 6. The percent change in effort (relative to base model results) for the local removal of Asian carps when: fish aggregations of 0.75 occurred (aggregation), random sampling was implemented (random sampling), repeat sampling occurred with three samples per site (repeat), fish exhibited avoidance behavior with a rate of 0.25 (avoidance), crews sampled the entire 75 ha sampling area but only 50% of the response area was suitable for Asian carp (large buffer), and when crews were informed and only sampled the suitable area for Asian carp that composed 50% of the response area (small buffer). The scenarios were compared to base model conditions that differed for each panel, with fish aggregations of 0.50 when abundance was 3 fish and a) probability of capture was 0.05 and b) 0.70; and, when abundance was 25 fish and a c) probability of capture was 0.05 and d) 0.70.

Sources of Uncertainty

- The effort to detect and locally remove Asian carps was strongly influenced by the probability of capture, which is poorly known for most sampling gears and will vary in relation to fish size, fish abundance, and habitat characteristics. Knowledge of the probability of capture for gears currently employed by field crews will refine effort estimates for detection and local removal for current gears.
- Body size is known to affect vulnerability to capture and can produce among-individual variation (heterogeneity) in the probability of capture. Presented analyses assumed that all fish were equally vulnerable to the gear. If heterogeneity among individuals exists, this could affect the model predictions, especially for local removal.
- The likelihood that fish leave the response area and are therefore unable to be captured by field crews increases with sampling time. Fish movement into and out of the response area was not incorporated in the analysis.
- The current model incorporates an avoidance response by fish to fishing activity, but otherwise assumes fish remain stationary in the response area during sampling. If fish move into previously sampled sites the effort required to encounter all fish would increase.
- Combinations of sampling schemes (e.g., informed plus repeat sampling) and iterative sampling approaches were not evaluated, but may be associated with further effort reductions relative to the base model and informed sampling.
- Although the simulation was generalized across species, habitats and sampling methods, the simulation most closely approximates active fishing in a systematic or random manner. Future work is needed to understand whether different gear deployment methods align with modelled outcomes.
- The ability of repeat sampling to reduce effort for local removal is sensitive to the degree of fish aggregation, which remains largely unknown for Asian carps.

Despite analyzing several model scenarios, numerous uncertainties remain. During responses, field crews implement multiple sampling gears including trammel nets and boat electrofishing across a variety of habitat types. The probability of capture of these gears across response area conditions remains uncertain. The analysis incorporated a range of fixed probability of capture rates (primarily 0.05 – 0.70) to account for catchability varying across gear type and habitat condition (see Smyth et al. 2022). However, the large differences in effort required for detection and local removal across the probability of capture values demonstrates that understanding the probability of capture by field crews under various response conditions is needed to understand the efficacy of current field sampling.

In addition, the influence of fish size on the probability of capture across gear types remains relatively unknown. Only adult fish have been captured through response efforts (DFO unpublished data); however, it is possible that juvenile fish may inhabit response areas. Smaller fish may be more likely to avoid capture, to the point of complete avoidance in some gear types (see Hubert et al. 2012 and Hayes et al. 2012). Heterogeneity of fish sizes within the response area may lead to greater effort required for local removal than if a single, larger size class is present. Further knowledge on the relationship between probability of capture and fish size across gear types would refine the likely range of effort required for local removal.

The potential for Asian carps to leave the response area following the initial detection or during response activities remains uncertain. If fish are prone to departing the response area, then responses that require substantial time for completion (i.e., > 10 complete passes of the response area) or are delayed following the initial detection may lead to fish successfully evading capture. The factors that influence Asian carp movements at a small scale (100's of meters) are difficult to generalize and, therefore, were not incorporated in the analysis. Data on fish movement in and out of the response area would refine effort estimates and potentially identify scenarios where local removal is difficult given the departure of remaining Asian carps from the response area. Similarly, a high degree of movement within the response area may increase the effort required for detection and local removal. Further information on small scale movements of Asian carps can improve estimates of movement during a response and therefore, refine effort estimates for detection and local removal.

The study examined multiple response scenarios (response area size, sampling scheme, and fish avoidance rate) independently; however, certain combined scenarios (e.g., informed plus repeat sampling) may have cumulative benefits on the effort required for detection and local removal. Exploring these combinations may further provide field crews with alternative options to reduce the effort required for detection and local removal in the field.

The analysis simulates sampling through an active fishing approach; however, the influence of passive fishing gears (or combined active and passive gears) on detection and removal remains uncertain. Field crews currently employ boat electrofishing and trammel nets during a response; however, trammel nets are sampled actively, with nets retrieved immediately following boat electrofishing or other disturbance techniques around the net (DFO unpublished data). If trammel nets are sampled passively, the effort for detection and local removal may be more sensitive to fish movement between sites compared to active fish sampling methods. In addition, results may not apply to gear deployments that do not behave in a standard systematic or system-wide random manner. Therefore, alternative gears may yield substantially different results and further analysis could inform such effects.

The aggregation of Asian carps can influence the efficacy of certain sampling schemes, particularly repeat sampling. Repeat sampling was found to substantially decrease effort for local removal, particularly at high fish abundances; however, the benefit of repeat sampling was sensitive to fish aggregation, where higher aggregation (large groups of fish within a site) led to less effort for local removal when all else was equal (Smyth et al. 2022). Aggregations of Grass Carp have been observed in the field through the capture of multiple fish in the same net set and within the same site (e.g., Lake Gibson; DFO unpublished data) but understanding the prevalence of this behavior is challenging due to limited data. A better understanding of the degree of fish aggregation would be valuable for determining whether effort for repeat sampling would be more effectively spent on sampling additional unsampled sites, such as when aggregation is low.

CONCLUSIONS AND ADVICE

The effort required to detect Asian carps was lower when there was a higher abundance of Asian carps present, the probability of capture of the gear was high, and fish exhibited a lower propensity to aggregate. Small increases in the probability of capture beyond 0.05 substantially decreased the effort needed for detection when fish abundance was low. For example, when the probability of capture was 0.05, 13.48 passes were, on average, required for detection when only a single fish was present; however, when the probability of capture was increased to 0.25, only 2.42 passes, on average, were required for detection. Effort required for detection also decreased as fish abundance increased. For example, when probability of capture was 0.05, only 4.64 passes were required for detection, on average, when three fish were present compared to 13.48 passes, on average, required when a single fish was present.

The effort required for local removal of Asian carps was lower when there were fewer Asian carps and when the probability of capture was high. For example, when five fish were present and the probability of capture was 0.05, 40.36 passes were, on average, required for local removal, but 7.16 passes were, on average, required when the probability of capture was increased to 0.25. Effort required for local removal increased as fish abundance increased. For example, when probability of capture was 0.05, 31.25 passes were required, on average, when abundance was three fish compared to 13.48 passes, on average, required when abundance was one fish.

When probability of capture was low, detection and local removal effort was sensitive to targeted sampling (e.g., informed sampling had a strong effect on required effort; Fig. 4 and 5). When the probability of capture was high, effort was sensitive to more variables; detection was most sensitive to avoidance and aggregation behaviour, while local removal was most sensitive to avoidance and the sampling scheme.

LIST OF MEETING PARTICIPANTS

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SOURCES OF INFORMATION

This Science Advisory Report is from the January 13–15th 2021 regional peer review meeting on Sampling effort to detect Asian carps during response activities in the Great Lakes basin. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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Smyth, E.R.B., Koops, M.A., and Drake, D.A.R. 2022. Looking for a needle in a haystack: Sampling effort to detect Asian carps during response activities in the Laurentian Great Lakes basin. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/023.. viii + 51 p.

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MPO. 2022. Effort d’échantillonnage pour détecter les carpes asiatiques pendant les activités d’intervention dans le bassin des Grands Lacs. Secr. can. des avis sci. du MPO. Avis sci. 2022/011.