Considerations for the Design of a SARA-listed Freshwater Fish Monitoring Program in Point Pelee National Park

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Four fish species listed under the *Species at Risk Act* (SARA) occupy ponds within Point Pelee National Park (PPNP; Lake Chubsucker *Erimyzon sucetta*, Spotted Gar *Lepisosteus oculatus*, Grass Pickerel *Esox americanus vermiculatus*, and Warmouth *Lepomis gulosus*) but the status of these populations is poorly understood. Here, considerations for the design of a long-term monitoring program for SARA-listed freshwater fishes in PPNP are presented, informed by prior sampling efforts. Based on a randomized resampling with replacement approach using mini-fyke net capture data from 2019, Warmouth had the highest capture probability among SARA-listed species while Lake Chubsucker had the lowest. Warmouth was the only species captured in sufficient abundance to allow future trend evaluation. The power to detect changes in adult Warmouth abundance increased with the number of sites sampled and surveys performed, the magnitude of change, and the magnitude of site-level variance explained by the model. At least 10 years of annual sampling is recommended for monitoring, where 125 or more mini-fyke nets are set across Lake, East Cranberry, and West Cranberry ponds. This would provide 78.20% (95% confidence interval = 74.32–81.74%) and 67.80% (63.51–71.88%) power for detecting a 30% decrease and increase in abundance, respectively, at the lowest level of random site-level variance tested, and would provide ~80% probability of capturing Grass Pickerel, Lake Chubsucker, and Spotted Gar. Overall, the content of this report provides quantitative guidance on sampling effort requirements for the development and implementation of a fish species monitoring program in PPNP.

RÉSUMÉ

Lamothe, K.A., and Drake, D.A.R. 2025. Considerations for the Design of a SARA-listed Freshwater Fish Monitoring Program in Point Pelee National Park. Can. Manuscr. Rep. Fish. Aquat. Sci. 3308: vi + 19 p. https://doi.org/10.60825/3d07-0q37

Quatre espèces de poissons inscrites en vertu de la *Loi sur les espèces en péril* (LEP) sont présentes dans des étangs au sein du parc national du Canada de la Pointe-Pelée (ci-après appelé « parc national »), mais l'état de leurs populations est mal compris. Il s'agit du sucet de lac (*Erimyzon sucetta*), du lépisosté tacheté (*Lepisosteus oculatus*), du brochet vermiculé (*Esox americanus vermiculatus*) et du crapet sac-à-lait (*Lepomis gulosus*). Ce document présente des éléments à considérer pour la conception d'un programme de suivi à long terme des poissons d'eau douce inscrits en vertu de la LEP qui sont présents dans le parc national, en fonction des efforts d'échantillonnage préalablement déployés. Un rééchantillonnage aléatoire avec remplacement effectué au moyen des données de capture par mini-verveux de 2019 a révélé que le crapet sac-à-lait était l'espèce inscrite en vertu de la LEP la plus susceptible d'être capturée, tandis que le sucet de lac était l'espèce la moins susceptible de l'être. Le crapet sac-à-lait a été la seule espèce capturée en abondance suffisante pour permettre une évaluation des tendances futures. La capacité de détecter des changements dans l'abondance des crapets sac-à-lait adultes a augmenté avec le nombre de sites échantillonnés et de relevés effectués, l'ampleur du changement et de la variance au niveau du site étant expliquée par le modèle. Pour assurer un suivi, il est recommandé de procéder à un échantillonnage annuel pendant au moins 10 ans en installant au moins 125 mini-verveux dans les étangs Lake, East Cranberry et West Cranberry. Cette façon de faire permettrait de détecter une diminution et une augmentation de 30 % de l'abondance avec une efficacité de 78,20 % (intervalle de confiance à 95 % : de 74,32 à 81,74 %) et de 67,80 % (63,51 à 71,88 %), respectivement, au plus bas niveau de variance aléatoire au niveau du site testé, et elle fournirait une probabilité d'environ 80 % de capturer des brochets vermiculés, des sucets de lac et des lépisostés tachetés. De façon générale, le présent document fournit des lignes directrices quantitatives à propos des efforts d'échantillonnage nécessaires pour l'élaboration et la mise en œuvre d'un programme de suivi des espèces de poissons présentes dans le parc national.

INTRODUCTION

Point Pelee National Park (PPNP) supports a diverse warmwater freshwater fish assemblage that includes four species listed under the *Species at Risk Act* (SARA): Lake Chubsucker (*Erimyzon sucetta*; Endangered), Spotted Gar (*Lepisosteus oculatus*; Endangered), Grass Pickerel (*Esox americanus vermiculatus*; Special Concern), and Warmouth (*Lepomis gulosus*; Special Concern). Sampling of the PPNP freshwater fish community over the last two decades in support of SARA-listed species recovery efforts has provided important background information on fish community composition (Surette 2006; Barnucz et al. 2021, 2024). However, differences in methodology between these sampling efforts makes comparisons over time challenging, and causes uncertainty around the status (abundance, distribution, and condition) of SARA-listed species. Implementing a long-term monitoring program could reduce the underlying uncertainty around the status of SARA-listed species in the park and support future management decisions.

Monitoring freshwater fishes is challenging due to the heterogenous, dynamic nature of freshwater ecosystems, with the challenges amplified when monitoring SARA-listed species. Freshwater fishes listed under SARA are inherently rare and often require unique gears and an appropriate level of care to detect individuals. Strategic planning is therefore required to determine how fishes will be sampled that allows reliable inference while reducing the chance of harm during monitoring efforts. To inform decisions on the development of a monitoring program in PPNP, we review approaches to monitoring freshwater fishes, including consideration of sampling design and effort requirements for generating reliable information on the abundance of SARA-listed species. This review was approached under the assertion that the primary goal of monitoring was to collect data that would allow analysis of change in SARA-listed fish species abundance over time. Overall, this research provides recommendations for managers in charge of implementing species monitoring programs in support of the recovery of SARA-listed fish species in PPNP.

MONITORING FRESHWATER FISH ABUNDANCE IN PPNP

Species abundance, distribution, and condition are three of the most common endpoints for freshwater fish monitoring programs. For the purposes of monitoring SARA-listed freshwater fish species, species abundance is often the endpoint of greatest interest as it represents the first quantitative criteria used when evaluating the status of imperilled species in Canada (COSEWIC 2021). Although it is the gold standard for monitoring, estimating the absolute abundance of freshwater fish species is, in most cases, challenging. As a result, freshwater fish species monitoring programs must often rely on indices of relative abundance such as catch-per-unit effort (CPUE) or attempt to account for sampling deficiencies through careful sampling design and sophisticated modelling techniques.

Indices of relative abundance are commonly used as indicators of true, absolute species abundance. Using relative abundance estimates in place of true absolute abundance assumes that the probability of capturing individuals of a species is constant over space and time, an assumption that is rarely satisfied in a fish species monitoring program. There are many reasons why the probability of capturing individuals may not be constant in space or time, such as differences in detection probability across environmental characteristics (e.g., substrate type; Dextrase et al. 2014), seasons (Fischer and Quist 2014), or gear types (Wagner et al. 2019). Estimating species detection probability to inform estimates of species abundance can be resource intensive, requiring the use of mark-recapture methods (Nichols 1992) or repeated surveys of unmarked individuals (MacKenzie et al. 2003, 2005; Dextrase et al. 2014; Lamothe and Drake 2022). Even in the case of monitoring for changes in species occupancy (i.e., presence–absence), a high level of effort (i.e., number of sites and surveys) is needed to draw conclusions with reasonable statistical power (Guillera-Arroita and Lahoz-Monfort 2012). Therefore, choosing what to measure requires consideration of the effort required to collect robust data, assumptions of the data collection approach, and uncertainty associated with each monitoring program endpoint (e.g., detecting trends in abundance) for achieving the monitoring program objectives.

The spatial and temporal allocation of sampling effort are critical factors in the design process for reducing bias in the relative abundance data collected from long-term species monitoring programs (Fournier et al. 2019). Methods for allocating effort spatially (i.e., site selection) are commonly divided into probabilistic or non-probabilistic approaches, with their use being dependent on the system and scale of interest. Probabilistic sampling describes the situation when all possible locations for sampling within an identified sampling frame (i.e., spatial extent of interest for drawing conclusions from the data) are included in the site-selection process, and sites are selected randomly (or an approximation thereof) based on some identified probability (Pope et al. 2009). Included among probabilistic approaches for sampling are simple random sampling and stratified random sampling, among others (Stevens Jr. and Olsen 2004; Pope et al. 2009; Radinger et al. 2019). Non-probabilistic sampling describes situations when sites are targeted for sampling rather than being chosen probabilistically. The choice of probabilistic or non-probabilistic approaches influences how sampling results can be interpreted and extrapolated.

Determining the optimal approach for site selection depends on the spatial scale of interest, knowledge of the focal species, and objectives of the monitoring program. Site selection can occur once at the beginning of a monitoring program (i.e., fixed sites) or can be selected before each season of sampling (i.e., random sites). Random site selection across available habitat per sampling period is recommended because it provides data that better represent the spatial heterogeneity in abundance and can be more easily extrapolated to the entire population (Mackenzie et al. 2006). Alternatively, initial random site selection followed by resampling of these sites (i.e., fixed sites) can improve sensitivity to changes in abundance over time, but trends in abundance may not be representative of the entire population and comparing estimates between systems becomes challenging (Quist et al. 2006; Fournier et al. 2019). For closed aquatic systems or for species with restricted ranges, the uncertainty associated with fixed sites may be reduced if a sufficient proportion of available habitat is sampled per sampling period.

Allocation of sampling effort temporally requires consideration of when to sample for fish within a year, how frequently to sample within a year, and how often sampling will occur across years. Determining the best time to sample within the year (i.e., season) will depend on the monitoring program endpoint under consideration and general logistical constraints. Sampling in different seasons provides an opportunity to capture individuals at different life stages. For example, spawning of many freshwater fishes in southern Ontario occurs in the spring when water temperatures reach a species-specific threshold, and therefore sampling in the spring can provide data about species recruitment. Although multi-season monitoring programs provide a greater opportunity to understand the complex, seasonal dynamics of wetland fishes, it requires significant resources and therefore sampling during a single season is most often the selected approach. In addition to the choice of season(s), the frequency of visits per selected site within a season can vary across monitoring programs. Replication at the site-level leads to reduced variation in site capture data and, therefore, improves inference about trends in species abundance. However, repeating surveys at sites typically reduces the number of sites that can be visited for sampling given a fixed number of resources. Ultimately, replication of sampling efforts will limit the influence of environmental variation on capture results and allow easier inference about change in status over time.

Power analysis is a useful approach to estimate the effort needed to make informed decisions about trends in species abundance over time. Statistical power is defined as $1 - \beta$, where β is the probability of making a Type II error (i.e., false negative). Hence, statistical power is the probability that a statistical test correctly rejects the null hypothesis (Peterman 1990). Monitoring programs should be designed to maximize statistical power given available sampling resources. Sample size, effect size, and statistical significance are the primary factors that influence statistical power (Peterman 1990; Strayer 1999). Here, sample size describes the number and frequency of sampling events, effect size describes the anticipated level of change over time, and statistical significance describes the probability that a hypothesis test incorrectly rejects the null hypothesis. The goal of a power analysis is to determine the optimal number of sites and frequency of surveys for achieving an identified power criterion that considers the particular effect of interest and selected level of statistical significance (e.g., α = 0.05). A power of 0.80 is commonly used as a criterion for hypothesis testing, which describes an 80% probability of detecting a significant trend in abundance given that a change has occurred, or alternatively, a 20% probability of falsely concluding that a change has not occurred. Lower power values can be used that require reduced effort, but also decrease the probability of detecting true changes in species abundance if they occurred.

In the next section, approaches previously used to sample freshwater fishes in PPNP are described followed by an overview of quantitative methods used to inform a potential future long-term monitoring program. Included in this analysis is an evaluation of the capture probability for SARA-listed fish species using hoop nets and mini-fyke nets, and a power analysis for estimating the effort requirements (i.e., number of sites and annual surveys) for detecting proportional changes in SARA-listed species abundance over time. Much of the analysis is based on data collected from 2019, but it also considers data collected in 2002, 2003, and 2021. Following the description of the methods, results of the analysis are presented and protocols for a long-term monitoring program are discussed.

METHODS

HISTORICAL SAMPLING EFFORTS

Sampling for freshwater fishes in PPNP occurred in 2002, 2003, 2019, and 2021. Methods used for sampling freshwater fishes were originally described in Surette (2006), Barnucz et al. (2021), and Barnucz et al. (2024). A brief description of the sampling methods is provided below.

Sampling for freshwater fishes in 2002 and 2003 was performed in all seven open-water ponds, along with the channel connecting West Cranberry Pond and Lake Pond (hereafter referred to as West Cranberry Channel; see Figure 1 for pond configuration). Site selection and effort was allocated relative to the size of each pond with the objectives of resampling historical sites, sampling a diversity of representative habitats, maintaining a minimum of 50 m between sites, and ensuring the ability to sample the site effectively with the chosen gear type (Surette 2006). Sampling in 2002 and 2003 occurred at both nearshore and offshore sites. Offshore sites were exclusively sampled using hoops nets, whereas nearshore sites were sampled consecutively with a variety of gear types whenever possible (i.e., when habitat was < 2 m deep). Passive gear types deployed nearshore in 2002 included hoop nets, a trap net, Windermere traps, and minnow traps. All passive gears were set in the mid-afternoon and retrieved the following morning. Approximately 20 hours passed between gear deployments at a site to minimize the potential effects of disturbance of the previous gear type on the fish community. Seine nets were also used at nearshore sites to complement passive sampling devices; where seines were deployed, a single haul was performed at sites in 2002 and three hauls were performed in 2003. In 2003, the number of gears was reduced to include only nearshore and offshore hoop nets, trap nets, and seine nets after investigating the relative effectiveness of each gear type (Surette 2006).

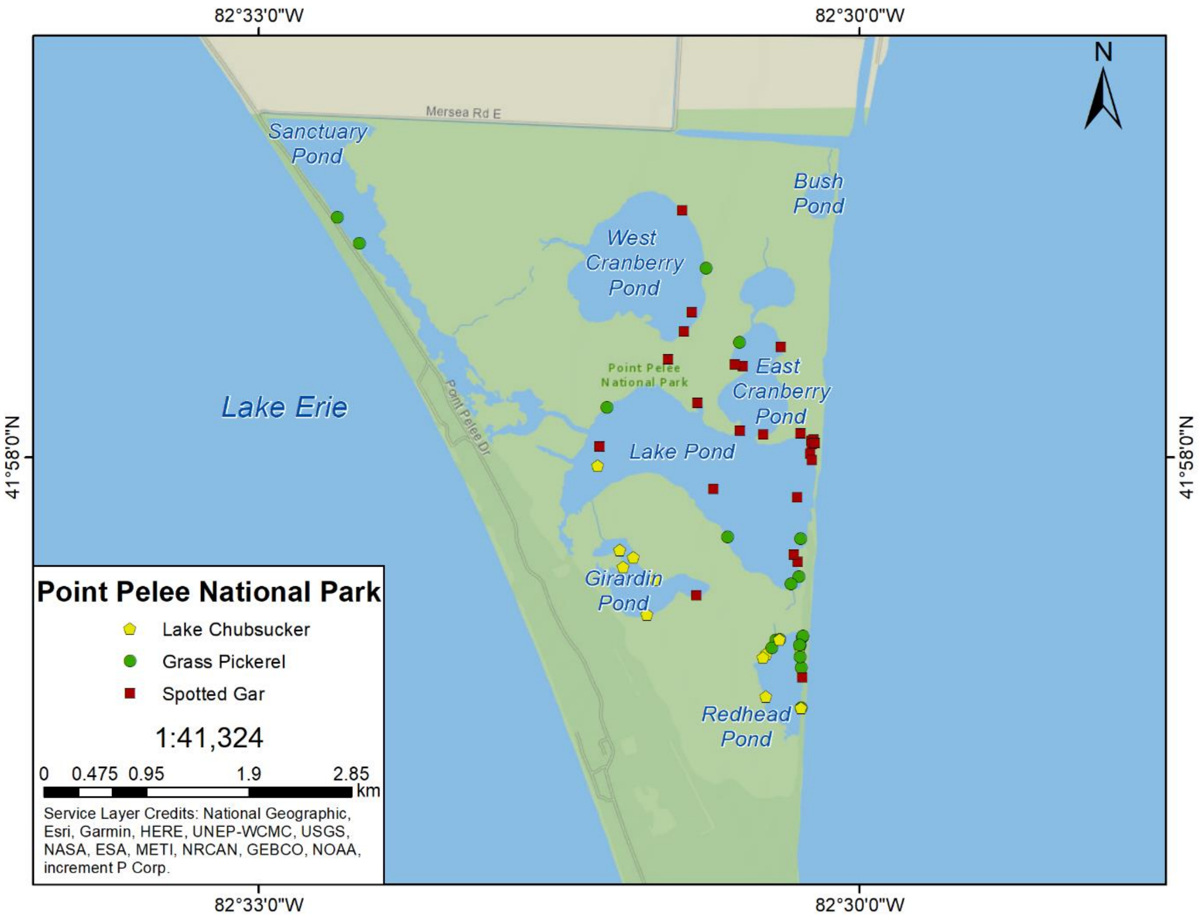

Figure 1. *Open water ponds in Point Pelee National Park. Plotted are the locations of Lake Chubsucker, Grass Pickerel, and Spotted Gar detections from 2002, 2003, 2019, and 2021.*

In 2019, freshwater fish sampling was restricted to three interconnected ponds known to support SARA-listed species: Lake Pond, East Cranberry Pond, and West Cranberry Pond. Sampling for fishes was divided into two time periods: 1) June 17 to July 10, and 2) July 19 to August 7 (Barnucz et al. 2021). The study was originally implemented as a mark-recapture study, but no recaptures occurred in the second time period. The total number of sites was allocated proportionally to the surface area of each pond with a target of 100 nets set. Sites were selected to ensure effective fishing of mini-fyke nets (< 2 m depth and nearshore) while maintaining a minimum spacing of 100 m between sites. A single mini-fyke net was set per site in the mid-afternoon and retrieved the next morning. Sampling efforts were significantly reduced in 2021 compared to 2019. The focus of 2021 sampling was to obtain fish community data from Girardin and Redhead ponds. Twenty-four sites were sampled using mini-fyke nets in Girardin and Redhead ponds and seven sites were sampled with a seine in Lake Pond (three repeat seine hauls per site; Barnucz et al. 2024).

PROBABILITY OF CAPTURING SARA-LISTED SPECIES

An approach to estimate the probability of capturing SARA-listed species was developed to determine the effort required to detect each species as a potential alternative monitoring endpoint. The probability of capture (P_{cap}) describes the probability of capturing a species at $1 \ldots j$ sites and is calculated using a random sampling with replacement procedure of the capture data (Jackson and Harvey 1997). To generate this metric, survey data were first aggregated per site and converted to occurrences, creating a vector **V** of 0s and 1s. For each site j from 1 to 200, a resampling procedure with 999 iterations was performed where a random sample of **V** of size j was performed and summed. P_{cap} was calculated as the number of iterations per site j where the species was captured as least once, divided by the total number of iterations (i.e., 999). P_{cap} was used to estimate the number of hoop nets (2002 and 2003) or mini-fyke nets (2019) set required to detect the SARA-listed species in Lake Pond. Only capture data of Warmouth and Spotted Gar from Lake Pond were used for 2002 and 2003 as the pond had the greatest number of hoop nets set and these species were the only SARA-listed species captured during this period. Alternatively, all four SARA-species were incorporated for the 2019 data, including analysis that considered only adult Warmouth.

POWER ANALYSIS

Regression-based approaches can be used to evaluate annual trends in the relative abundance of species over time. Generalized linear mixed models (GLMMs) provide several benefits when evaluating trends in rare species abundance relative to traditional least-squares linear regression, including the ability to incorporate non-Gaussian distributions for modelling species counts and an ability to include random effects (Bolker et al. 2009). For the purposes of evaluating the power to detect changes in relative abundance over time, Poisson models were built that included year and effort as fixed effects and site as a random effect (Figure 2). For future work, alternative distributions (e.g., negative binomial, zero-inflated distributions) and model structures (e.g., including effort as an offset, additional pond effect) should be considered for evaluating trends in the capture data.

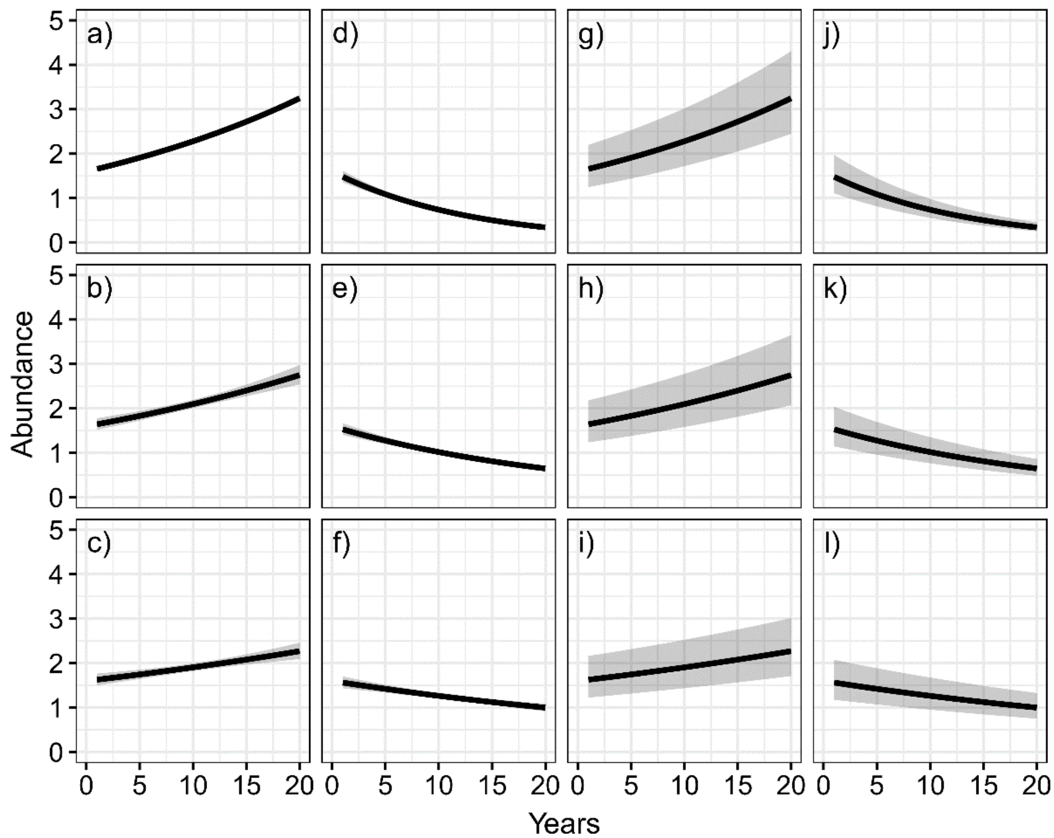

Figure 2. *Example effect plots for Poisson models of annual trends in adult Warmouth abundance over time (years) with two different variance parameterizations for random site-level effects (a–f: var = 0.01; g–l: var = 2.00). Shown are models of: a) and g) 70% growth; b) and h) 50% growth; c) and i) 30% growth; d) and j) 70% decline; e and k) 50% decline; and f) and l) 30% decline. Note that only fixed effects are plotted. The total time frame shown in the x-axis is approximately three generations.*

Power analysis was used to evaluate the number of sites and annual sampling effort needed to reliably detect trends in adult Warmouth abundance over time. Warmouth was selected as the species of interest as it is the only SARA-listed species present in PPNP with sufficient relative catch to evaluate trends over time. Adults were the focus of evaluation (individuals ≥ 89 mm; Carlander 1969; COSEWIC 2015) to align with COSEWIC criteria for species assessment (COSEWIC 2021). Power analyses were performed for situations when adult Warmouth experienced proportional reductions (-30%, -50%, -70%) or gains (30%, 50%, 70%) in abundance over time. Proportional reductions and gains were evaluated based on generation time ($G \approx 5$ years; van der Lee and Koops 2020), where the effect size of annual changes in abundance was defined as:

- 30% reduction: -0.0235
- 50% reduction: -0.0452
- 70% reduction: -0.0771
- 30% growth: 0.0175
- 50% growth: 0.0271
- 70% growth: 0.0354 (Figure 2).

To evaluate power for detecting changes in adult Warmouth abundance, count data were generated based on a Poisson distribution fitted to the 2019 sampling data, the aforementioned GLMM was fit to the generated count data with the different effect sizes, and a z-test was applied to test the fit. Power to detect changes in adult Warmouth abundance was estimated for situations where 25, 50, 75, 100, 125, or 150 sites were surveyed annually for 2–20 years. The average site-level abundance of Warmouth in 2019 across all ponds (0.47 ± 0.99 SD) was used as the model intercept, with the effect of effort drawn from a normal distribution with mean = 0 and SD = 1, and where random site-level variance was set to 0.01, 0.05, 0.10, 0.50, 1.00, or 2.00. An increase in the random site-level variance suggests greater variance in the annual catch per year. Variance in site-level catch of adult Warmouth in Lake Pond in 2019 was 1.40. Power estimates were made using a Monte Carlo simulation (1,000 iterations; Green and MacLeod 2016), assessed at a power of 0.80, and evaluated at α = 0.05. Each test that suggested a significant change in abundance was considered as a true positive, while tests that identified no change in abundance were considered false negatives (Green and MacLeod 2016). All analyses were performed using R (R Core Team 2022); Poisson models were built using the ‘lme4’ package (Bates et al. 2015) and power curves were built using the ‘simr’ package (Green and MacLeod 2016).

RESULTS

SARA-LISTED SPECIES

Three of the four SARA-listed species were captured in 2002 and all four were captured in 2003, 2019, and 2021 (Table 1). Hoop nets, mini-fyke nets, and seine nets were successful at capturing all four SARA-listed fish species in the park (Table 2). In addition, minnow traps were successful at capturing Warmouth, trap nets were successful at capturing Warmouth and Spotted Gar, and Windermere traps were successful at capturing Grass Pickerel, Spotted Gar, and Warmouth (Table 2). All four SARA-listed species were captured in Lake Pond and Redhead Pond. Grass Pickerel was also captured in East Cranberry Pond, Sanctuary Pond, and West Cranberry Pond. Lake Chubsucker was also detected in Girardin Pond, and Spotted Gar was also captured in East Cranberry Pond, Girardin Pond, and West Cranberry Pond (Table 1; Figure 1). Among the SARA-listed species, Warmouth was captured in the greatest abundance (892 captured) across all waterbodies (Table 1). Twenty-eight individuals were captured for each of the three other SARA-listed species (Table 1).

Table 1. *Number of Lake Chubsucker, Grass Pickerel, Spotted Gar, and Warmouth captured in Point Pelee National Park per waterbody and year.*

Waterbody	Year	Lake Chubsucker	Grass Pickerel	Spotted Gar	Warmouth
Bush Pond	2002	0	0	0	25
East Cranberry Pond	2002	0	0	0	5
Girardin Pond	2002	0	0	0	40
Lake Pond	2002	0	1	7	136
Redhead Pond	2002	0	6	1	59
Sanctuary Pond	2002	0	2	0	5
West Cranberry Pond	2002	0	0	1	29
West Cranberry Channel	2002	0	0	0	48
Bush Pond	2003	0	0	0	81
East Cranberry Pond	2003	0	0	3	115
Girardin Pond	2003	12	0	0	10
Lake Pond	2003	0	0	6	38
Redhead Pond	2003	13	11	0	51
Sanctuary Pond	2003	0	0	0	2
West Cranberry Pond	2003	0	0	1	2
West Cranberry Channel	2003	0	0	0	5
East Cranberry Pond	2019	0	1	3	26
Lake Pond	2019	1	4	3	89
West Cranberry Pond	2019	0	1	2	17
Girardin Pond	2021	1	0	1	45
Lake Pond	2021	0	0	0	2
Redhead Pond	2021	1	2	0	62
Total		**28**	**28**	**28**	**892**

Table 2. *Counts of individuals captured by gear type across years for SARA-listed species in PPNP. HN = hoop net; MFN = mini-fyke net; MT = minnow trap; SN = seine net; TN = trap net; WT = Windermere trap.*

Species	HN	MFN	MT	SN	TN	WT
Grass Pickerel	4	8	0	14	0	2
Lake Chubsucker	21	3	0	4	0	0
Spotted Gar	8	9	0	5	5	1
Warmouth	483	239	55	20	3	103
Total	**516**	**259**	**55**	**43**	**8**	**106**

PROBABILITY OF CAPTURING SARA-LISTED SPECIES

Based on the randomized resampling of the capture data, approximately two sites were required to achieve an 80% probability of capturing Warmouth (all life stages) in Lake Pond in 2002 using hoop nets, and five sites were required in 2003 (Figure 3). A probability of Warmouth detection greater than 0.99 was reached with approximately six hoop nets set in 2002 and 15 hoop nets set in 2003. Far more hoop nets were needed to effectively capture Spotted Gar in Lake Pond (Figure 3); approximately 80 and 90 hoop nets were needed to achieve an 80% probability of capturing at least one Spotted Gar in 2002 and 2003, respectively.

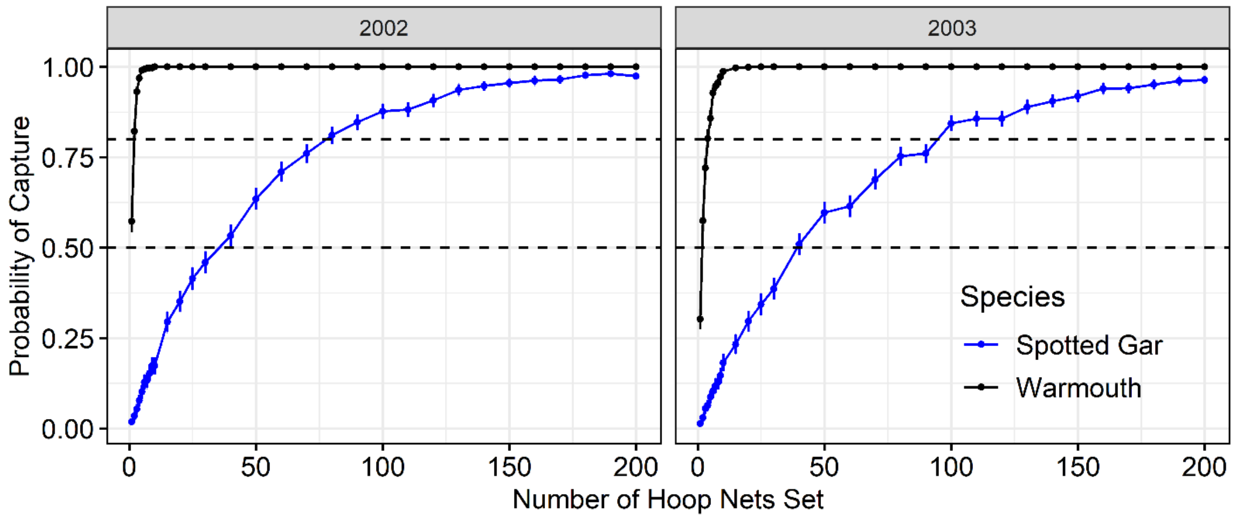

Figure 3. *Probability of capturing at least one Spotted Gar (blue) and Warmouth (black) given 0–200 hoop nets set in Lake Pond. Plotted are 95% confidence intervals. Dashed lines indicate 50% and 80% capture probability.*

Similar to data collected using hoop nets in 2002 and 2003 (Figure 3), few sites (n = 3) were needed to achieve an 80% probability of capturing Warmouth (all life stages) using mini-fyke nets in Lake Pond (adult Warmouth = 4 nets; Figure 4); approximately 15 mini-fyke nets were needed to achieve a probability of detection greater than 0.99 for adult Warmouth (Figure 4). The probability of capturing Spotted Gar was higher in 2019 when using mini-fyke nets than in 2002 or 2003 when hoop nets were used (Figure 3; Figure 4). However, sample sizes differed between the number of hoop nets (2002: 49; 2003: 59) and mini-fyke nets (2019: 88) deployed in Lake Pond between years.

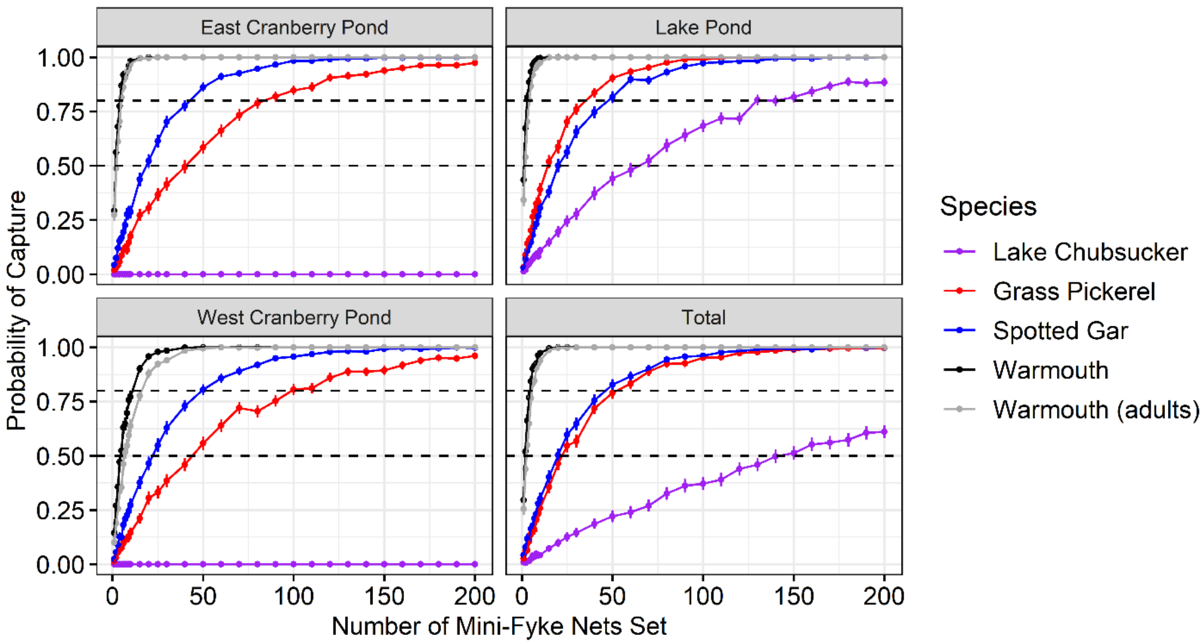

Figure 4. *Probability of capturing at least one Lake Chubsucker (purple), Grass Pickerel (red), Spotted Gar (blue), Warmouth (all life-history stages; black), and adult Warmouth (grey) given 0–200 mini-fyke nets set in East Cranberry Pond, Lake Pond, West Cranberry Pond, and the three ponds combined (Total). Plotted are 95% confidence intervals. Dashed lines indicate 50% and 80% capture probability.*

Relative to the other ponds, fewer mini-fyke nets set were needed in Lake Pond to sample SARA-listed species (Figure 4); approximately 40 mini-fyke nets set were required to achieve an 80% probability of capture for Grass Pickerel, 50 for Spotted Gar, and 130 for Lake Chubsucker (Figure 4). A capture probability of adult Warmouth greater than 0.99 was reached with approximately 15 mini-fyke nets set in East Cranberry Pond and 50 mini-fyke nets set in West Cranberry Pond (Figure 4). Capture probability of Spotted Gar and Warmouth (all life-history stages or adults) was consistent across ponds, whereas there was greater variation for Grass Pickerel (Figure 4). Because Lake Chubsucker was only detected in Lake Pond, the probability of capturing it in East and West Cranberry ponds was zero, and the probability of capturing it across all ponds was reduced (“Total” panel in Figure 4).

POWER TO DETECT TRENDS IN ADULT WARMOUTH ABUNDANCE OVER TIME

Eighty adult Warmouth were captured in 2019: 22 in East Cranberry Pond, 47 in Lake Pond, and 11 in West Cranberry Pond (Figure 5a, b). Captures of adult Warmouth occurred across the entire duration of sampling (Figure 5a). The capture rate of adult Warmouth across ponds was 0.39 individuals per net (80/205), with capture rates differing between ponds (East Cranberry Pond: 0.87 ind./net; Lake Pond: 0.53 ind./net; West Cranberry Pond: 0.17 ind./net). Of the 31 days of sampling, there were only seven days when adult Warmouth were not captured, five of which occurred when sampling West Cranberry Pond (Figure 5a). Mini-fyke nets without adult Warmouth captures were distributed around the entirety of the perimeter in West Cranberry Pond (n = 33 nets; 52% of nets set in West Cranberry Pond), while mini-fyke nets with zero captures in East Cranberry Pond were restricted to the southwestern shore (n = 5; 9% of nets set), and nets with zero captures in Lake Pond were restricted to the northern shore (n = 6; 7% of nets set).

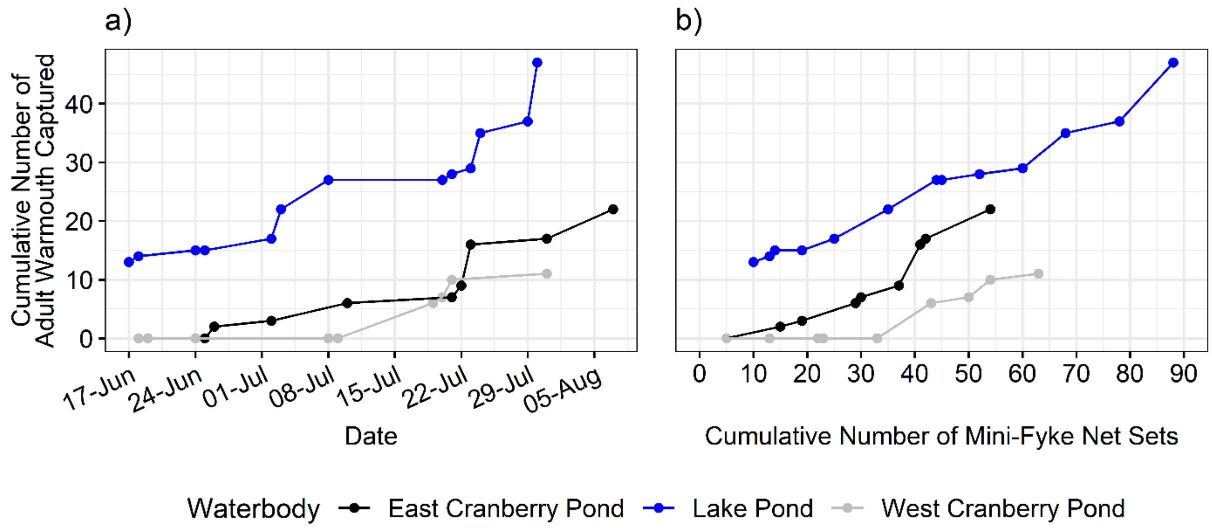

Figure 5. *Cumulative number of adult Warmouth captured in 2019 a) over the course of the sampling period, and b) per mini-fyke nets set in East Cranberry Pond (black), Lake Pond (blue), and West Cranberry Pond (grey).*

The power to detect changes in adult Warmouth abundance improved as the number of sites, years surveyed, and amount of variance explained by the random site variable increased (Figure 6; Figure 7). Documenting 30% increases in abundance required the most effort among the scenarios considered, and 70% reductions in abundance required the least (Figure 6; Figure 7). Approximately the same amount of effort was required to detect 50% reductions or 70% gains in abundance with 80% power (Figure 6; Figure 7) due the multiplicative model of decline (i.e., constant proportion of change over time) used. More sites were needed to achieve 80% power when the random effect of site explained less variance in adult Warmouth abundance between sites over time (Figure 6; Figure 7). For example, assuming 10 years of annual sampling, approximately 150 sites are needed to detect a 30% reduction in abundance with power > 80% when variance = 0.01 compared to approximately 75 sites when variance = 2.00 (Figure 6). Eighteen to twenty years of annual sampling were needed to achieve power approximately equal to 0.80 for detecting changes in adult Warmouth abundance if only 25 nets were set per year (Figure 6; Figure 7).

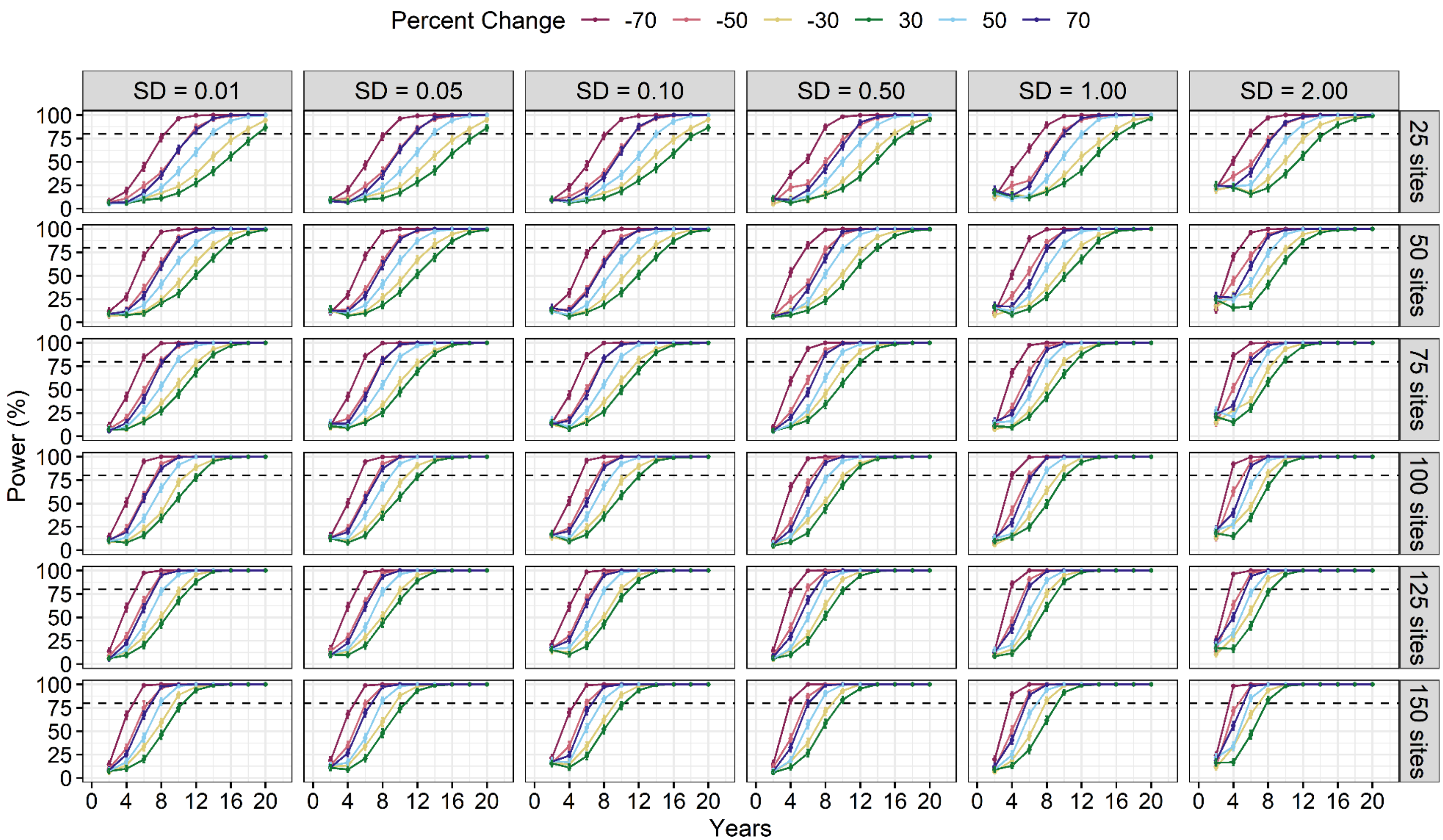

Figure 6. *Power curves for generalized linear mixed models developed to detect 30%, 50%, and 70% gains and reductions (denoted by colours) in adult Warmouth abundance in Point Pelee National Park. Presented are estimates of percent power as a function of years of annual sampling (2–20) at 25–150 sites where variance of random site-level effects range from 0.01 to 2.00. 95% confidence intervals are generated from 500 simulations. Dashed lines indicate 80% power.*

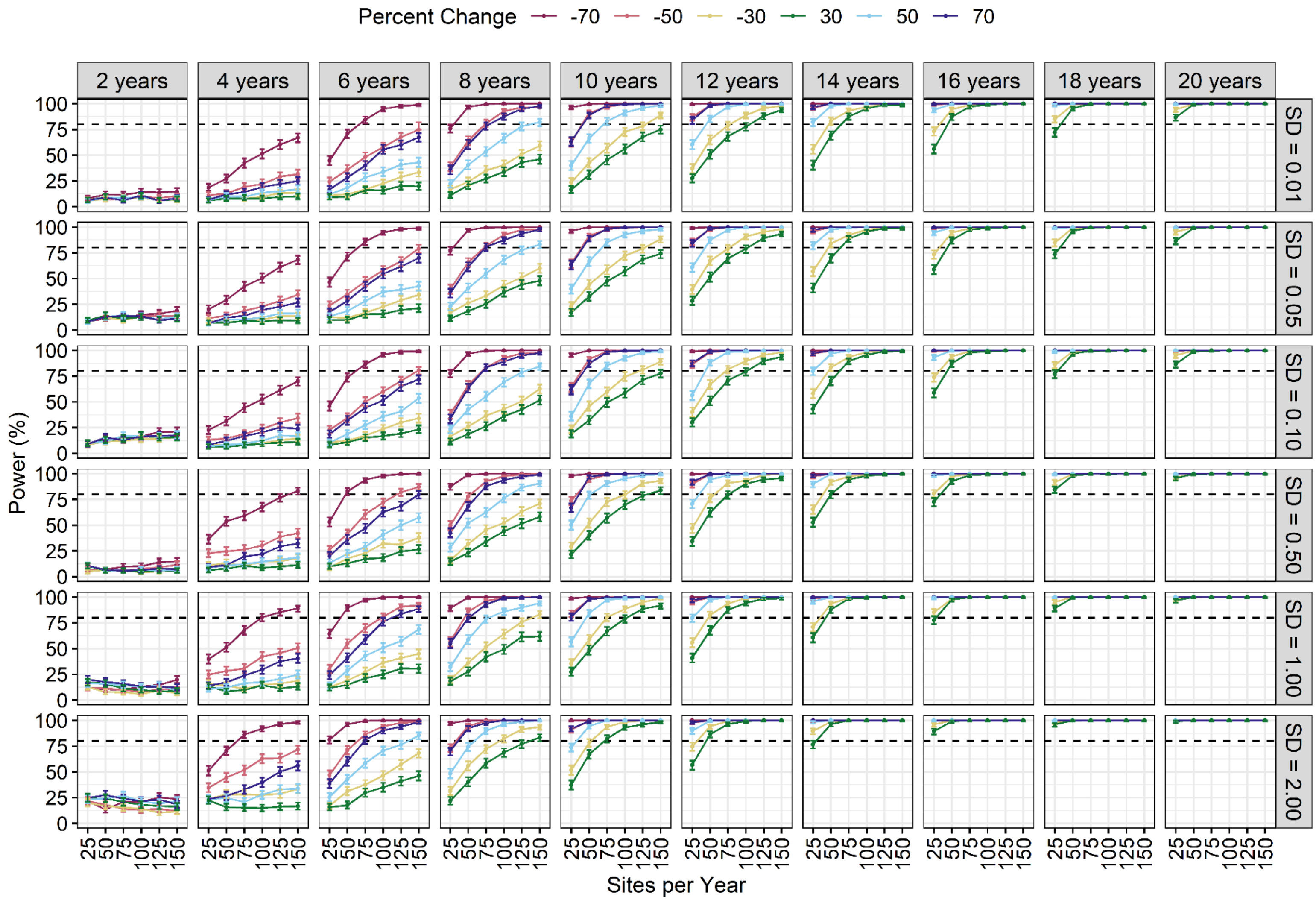

Figure 7. *Power curves for generalized linear mixed models developed to detect 30%, 50%, and 70% gains and reductions (denoted by colours) in adult Warmouth abundance in Point Pelee National Park. Presented are estimates of percent power as a function of the number of sites sampled per year (25–150) for 2–20 years where variance of random site-level effects ranged from 0.01 to 2.00. 95% confidence intervals are generated from 500 simulations. Dashed lines indicate 80% power.*

Deploying 125 or more mini-fyke nets per year in Lake Pond for 10 years would provide greater than 75% probability of capturing all four SARA-listed species each year (Lake Chubsucker: 76.0%; Grass Pickerel: 99.7%; Spotted Gar: 98.3%; Warmouth: 100%; Figure 4) and ensure that a sufficient number of adult Warmouth are captured (Figure 5b) to allow evaluations of 30%, 50%, and 70% reductions or gains with sufficient power (~0.80; Figure 6; Figure 7). For example, 10 years of annual sampling at 125 sites would provide between 78.2–99.8% power for detecting a 30% reduction in abundance and 67.8–96.0% power for detecting a 30% increase across all variance scenarios (Figure 6; Figure 7).

DISCUSSION

One potential objective of a monitoring program in PPNP is to allow analysis of changes in SARA-listed freshwater fish species abundance. Due to the low captures and inferred rarity of Grass Pickerel, Lake Chubsucker, and Spotted Gar, adult Warmouth was selected as the only SARA-listed species that could allow for monitoring trends in abundance over time, with the detection of the rarer species being indicative of their ongoing occurrence. The low observed abundance of SARA-listed species in PPNP is not surprising given the low densities of these species in Ontario wetlands or embayments (Beauchamp et al. 2012; COSEWIC 2021). For example, a mark-recapture study performed in May 2009 estimated the abundance of Spotted Gar in Lake Pond was 483 individuals (2.2 individuals/ha) based on six recaptures of 93 tagged individuals captured using 1.2-m fine-mesh fyke nets (6.35 mm; Glass et al. 2012; Fisheries and Oceans Canada 2024). Only three Spotted Gar were captured in Lake Pond in 2019 across 205 nets set with no recaptures of individuals (Barnucz et al. 2021).

To best achieve the objective of monitoring for changes in adult Warmouth abundance, it is recommended that 125 sites are surveyed annually in late summer to early fall across Lake Pond, East Cranberry Pond, and West Cranberry Pond using mini-fyke nets for at least 10 years, where site selection occurs annually and randomly across nearshore areas where mini-fyke nets can be effectively fished. The number of sites sampled per pond should be chosen in proportion to the perimeter of each pond, as mini-fyke nets are set in nearshore areas (< 2 m depth). For example, if 125 sites were surveyed per year, 61 mini-fyke nets would be set in Lake Pond (~5.28 km perimeter), 26 in East Cranberry Pond (~2.25 km perimeter), and 38 in West Cranberry Pond (~3.28 km perimeter). The reasoning behind these recommendations is provided below, followed by a discussion of the assumptions and limitations of the methods performed and sampling design recommended.

There are benefits to monitoring Lake Pond, East Cranberry Pond, and West Cranberry Pond compared to other ponds in PPNP. These three ponds contain the highest biodiversity and may function as an important source of individuals for the connected ponds in the park (Surette 2006; Barnucz et al. 2021, 2024). Most importantly, all four SARA-listed species are known to occupy at least one of these ponds. Sampling all three ponds, as opposed to putting more effort into sampling just one, represents a trade-off between capturing the spatial variation in SARA-listed species abundance across ponds and maximizing the probability of capturing each species. For example, assuming 125 nets are set across the three ponds, the probability of capturing Lake Chubsucker in Lake Pond is reduced to approximately 48% compared to 76% when effort is allocated exclusively to Lake Pond. However, allocating effort across the three ponds provides a more accurate understanding of how adult Warmouth abundance is changing in the park, while maintaining the ability to detect the other three SARA-listed species (Figure 4). Moreover, by sampling three ponds, pond-specific differences in adult Warmouth abundance could be evaluated. Nevertheless, sporadic sampling of the non-focal ponds using mini-fyke nets could provide evidence of ongoing persistence of Grass Pickerel, Lake Chubsucker, and Spotted Gar. In particular, sporadic sampling in Girardin and Redhead ponds may provide the best opportunity to document persistence of these three species given the previous detections in these locations (Figure 1).

Quantifying statistical power for detecting trends in species abundance is difficult when the natural level of spatial and temporal variation in species abundance is unknown (Underwood 1992). The results presented in this study suggest that sampling 125 sites per year for 10 years following the net deployment procedures documented in Barnucz et al. (2021) would be sufficient effort to detect 30%, 50%, or 70% increases or declines in adult Warmouth abundance across all site-level variance scenarios with a statistical power of approximately 0.80. If all fishes are identified and counted, sampling would also provide information about the composition of the fish community. Although outside the scope of this research, a simulation approach like the one presented in this study could be used to estimate the power to perform multivariate approaches for detecting changes in fish species composition over time (e.g., PERMANOVA; Irvine et al. 2011; Kelly et al. 2015).

The use of passive sampling gears is an effective approach for capturing SARA-listed and co-occurring fish species in PPNP (Surette 2006; Barnucz et al. 2021, 2024). In 2019, mini-fyke nets were selected as the sole sampling gear due to their past ability to reliably capture Lake Chubsucker, Spotted Gar, Grass Pickerel, and Warmouth in other Canadian freshwater ecosystems combined with limitations regarding the use of other methods for sampling fish species in the park (e.g., boat electrofishing, trawling). Mini-fyke nets are smaller than traditional fyke nets, with fewer chambers and a smaller mesh size (3 mm). These differences make transport and deployment in the field less cumbersome, while also providing the ability to capture smaller fishes. Field crews would benefit from deploying mini-fyke nets during the late summer or early fall, with the chosen temporal period being consistent over time to minimize the effects of environmental variation on capture rates. Sampling during late summer or early fall reduces the handling time of fishes at vulnerable life stages (i.e., fewer juvenile captures) and reduces the probability of species misidentification in the field as larger individuals are easier to identify to the species level. However, sampling in the late summer or early fall likely comes with the trade-off of capturing fewer Spotted Gar, which tend to aggregate in the spring prior to, and during, spawning.

Eight mini-fyke nets would be sufficient for conducting the annual sampling of fishes, and it is recommended that nets be modified based on the specifications in Barnucz et al. (2021). Deploying eight mini-fyke nets four times a week could satisfy the objective of 125 nets set in approximately one month [125 nets/ (8 nets * 4 days per week) = 3.91 weeks]. The mini-fyke nets deployed in 2019 and 2021 were modified by placing a large-diameter protective net over the opening box to reduce incidental mortality and to deter turtles (Barnucz et al. 2021). As well, a zipper was installed on the box to allow for the rapid removal of large fishes and incidental turtle captures, and further allowed a large float to be inserted into the cod end to ensure that captured turtles could reach the water's surface (Larocque et al. 2012; Barnucz et al. 2021). Nevertheless, it remains critical that nets are set for less than 24 hours to minimize the potential for harm.

There are limitations to the analysis and caveats to the monitoring program design that must be considered. First, inappropriate model design may inflate power for detecting changes in abundance over time. For example, a Poisson distribution was used in this study to estimate abundance of Warmouth and evaluate power to detect trends over time. Using the Poisson distribution is a simplification of what is often observed for SARA-listed species, specifically zero-inflation and overdispersion of counts. This is the case for observed Warmouth captures in PPNP, where there were more nets that failed to capture Warmouth than were successful. As well, spatial autocorrelation between sites could result in reduced power to detect trends. In addition, due to low capture rates at current effort levels, quantifying trends in the abundance of

Grass Pickerel, Lake Chubsucker, or Spotted Gar is unachievable. When trends in abundance are unable to be estimated for a species, changes in species detections over time may be the best option for evaluating changes in SARA-listed freshwater fish species within the park. Changes in the capture probability over time could suggest that the abundance of individuals is changing. For example, based on comparisons of hoop net and mini-fyke nets from 2002/2003 and 2019, respectively, there was a greater probability of detecting a Spotted Gar in 2019 assuming the same amount of effort. However, basing inferences on the detection of a species adds assumptions to those already implied when analysing changes in relative abundance. For example, evaluating capture probability as a metric for change assumes a direct relationship between species detection, occurrence, and abundance. As well, the approach to quantifying capture probability used in this study ignores environmental variation or how movement activity may influence catch patterns. It is unclear how much variation exists in the movement of individuals in PPNP, or how frequently individuals of a species encounter a trap, and how that might affect capture probability. Moreover, there may be situations where the abundance of individuals is being reduced but the capture probability of the species remains unchanged. A future manipulative experiment using passive traps to sample fishes inside a closed wetland system with known community composition could improve estimates of species detection and be used to inform future estimates of population abundance in the park. These considerations emphasize the importance of developing monitoring protocols that are consistent and performed regularly (e.g., annually).

Interpreting the *cause* of changes in adult Warmouth abundance over time using the monitoring program design described in this study is unlikely to be achieved. Understanding the cause of change would require long-term monitoring of fishes, habitat, threats, and other environmental characteristics both within and outside of the park (independent ‘control’ populations) to account for natural spatial and temporal patterns (Underwood 1992, 1994). This would require identifying control populations that simply may not exist in Canada for SARA-listed species. Nevertheless, understanding the change in relative abundance of adult Warmouth over time from spatially and temporally replicated sites within the park can at least measure an inferred or suspected reduction in the total number of mature individuals over three generations for informing species assessment decisions (COSEWIC 2021 *sensu stricto*), albeit with uncertainty. As such, decisions around the spatial and temporal allocation of effort are critical. Ultimately, annual monitoring of adult Warmouth provides the best opportunity to quantify changes in SARA-listed species abundance but will require a significant investment in time and resources to ensure that sufficient power is attained.

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