Seasonal daily depth use patterns of acoustically tagged freshwater fishes informs nearshore fish community sampling protocols

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ABSTRACT

Larocque, S., Boston, C.M., Midwood, J.D. 2020. Seasonal daily depth use patterns of acoustically tagged freshwater fishes informs nearshore fish community sampling protocols. Can. Tech. Rep. Fish. Aquat. Sci. 3409: viii + 38 p.

Standardized fish sampling and monitoring programs provide valuable information pertaining to changes in fish habitat, community composition and structure, and population abundance. However, fish may utilize different depth distributions based on the season or time of day, and sampling may not occur when fish are at catchable depths, particularly if sampling occurs infrequently or, for example, only once per year. With acoustic telemetry, we can compare the depth use of multiple acoustically tagged fish species (Common Carp (*Cyprinus carpio*), Freshwater Drum (*Aplodinotus grunniens*), Goldfish (*Carassius auratus*), Largemouth Bass (*Micropterus salmoides*), Longnose Gar (*Lepisosteus osseus*), Northern Pike (*Esox lucius*), and Walleye (*Sander vitreus*)) with the depths surveyed by nearshore fish sampling methodologies. In Hamilton and Toronto harbours, we determined seasonal, daily detection probabilities of multiple fish species by examining occurrence at depths over a 24-hour period. Similar diel and seasonal patterns were seen in both harbours, however, fish from Toronto Harbour showed greater variability in depth use than fish from Hamilton Harbour. Results showed that active fish sampling surveys such as electrofishing would capture more species at night due to the diel depth distribution patterns of some species. Nearshore (< 2 m) fish community surveys will effectively target more species if done in the spring or summer compared to the fall and winter. Depth use trends determined from acoustic telemetry revealed patterns that can be used to maximize catches with nearshore community sampling protocols.

RÉSUMÉ

Larocque, S., Boston, C.M., Midwood, J.D. 2020. Seasonal daily depth use patterns of acoustically tagged freshwater fishes informs nearshore fish community sampling protocols. Can. Tech. Rep. Fish. Aquat. Sci. 3409: viii + 38 p.

Les programmes normalisés d'échantillonnage et de surveillance des poissons fournissent des renseignements précieux concernant les changements dans l'habitat des poissons, la composition et la structure des communautés et l'abondance des populations. Toutefois, la répartition en profondeur des poissons peut varier en fonction de la saison ou du moment de la journée, et l'échantillonnage pourrait se dérouler lorsque le poisson ciblé se trouve à une profondeur où il est impossible de le capturer, notamment lorsque l'échantillonnage a lieu peu souvent ou, par exemple, seulement une fois par année. La télémétrie acoustique nous permet de comparer les profondeurs de plongée de nombreuses espèces de poissons marqués d'une étiquette acoustique (carpe commune [*Cyprinus carpio*], malachigan [*Aplodinotus grunniens*], cyprin doré [*Carassius auratus*], achigan à grande bouche [*Micropterus salmoides*], lépisosté osseux [*Lepisosteus osseus*], grand brochet [*Esox lucius*] et doré jaune [*Sander vitreus*]) grâce aux profondeurs recensées par les méthodologies d'échantillonnage riverain. Dans les ports de Hamilton et de Toronto, nous avons déterminé les probabilités de détection quotidiennes et saisonnières pour différentes espèces de poisson en examinant les occurrences à différentes profondeurs sur une période de 24 heures. Des profils saisonniers et journalières semblables ont été observés dans les deux ports, mais une plus grande variabilité des profondeurs de plongée a été observée chez les poissons du port de Toronto comparativement à ceux du port de Hamilton. Les résultats révèlent que les méthodes d'échantillonnage actives du poisson, comme la pêche à l'électricité, permettent de capturer davantage d'espèces la nuit en raison des profils journalières de répartition en profondeur de certaines de ces espèces. L'échantillonnage riverain (< 2 m) des communautés de poissons permettra de cibler davantage d'espèces s'il est effectué au printemps ou à l'été comparativement à l'automne ou à l'hiver. Les tendances de profondeur de plongée établies à l'aide de la télémétrie acoustique ont révélé des profils dont on peut se servir pour maximiser les prises avec les protocoles d'échantillonnage riverain des communautés de poissons.

INTRODUCTION

Fish sampling protocols and monitoring programs provide valuable information pertaining to changes in fish habitat, community composition and structure, and population abundance. Standardized methodologies provide repeatability across studies and allow for comparison among sampling events; however, all fishing gears have inherent biases related to catchability (Bonar et al. 2009). While the sampling approach or gear itself may influence the abundance and composition of fishes that are caught, fish may utilize different areas based on the season, depth, and time of day and sampling may not be spatially or temporally aligned with fish occurrence. This is particularly true if sampling occurs infrequently or only once per year. Thus, it is important to assess the efficacy of fishing gear with regards to the probability of fish encountering the fishing gear.

Acoustic telemetry allows for the near-continuous collection of information on the position of an individual fish and (with certain sensors) information on their depth or proximate water temperature among other metrics (Cooke et al. 2013). Unlike traditional sampling methods, acoustic telemetry provides information on a fish's whereabouts when detected within an array without having to catch it. With these newer technologies available, there are opportunities to incorporate information generated from acoustic telemetry into biological assessments and fisheries management (Cooke et al. 2016). For example, Gorman et al. (2019) used acoustic telemetry to investigate whether different gill net depths effectively caught Walleye (*Sander vitreus*) relative to their diel depth use. With acoustic telemetry, we can verify whether fishing gear sampling protocols are effective in capturing fish relative to the seasonal and diel depth use of acoustically tagged fish.

In nearshore littoral areas, actively sampling for fish using electrofishing and passively sampling using trap nets are common methods for assessing fish assemblages (Brousseau et al. 2005; Stirling 1999). Sampling depths for both electrofishing and trap netting are approximately 0.1 to 2.0 m but can vary depending on local conditions. Information on depth use of multiple fish species, throughout the day and seasonally derived from acoustic telemetry, can be used to assess the effectiveness of and potentially optimize electrofishing and trap net sampling protocols. Ward and Myers (2005) found that depth use from tracking studies could be site specific and not comparable to a broad area due to small numbers of tagged fish (<10), short tracking periods (a few days), and habitat specific behaviour. Assessing depth use over long durations and at two locations can verify whether there are any consistent patterns in depth use. In Hamilton and Toronto harbours (Lake Ontario), littoral areas have been sampled for fishes via standardized electrofishing monitoring protocols since the late 1980s by Fisheries and Oceans Canada (DFO) and the Toronto and Region Conservation Authority (TRCA). In addition, a standardized nearshore community index trap netting program (NSCIN) commenced at both areas by the Ontario Ministry of Natural Resources and Forestry (OMNRF) in 2006. Both harbours also have established telemetry arrays; Toronto (2010-present) and Hamilton Harbour (2015-present) where multiple species of fish have been tagged and tracked (Brooks et al. 2017). The existence of the concurrent sampling programs in the two areas (i.e., nearshore fish community surveys and acoustic telemetry) provides a unique opportunity to explore and validate the depth use of multiple acoustically tagged fish species with traditional fish sampling methodologies. The objectives of the present report were to determine optimal seasonal and diel sampling times for two fish sampling methods, boat electrofishing and trap netting, using acoustic telemetry. Using acoustic telemetry data from Hamilton and Toronto harbours, we will determine: 1) seasonal, hourly- and depth-based detection probabilities (herein referred to just as detection probability) of fish at depths throughout the day; and 2) provide guidance on how to adjust sampling approaches if needed (i.e., shift in depth or timing of sampling) to optimize the chance of capturing a specific species with boat electrofishing and trap netting.

METHODS

STUDY SITES

Hamilton Harbour (43°14’N, 79°51’W) is a 21 km^2 embayment connected to the western end of Lake Ontario by the Burlington ship canal (Figure 1). The harbour was designated as a Great Lakes Area of Concern in 1987 due to a legacy of development and industrialization that resulted in impairments to fish and wildlife populations and habitat, polluted waters, and contaminated sediments.The harbour has a mean depth of 13 m and maximum depth of 26 m; approximately 35% of area in the harbour is < 11 m depth (Appendix A1). Three major creeks flow directly into Hamilton Harbour : Red Hill, Indian, and Grindstone Creeks. A fourth creek, Spencer Creek, flows into Cootes Paradise from the west, which is then connected to the harbour by the Desjardins Canal. Silt-clay substrate dominates the majority of the harbour, with sand more prevalent on the north and east shore, some boulder on the east shore, and cobble on the southwest shore (Young et al. 2010). Moderate amounts of submerged aquatic vegetation are present at depths <3 m on the north, east, and west sides of the harbour (Leisti et al. 2016; Gardner Costa et al. 2019). Dissolved oxygen (DO) depletion occurs regularly in the hypolimnion (approx. >8 m depth) during the summer months, and the time period and variability of this depletion can differ across the harbour (Gertzen et al. 2016).

Toronto Harbour (43°38'N, 79°22'W) is a large and complex embayment system (18 km^2) located on the northwestern shore of Lake Ontario (Figure 1). Like Hamilton Harbour, the Toronto region (including the harbour) was designated a Great Lakes Area of Concern in 1987 with impairments to fish and wildlife habitat and populations persisting to this day. The harbour has a mean depth of 9 m and maximum depth of 14 m in which approximately 85% of the area in the harbour is < 11 m (Appendix A1). Toronto Harbour is composed of the Inner Harbour, which is defined by the area of water enclosed by the Toronto Islands, and the Outer Harbour, which is defined by the area of water enclosed by Tommy Thompson Park. Silt substrate dominates the Inner Harbour and sand dominates the Outer Harbour (Leisti et al. 2020). There is sparse and low-lying submerged aquatic vegetation throughout these regions of the harbour. Toronto Harbour is also composed of shallower (<5 m) artificial embayments in Tommy Thompson Park and the channels inside the Toronto Islands, which are characterized by slower currents, finer sand and mud substrates, and dense macrophytes (Leisti et al. 2020). Immediately outside the Outer Harbour there is a steep underwater escarpment that drops off to 75 m depth, making Toronto Harbour particularly sensitive to upwelling of hypolimnetic waters, and as such it can experience drastic temperature changes (Hlevca et al. 2015). The highly-urbanized Don River is the dominant source of flow and contaminant loading into the harbour.

ACOUSTIC TELEMETRY TAGGING AND ARRAYS

In Hamilton Harbour, detection data were available for fish with depth (pressure) sensors from August 2015 to December 2018. Over the course of the study period, 214 fish of 12 species were tagged in Hamilton Harbour with acoustic transmitters (henceforth called tags) that had depth sensors (V13P tags; 13 mm × 48 mm, 13 g in air, 69 kHz, mean delay=200 s, Innovasea, Bedford, Nova Scotia). Capture and surgical tag implantation followed the methods described by Brooks et al. (2019). The array in Hamilton Harbour was first deployed in summer 2015 and consisted of 27 acoustic receivers (VR2W 69 kHz, Innovasea, Bedford, Nova Scotia) that expanded to 51 in spring 2018. The array was arranged to maximize spatial coverage, capture a variety of habitat conditions (e.g., shoals, vegetated areas, deeper open waters, inlets) throughout the harbour, and determine if fish left the harbour via the Burlington shipping canal (see Brooks et al. 2019; Figure 1).

In Toronto Harbour, detection data were available for fish with depth sensors from September 2010 to December 2016. Over the course of the study period, 194 fish of four species were tagged in Toronto Harbour with tags that had depth and temperature sensors using V13TP (n = 171; 13 mm × 48 mm, 13 g in air, 69 kHz, mean delay=200 s, Innovasea, Bedford, Nova Scotia) and V9TP tags (n = 23; 9 mm ×31 mm, 4.9 g in air, 69 kHz, mean delay=120 s, Innovasea, Bedford, Nova Scotia). Capture and surgical tag implantation followed the methods described by Rous et al. (2017). The array in Toronto Harbour has expanded and evolved since its initial deployment 2010 but has consistently covered core habitats (see Midwood et al. 2019; Figure 1). The telemetry project in Toronto focused on assessing fish residency in a variety of habitats including shallow, vegetated habitat within the Toronto Islands and Tommy Thompson Park, deeper cool- and cold- water habitats in the Outer Harbour, and hardened shorelines in the Inner Harbour.

SEASONAL DESIGNATIONS

In Hamilton Harbour, seasons were based on temperature profiles collected using a chain of temperature loggers that was deployed annually at the centre of the Harbour from early-spring to late-fall (43.288° N, -79.845° W). Season was defined by temperature dynamics and thermocline delineation: spring (>5°C and warming isothermal), summer (established thermocline), fall (first full water column mixing), and winter (temperature is no longer declining and <5°C isothermal). Dates used to designate seasons are provided in Table 1.

Seasons in Toronto Harbour were more challenging to assign as there was no central temperature chain, rather a temperature chain in the Spadina Slip in combination with a nearby Lake Ontario (Ajax, Ontario) temperature chain were used to assign season. As the Spadina Slip temperature chain is close to the main inflow from Lake Ontario (and likewise the Ajax chain) and likely cooler, a more conservative threshold for seasons was used. Summer and winter were designated when water temperatures were consistently >15°C and <5°C, respectively. The start of spring was estimated to occur when water temperatures started increasing (>5°C) until they surpassed 15°C, and fall was estimated to occur when water temperatures were decreasing (<15°C) until they reached 5°C. Dates used to designate seasons are provided in Table 1.

DATA PREPARATION

Detection data were filtered to remove fish that were dead (or had expelled tags) or had malfunctioning depth sensors (Table 2). Fish were inferred to be dead if they continuously exhibited constant depth-use profiles and stayed within the same area of the array (potentially detected on multiple receivers all within the same vicinity). Fish that died soon after tagging were removed from the dataset. If fish were alive with a functioning depth sensor for a period >1 month prior to suspected mortality, then only the suspect data were removed from the dataset. All instances of depth sensor malfunctions were removed from the dataset. Depth data and detections outside of the harbours (i.e., on other receiver arrays deployed in Lake Ontario) were removed for the purposes of our analyses due to incomplete spatial coverage of these arrays. Overall, 63% and 76% of tagged fish were alive for their entire tag life in Hamilton Harbour and Toronto Harbour, respectively (Table 2). Additionally, data were excluded from our analyses if it met the criteria for false detections (Pincock 2012).

Both individual fish and species had to have adequate detections and sample sizes to be included for analyses. If individuals were detected for over 50% of the days within the season in at least a single year (as some fish were detected over multiple years) and had a minimum of five detections in every hour of the day within the season, then they were considered to have suitable detection coverage to be included for analyses. Table 2 provides a summary of the number of individuals of a species that met our criteria by harbour and season. Species with four or more individuals tagged or with adequate data representation were analyzed and included in the study. For Hamilton Harbour, Common Carp (*Cyprinus carpio*), Freshwater Drum (*Aplodinotus grunniens*), Goldfish (*Carassius auratus*), Largemouth Bass (*Micropterus salmoides*), Longnose Gar (*Lepisosteus osseus*), Northern Pike (*Esox lucius*), and Walleye were included. For Toronto Harbour, Common Carp, Largemouth Bass, and Northern Pike were included. There were insufficient numbers of individuals for the five other species that were tagged as part of the Hamilton Harbour acoustic telemetry project (Bowfin (*Amia calva*), Channel Catfish (*Ictalurus punctatus*), Rudd (*Scardinius erythrophthalmus*), Smallmouth Bass (*Micropterus dolomieu*), and White Sucker (*Catostomus commersonii*)). Similarly, there were insufficient Walleye to be included as part of the Toronto Harbour acoustic telemetry project.

DETECTION PROBABILITY

To reduce temporal autocorrelation, for each individual we randomly selected one detection within each daily hour bin of the raw data. We then used the random sample subsets of each individual to calculate the detection probability at depth and time of day. Detections were first binned into 1-hour bins for each hour of the day and then binned into 1-m depth bins up to 10 m; any detections at depths greater than 10 m were grouped into one bin.

For each species by season, detections per individual were summed and the proportion that fell within each depth bin among hourly bins were calculated (the probabilities across all depths and hours added up to 1). The mean and standard deviation (SD) depth/hour proportions were calculated across all individuals within that species by season and harbour. Heat maps showing the mean depth by hour probabilities using colours for visual interpretation, were plotted for each species by season and harbour. These figures identify the depth/hour combination that has the highest detection probability for a species for an entire day (daily peak). Associated SD heat maps can be found in Appendix B. Using the mean depth by hour probabilities for each species by season, we determined the cumulative mean detection probability at shallow depths (≤2 m) and deep depths (>2 m) for each hour to summarize hourly and seasonal detection probability trends across species. The shallow depths represent depths that would be sampled by nearshore fish community survey methods.

RESULTS

Within Hamilton Harbour, mean seasonal detection probabilities were calculated for seven species: Common Carp, Freshwater Drum, Goldfish, Largemouth Bass, Longnose Gar, Northern Pike, and Walleye (Figure 2-8). There was an overall seasonal pattern where fish tended to be shallower in spring and summer (<1 m depths), shallow or deep in fall, and deeper in winter; however, Longnose Gar and Goldfish tended to stay shallower (<2 m) in the winter than the other species. Freshwater Drum and Walleye tended to use deeper waters than the other species, including depths greater than 10 m in the fall and winter. Common Carp and Goldfish were the only other species to spend time at 10+ m, which only occurred in the fall. A relatively consistent diel pattern within the seasons occurred for some species in which fish had either a higher detection probability at deeper depths during daylight hours and at shallow depths (<1 m) after dark or fish remained shallow at all hours but had lower detection probabilities during daylight hours. All species except Freshwater Drum showed a diel pattern in at least one season. The hours in which species would occur more frequently at shallower depths varied slightly with season presumably due to shifting sunrise and sunset times. In the spring and summer, approximately between 07:00 and 18:00, Common Carp, Goldfish, Largemouth Bass (summer only – albeit weakly and for a shorter duration), Northern Pike (weakly and for a shorter duration), and Walleye had either lower detection probabilities while still in shallow waters (<1 m; e.g., Common Carp, Largemouth Bass and Northern Pike) or were were more likely to be detected at deeper depths (>1 m but <4 m; e.g., Walleye). In the fall, between 08:00 and 16:00, Goldfish, Longnose Gar (fall and winter), Northern Pike, and Walleye had either fewer detections (and lower detection probabilities) while still in shallow waters (e.g., Longnose Gar and Northern Pike) or were more likely to be detected at deeper depths (>1 m but <6 m – except for Goldfish which went to 10+ m; e.g., Walleye and Goldfish). In the winter, the only species that appeared to have a diel pattern was Longnose Gar and this relationship was not strong. Diel depth patterns were strongest in Walleye, followed by Goldfish, while most other species (excluding Freshwater Drum) remained relatively shallow but had reduced detection probability during daylight hours. Multiple depth bands across all hours were seen in a few species in certain seasons indicating there may be some individual variation in depth use (i.e., individuals that generally use deeper or shallower waters) as occurred with Common Carp in the fall (Figure 2), Freshwater Drum in the fall and winter (Figure 3), Longnose Gar in winter (Figure 6) and Walleye in the spring (Figure 8). The cumulative detection probability at shallow (≤2 m) and deep (>2 m) depths showed similar diel and seasonal trends for each species as the mean seasonal detection probability heat maps (Figure 9). Although it does not provide specific depth information, while in shallow depths, fish still showed diel patterns in at least one season (except for Freshwater Drum), yet the diel pattern was not present at deep depths (except for Goldfish and Walleye). Spring and summer had a higher detection probability in shallow waters than deep waters, except for Walleye. Winter had higher detection probabilities in deep waters than shallow waters, and fall varied by species.

Within Toronto Harbour, mean seasonal detection probabilities were calculated for three species: Common Carp, Largemouth Bass, and Northern Pike (Figures 10-12). Similar to the tagged fishes in Hamilton Harbour, there was an overall seasonal pattern where fish were shallower in spring and summer, and deeper in the fall and winter. Diel patterns were also present in Toronto Harbour during some seasons in which fish had either a greater detection probability at deeper depths during daylight hours and at shallow depths (<1 m) during the night or lower detection probability during daylight hours. This diel trend was not prominent in Largemouth Bass (occurred weakly in spring and summer); however, Common Carp showed this pattern in fall and Northern Pike showed this pattern in spring and summer. No diel patterns in fish were apparent in winter. In the spring and summer, between 08:00 and 19:00, Northern Pike were found at deeper depths (>1 m and <4 m) and Largemouth Bass were shallow (<2 m) but had a lower detection probability. In the fall, between 08:00 and 16:00, Common Carp were found using deeper waters (>1 m and <8 m). It should be noted that Common Carp and Northern Pike used a wide variety of depths, particularly in the fall and winter while Largemouth Bass were more restricted in their depth use. The cumulative detection probability at shallow (≤2 m) and deep (>2 m) depths showed similar diel and seasonal trends for each species as the mean seasonal detection probability heat maps (Figure 13). Diel patterns were noteable at shallow depths in the spring and summer for all species, and fall for all species except Northern Pike. These diel patterns were also present at deeper depths in spring and summer, and fall for Northern Pike only. Like Hamilton Harbour, in Toronto Harbour, spring and summer had a higher detection probability in shallow waters than deep waters, except for Northern Pike. Winter had higher detection probabilities in deeper waters than shallow waters, and fall varied by species. Compared to Hamilton Harbour, both Common Carp and Northern Pike from Toronto Harbour utilized a wider variety of depths and generally occupied slightly deeper waters. Largemouth Bass had relatively consistent depth use among seasons in both harbours.

DISCUSSION

The detection probability of seven fish species within Hamilton Harbour and three species within Toronto Harbour was informative for seasonal and daily depth use trends and can be used to determine the season and time that electrofishing surveys (which are more time specific than trap nets) may be most effective. When diel patterns were present in a species (e.g., Walleye, Goldfish, Northern Pike), it generally indicated fish were shallower at night. Based on the detection probabilities, fish were more likely to be in the shallower depth zone (<2 m) sampled by electrofishing from 19:00 to 6:00 (e.g., at night). Some fish had no diel depth changes and stayed in shallow waters at all hours in the summer (e.g., Largemouth Bass and Longnose Gar); however, there was still a diel pattern in Largemouth Bass that generally had a higher detection probability in shallow waters during the night hours (as a result of being potentially more active at night). Studies have shown higher catch rates with boat electrofishing at night compared to during the day (Dumont and Dennis 1997; McInerny and Cross 2000; Pierce et al. 2001; Midwood et al. 2016). The increased catches and species richness at night may be due to inshore movements of certain species like Walleye (Portt et al. 2006), as was corroborated with Walleye depth-use in this study. The DFO protocol for boat electrofishing also recognizes catch differences between night and day (Brousseau et al. 2005). Therefore, it is important to consider time of day when sampling in the nearshore/littoral zone (<2 m) as there will be an increased likelihood of capture of species that are moving in shallower or have increased nearshore activity at night. This will optimize the potential capture of fish and/or species based on the sampling objectives.

Seasonally, there was a general shift with all seven fish species using deeper depths in winter (and to an extent in the fall, especially with Common Carp and Goldfish), and shallower depths in the spring/summer in Hamilton Harbour and Toronto Harbour. The range of depth use varied by species, and electrofishing and trap nets would be unlikely to capture Common Carp (Hamilton Harbour only), Freshwater Drum, Largemouth Bass, and Walleye at <3 m depth during winter based on low detection probabilities. Although fish community sampling via electrofishing and trap netting in temperate zones is generally unfavorable in winter due to ice, the depth-use data further reinforces that it would be less likely to encounter most fish species using shallow water sampling techniques during the winter season and could result in monitoring biases such as reduced population estimates. As such, sampling methods that can use deeper waters (e.g., gill nets) may be more effective in the winter months based on the increased detection probability at greater depths.

There were some differences in the depth use by species between harbours. In Toronto Harbour, Northern Pike showed a stronger diel pattern, and both Common Carp and Northern Pike had increased variability in depth use with deeper waters more frequently used compared to Hamilton Harbour. The increase in depth use of Northern Pike in Toronto Harbour indicates they are using a wider variety of habitats, instead of being restricted to shallow depths as in Hamilton Harbour. Northern Pike were not limited by depth in Hamilton Harbour as deeper depths are available within Hamilton Harbour (max depth of 26 m) compared to Toronto Harbour (max depth of 14 m). Northern Pike generally inhabit shallow, vegetated waters (Casselman and Lewis 1996), and larger individuals will occupy deeper depths, using both open waters and vegetated areas (Pierce et al. 2013). However, there were no size differences in Northern Pike from both harbours (mean ± SD of 700 ± 99 mm total length in Hamilton Harbour and 700 ± 188 mm total length in Toronto Harbour) that would be driving different depth use. Northern Pike can inhabit vegetated littoral zones more frequently in turbid environments (Jepsen et al. 2001) and Hamilton Harbour is more turbid than Toronto Harbour, which may result in Northern Pike using shallower depths. Common Carp have been captured at a variety of depths yet generally will be more littoral in the spring and deeper in winter (Garciá-Berthou 2001), as was seen in our study. The more restricted shallow depth use of species in the spring and summer of Hamilton Harbour compared to Toronto Harbour may be related to the available suitable habitat, specifically regarding dissolved oxygen levels. In Hamilton Harbour, the hypolimnion can be hypoxic (0-3 mg/L) in the summer and force some fish to be in the shallower, littoral areas (Hiriart-Baer et al. 2016; Gertzen et al. 2016), whereas Toronto Harbour does not experience such hypoxia. The thermocline in Hamilton Harbour is also not static as it is deflected by strong winds that can push hypoxic waters to the surface while pulling oxygen rich waters to deeper depths (B. Flood, pers. comm.). These seiche occur frequently during the stratified seasons and likely explain why there are still detections at depth below the thermocline in the summer (i.e., fish can find suitable oxygen conditions at deeper depths during a seiche event). Other environmental factors such as water temperature, vegetation and turbidity could influence fish depth use as well. Ward and Myers (2005) indicated that different behaviours and depth use between localities may make acoustic telemetry findings less extrapolatable. However, our study used larger sample sizes, depth data were acquired for a long period of time, and aside from increased variability of depth use for two of three species in Toronto Harbour, the seasonal and diel trends for the three overlapping species were similar between the harbours and thus applicable for informing sampling protocols.

CONCLUSION

Overall, we determined that we could use depth patterns from acoustic telemetry to assess the effectiveness of traditional fish community survey techniques. Summarizing the depth use patterns of the tagged species by day and season allows us to predict the likelihood of whether or not a species would be present and make recommendations on the timing of fish community surveys (Table 3; Figure 9 and 13). The detection probability based on depth and time of day, confirms that active fish sampling surveys such as boat electrofishing should occur at night due to the diel depth use patterns of some species and suggest that night fishing will increase capture rates of certain species and/or species richness. Nearshore fish community surveys will effectively target more species if done in the spring or summer compared to fall and winter;

however, this depends on the objectives of the sampling program and species of interest. Similar depth use trends were seen in both harbours, indicating that although there are site specific differences (i.e., greater depth variability in Toronto Harbour for two of the species), the trends determined from acoustic telemetry were generally consistent and also provided more species-specific depth use details than could be derived using traditional sampling gear. The knowledge gained on the core ecology of our target fish species can be used to improve the efficacy of fish sampling protocols. Furthermore, simliar analysis of acoustic telemetry data in other systems and for other fish species will further help to refine sampling protocols to ensure the accurate assessment of fish community and species population conditions.

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Table 1. Seasonal start dates by year within each harbour. Asterix (*) indicates the start of the telemetry project, not the seasonal start.

Harbour	Year	Spring	Summer	Fall	Winter
Hamilton	2015	-	*08-12	10-01	11-21
	2016	04-30	06-01	09-26	11-17
	2017	04-17	06-18	10-14	11-25
	2018	05-01	06-01	10-03	11-17
Toronto	2010	-	*09-13	10-03	11-12
	2011	04-22	06-07	10-16	11-30
	2012	04-13	05-21	09-22	11-15
	2013	04-20	06-12	10-18	11-19
	2014	04-26	06-19	10-05	11-24
	2015	04-21	06-17	10-14	11-26
	2016	04-15	05-28	10-23	11-21

Table 2. The number of tagged fish per species based on status (alive, dead, unknown [Unk]), depth (pressure) sensor functioning properly, raw data removal, and individuals included within a given season for detection probability calculation by harbour. Species with an asterix (*) were removed from further analyses due to low sample sizes.

		Status			Sensor		Data Removed			Individuals Included				Total
Harbour	**Species**	Alive	Dead	Unk	Good	Bad	None	Some	All	Spring	Summer	Fall	Winter	**Tags**
Hamilton	Bowfin*	3	1	0	3	1	2	1	1	0	0	3	1	**4**
	Channel Catfish*	2	0	3	4	1	0	1	4	1	1	1	1	**5**
	Common Carp	15	6	0	21	0	14	2	5	5	13	15	4	**21**
	Freshwater Drum	13	5	2	19	1	14	0	6	11	6	8	9	**20**
	Goldfish	11	3	4	18	0	11	0	7	4	5	10	4	**18**
	Largemouth Bass	20	2	8	20	10	18	11	1	13	19	22	17	**30**
	Longnose Gar	12	1	1	8	6	7	5	2	5	9	8	6	**14**
	Northern Pike	16	7	7	27	3	14	12	4	8	12	19	19	**30**
	Rudd*	0	1	0	1	0	0	0	1	0	0	0	0	**1**
	Smallmouth Bass*	2	2	0	4	0	2	2	0	2	3	2	2	**4**
	Walleye	29	11	1	29	12	16	14	11	25	23	22	26	**41**
	White Sucker*	12	10	2	24	0	14	0	10	7	0	3	2	**24**
Toronto	Common Carp	35	7	0	26	16	24	14	4	22	19	21	20	**42**
	Largemouth Bass	50	13	9	50	22	44	15	13	20	20	38	30	**72**
	Northern Pike	53	13	5	39	32	36	29	6	42	25	35	29	**71**
	Walleye*	8	0	0	7	1	7	1	0	4	3	1	3	**8**

Table 3. The optimal nearshore (<2 m depth) fish community sampling periods for each species during the day or night by season, based on species' seasonal daily depth-use patterns within each harbour determined from acoustic telemetry detection probabilities. Based on Figures 2-11, fish that had higher detection probabilities by being present at shallow depths (<2 m) and detected more frequently would be considered optimal for nearshore fish community sampling and would receive an "X".

		Spring		Summer		Fall		Winter	
Harbour	**Species**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
Hamilton	Common Carp		X		X				
	Freshwater Drum	X	X	X	X				
	Goldfish		X		X		X	X	X
	Largemouth Bass	X	X	X	X	X	X		
	Longnose Gar	X	X	X	X	X	X		X
	Northern Pike	X	X		X		X	X	X
	Walleye		X		X		X		
Toronto	Common Carp	X	X	X	X		X		
	Largemouth Bass	X	X	X	X	X	X		
	Northern Pike		X		X				

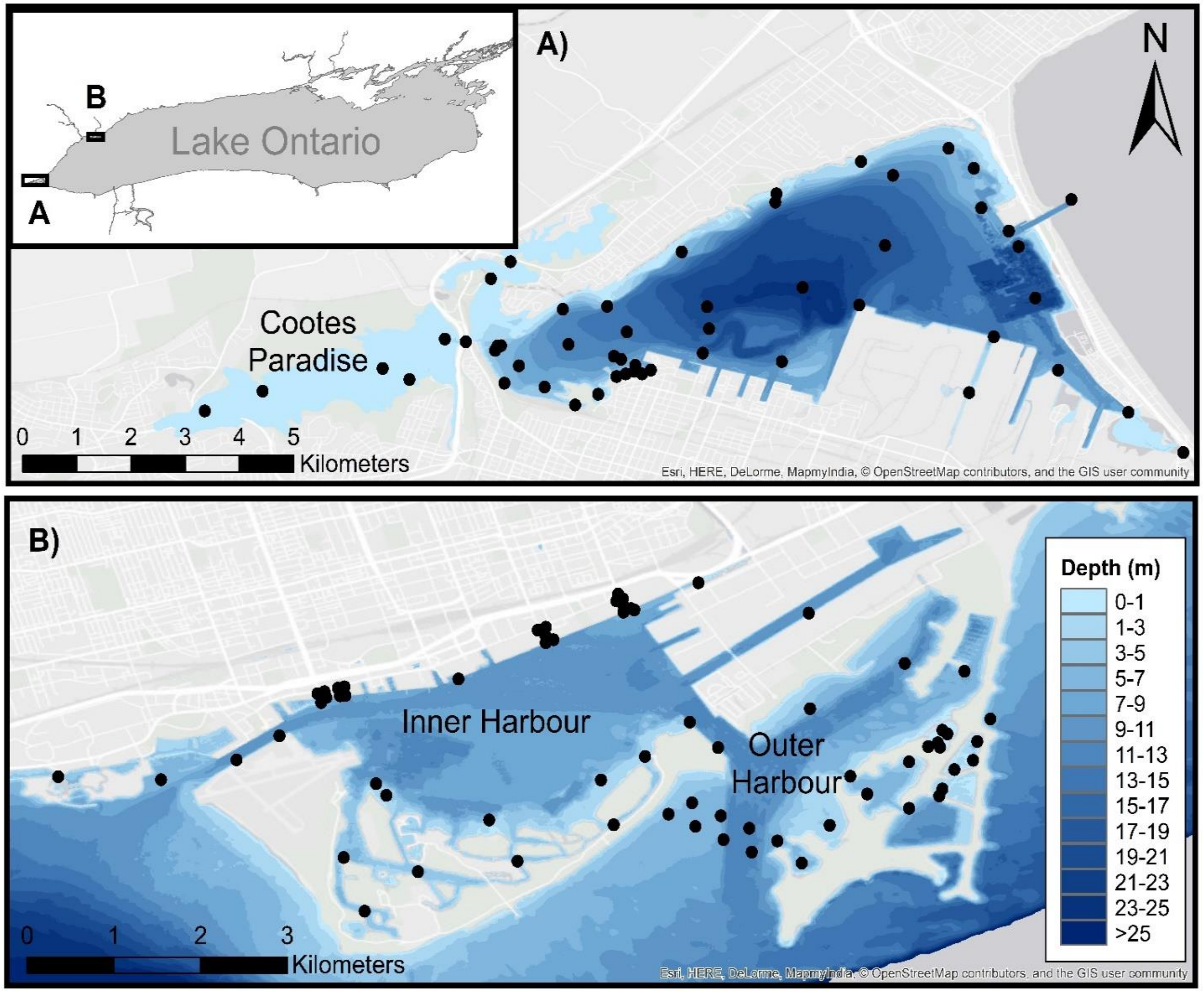

Figure 1. The location of the Hamilton Harbour (inset A) and Toronto Harbour arrays (inset B) in Lake Ontario and depth information for each harbour. Receiver locations (black points) are from the 2018 configurations.

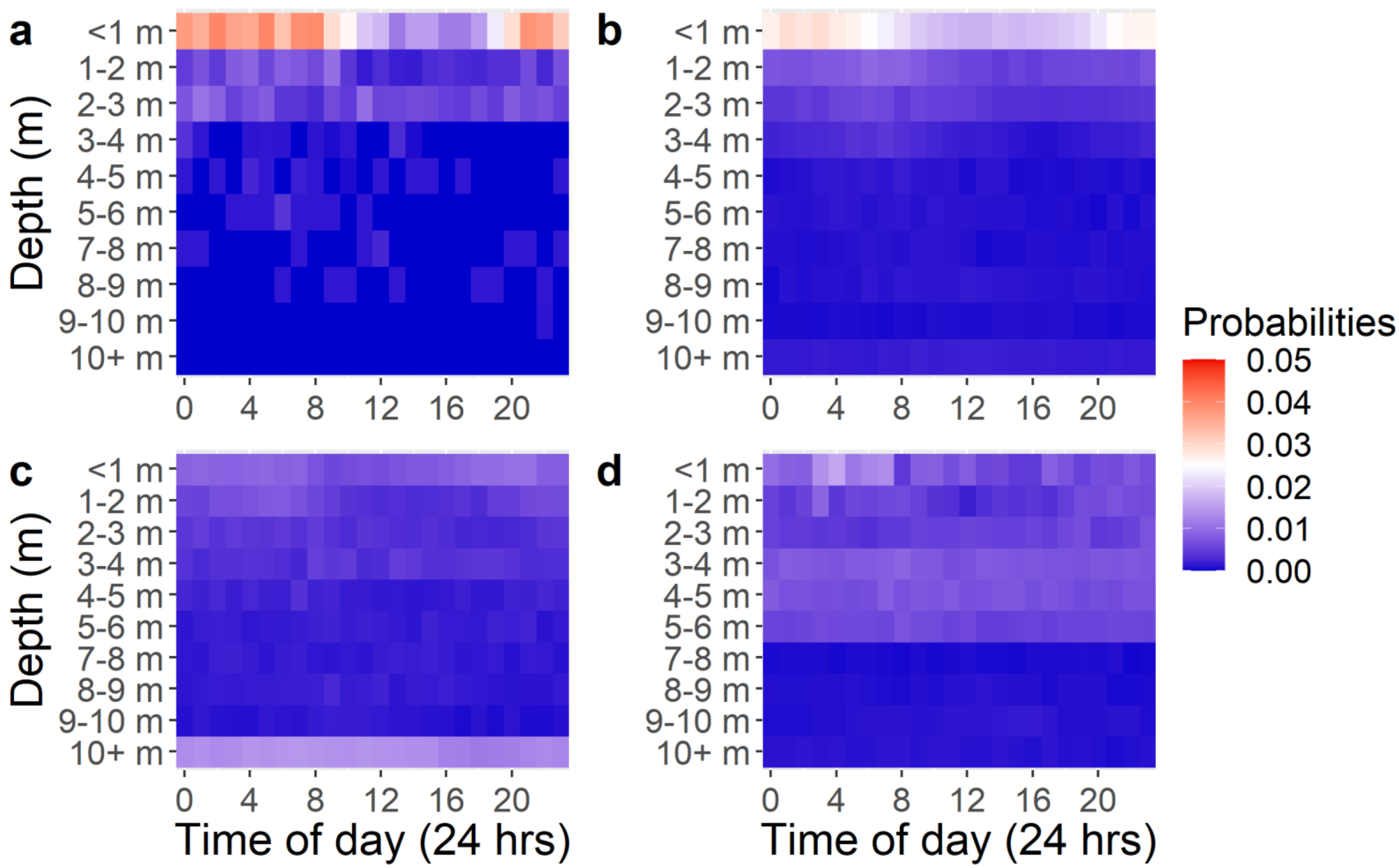

Figure 2. Mean detection probability at depth (m) and time of day (hours) for Common Carp in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

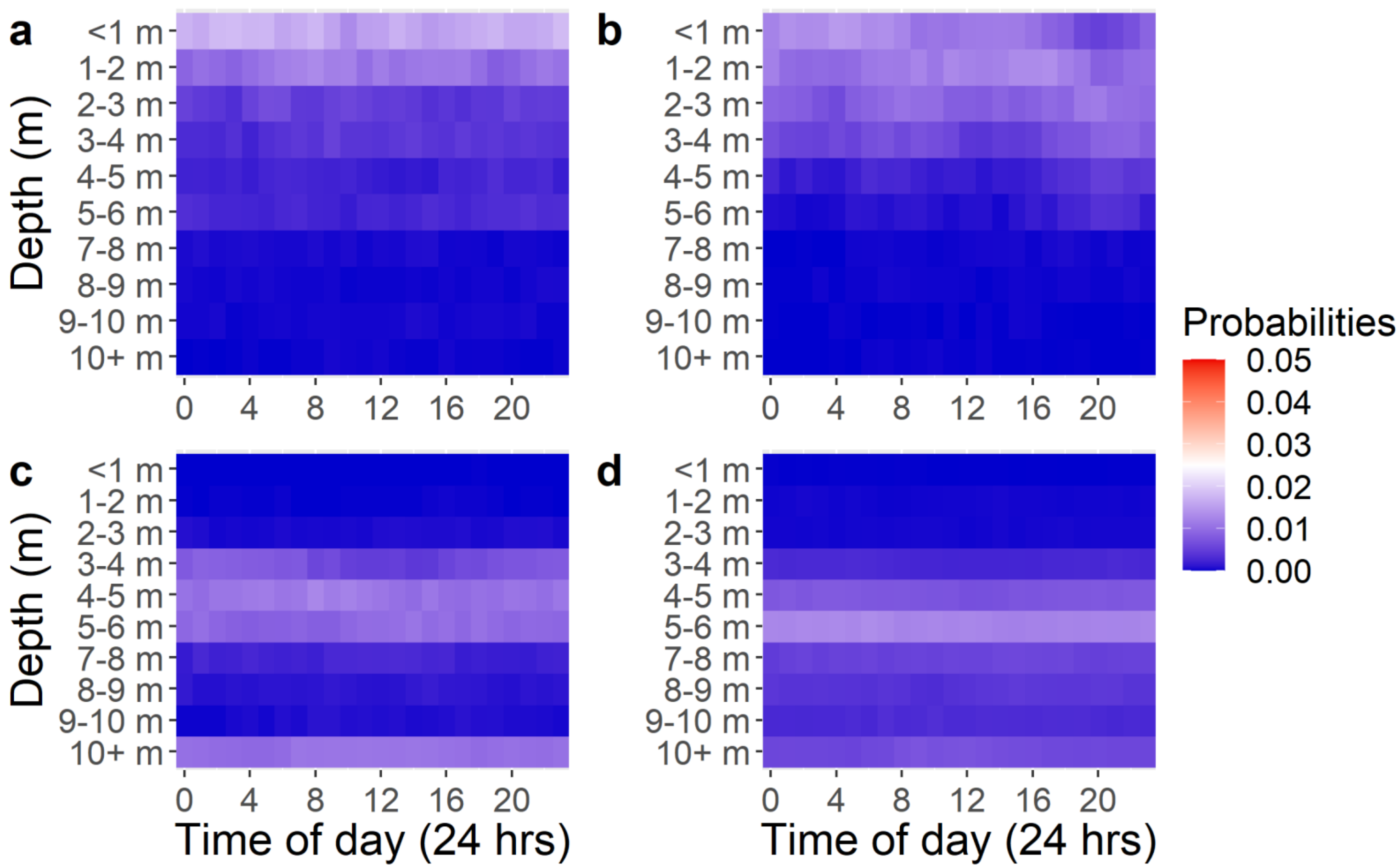

Figure 3. Mean detection probability at depth (m) and time of day (hours) for Freshwater Drum in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

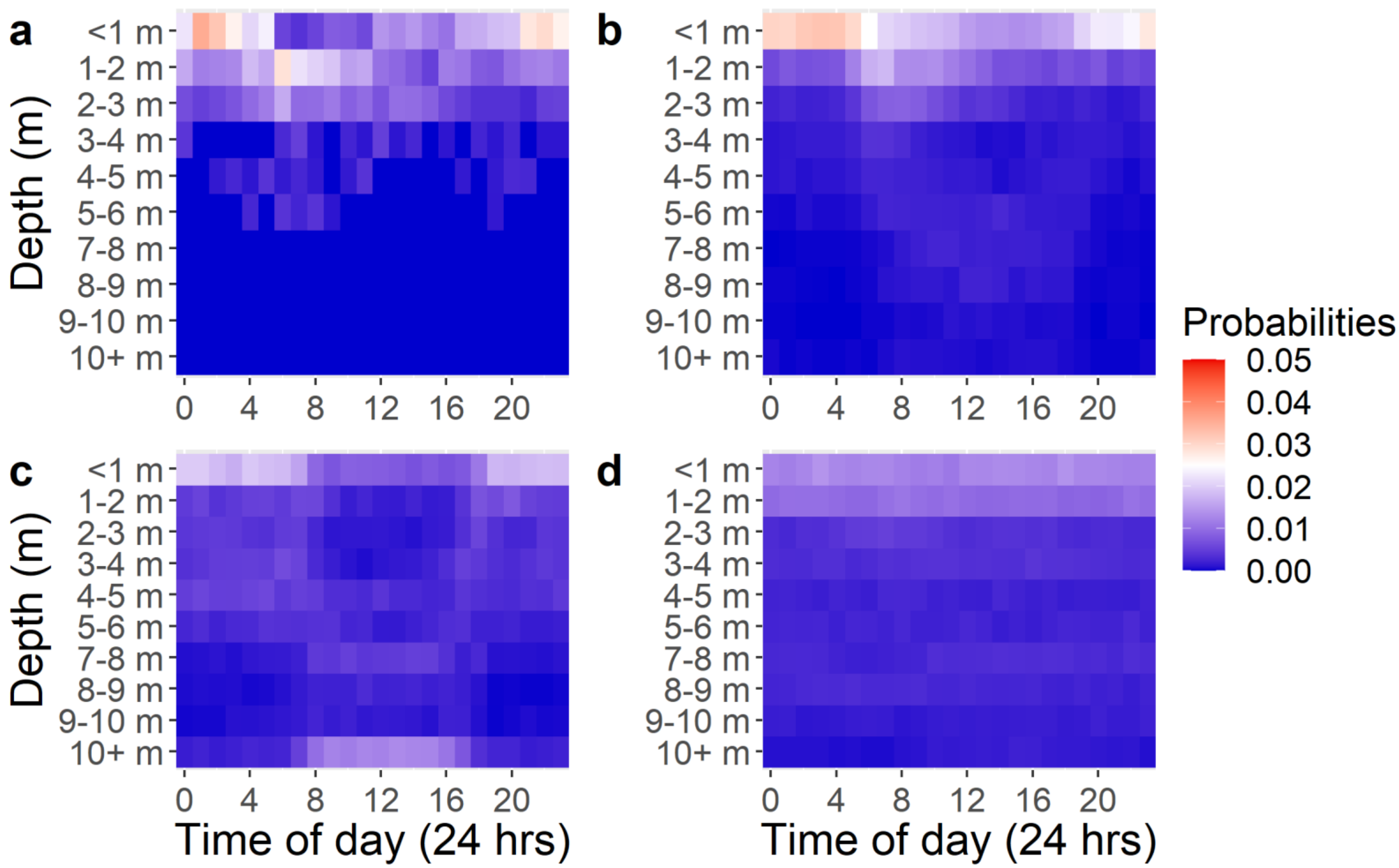

Figure 4. Mean detection probability at depth (m) and time of day (hours) for Goldfish in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

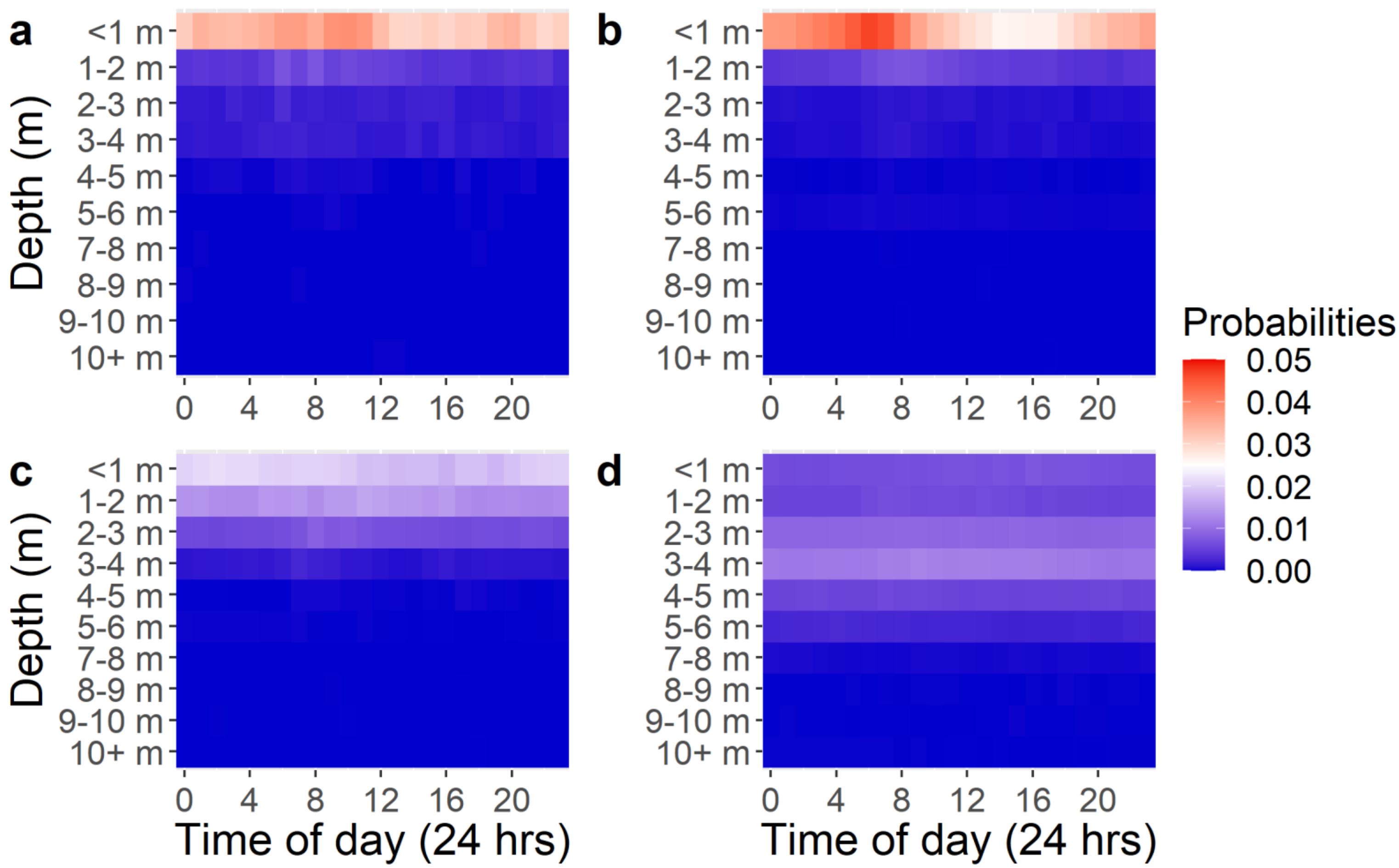

Figure 5. Mean detection probability at depth (m) and time of day (hours) for Largemouth Bass in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

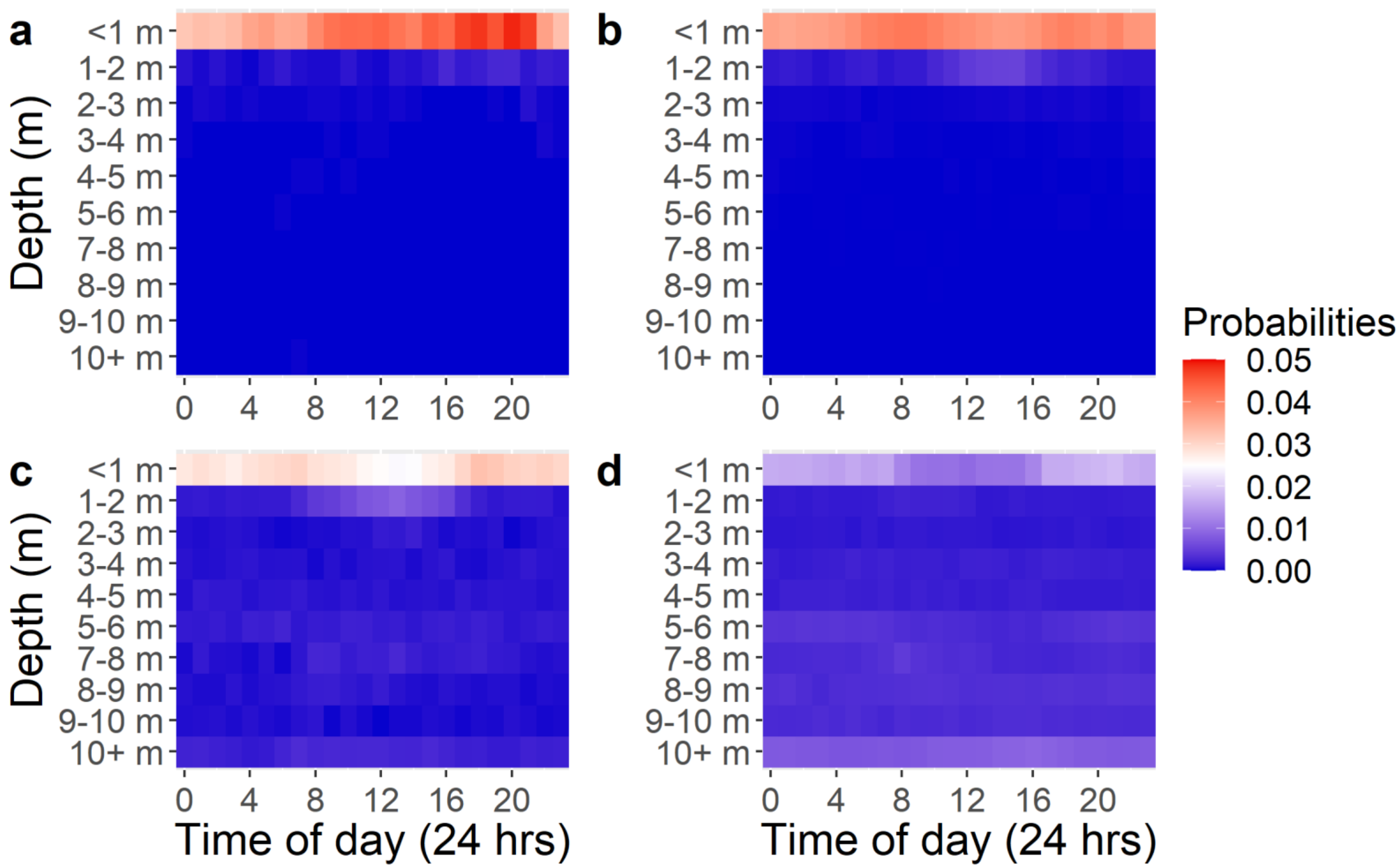

Figure 6. Mean detection probability at depth (m) and time of day (hours) for Longnose Gar in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

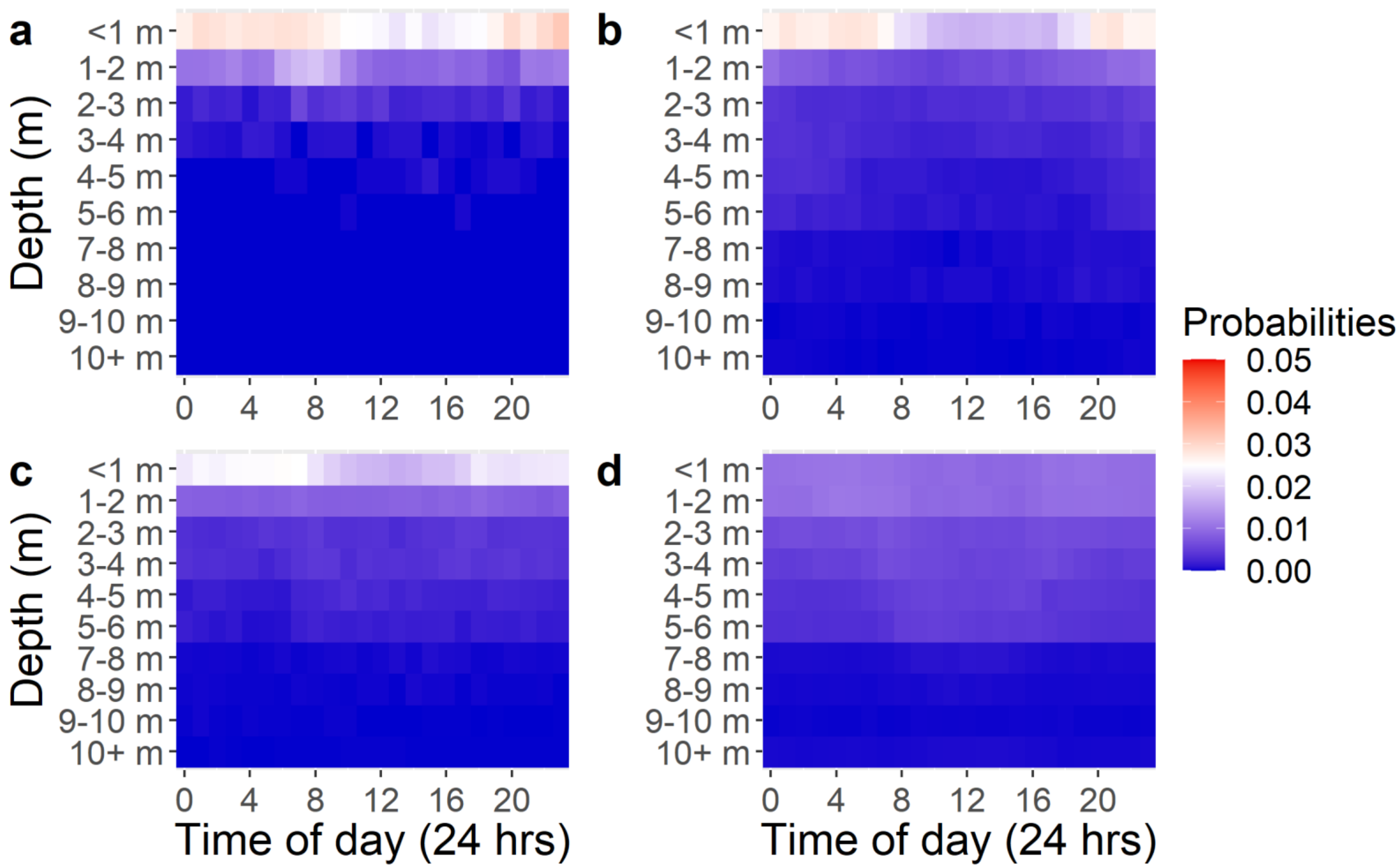

Figure 7. Mean detection probability at depth (m) and time of day (hours) for Northern Pike in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

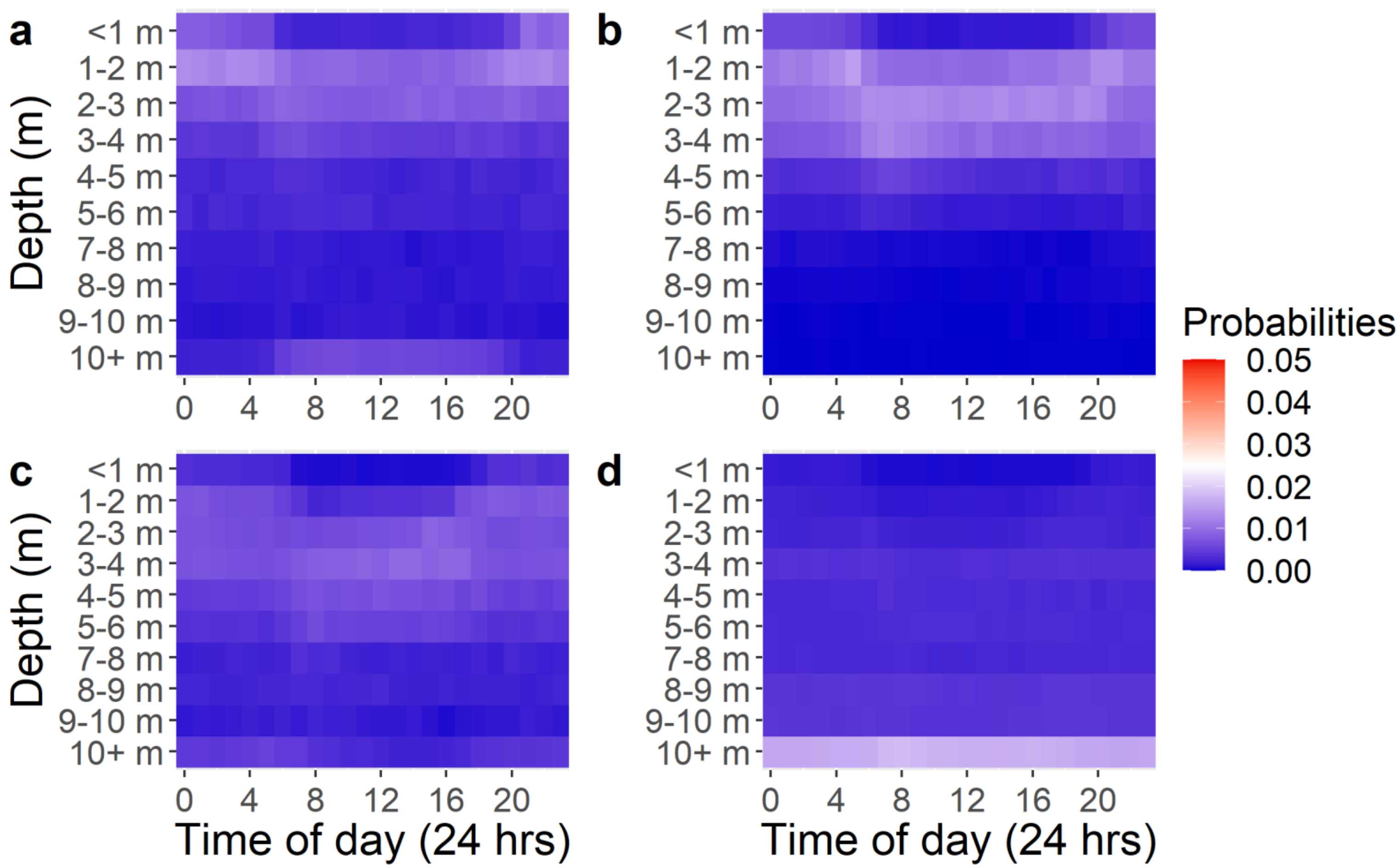

Figure 8. Mean detection probability at depth (m) and time of day (hours) for Walleye in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

Figure 9. The cumulative detection probability at depths ≤2 m (solid lines) and >2 (dashed lines) by the time of day (hours) across seasons in Hamilton Harbour for acoustic tagged a) Common Carp, b) Freshwater Drum, c) Goldfish, d) Largemouth Bass, e) Longnose Gar, f) Northern Pike, and g) Walleye.

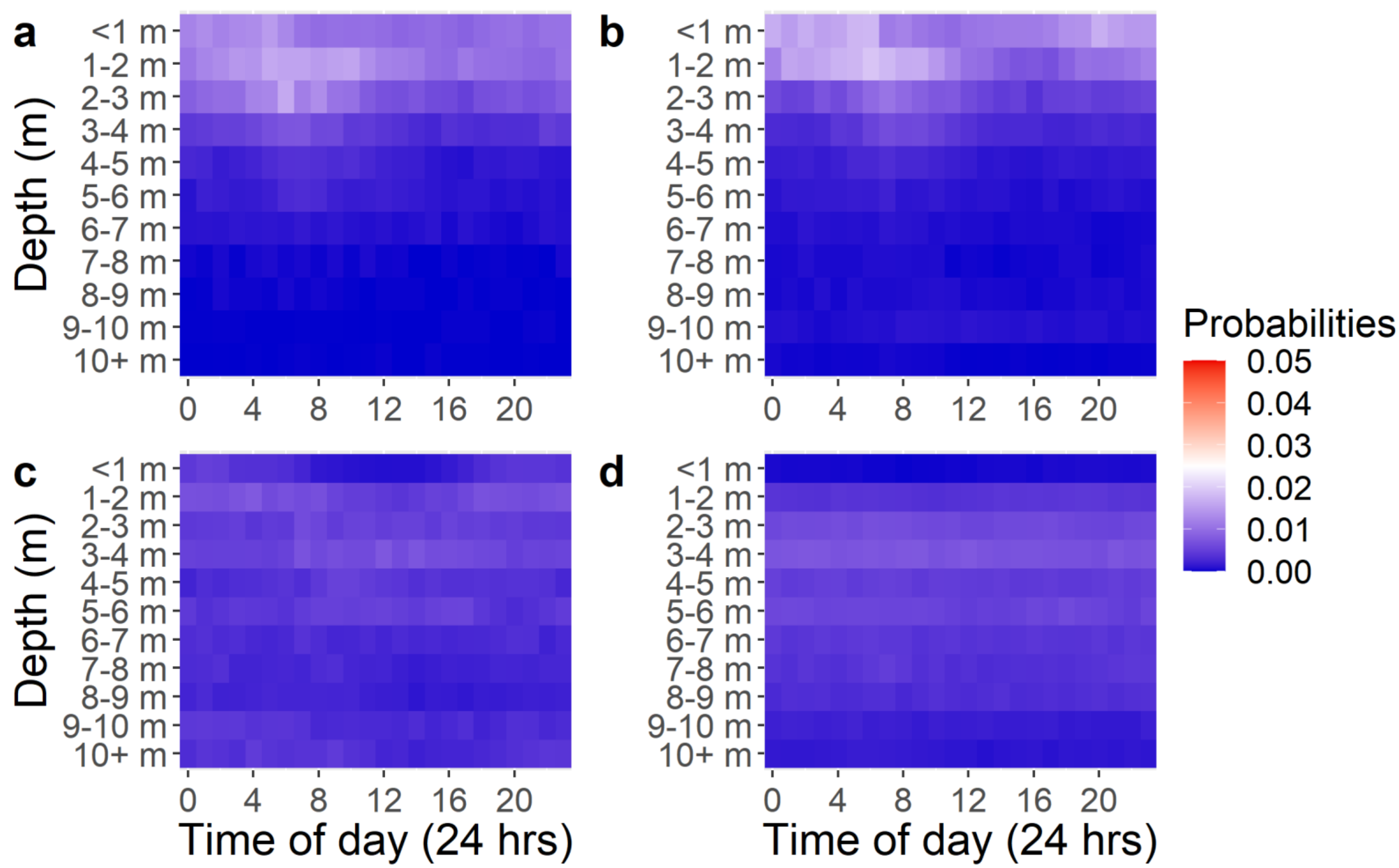

Figure 10. Mean detection probability at depth (m) and time of day (hours) for Common Carp in Toronto Harbour during a) spring, b) summer, c) fall, and d) winter.

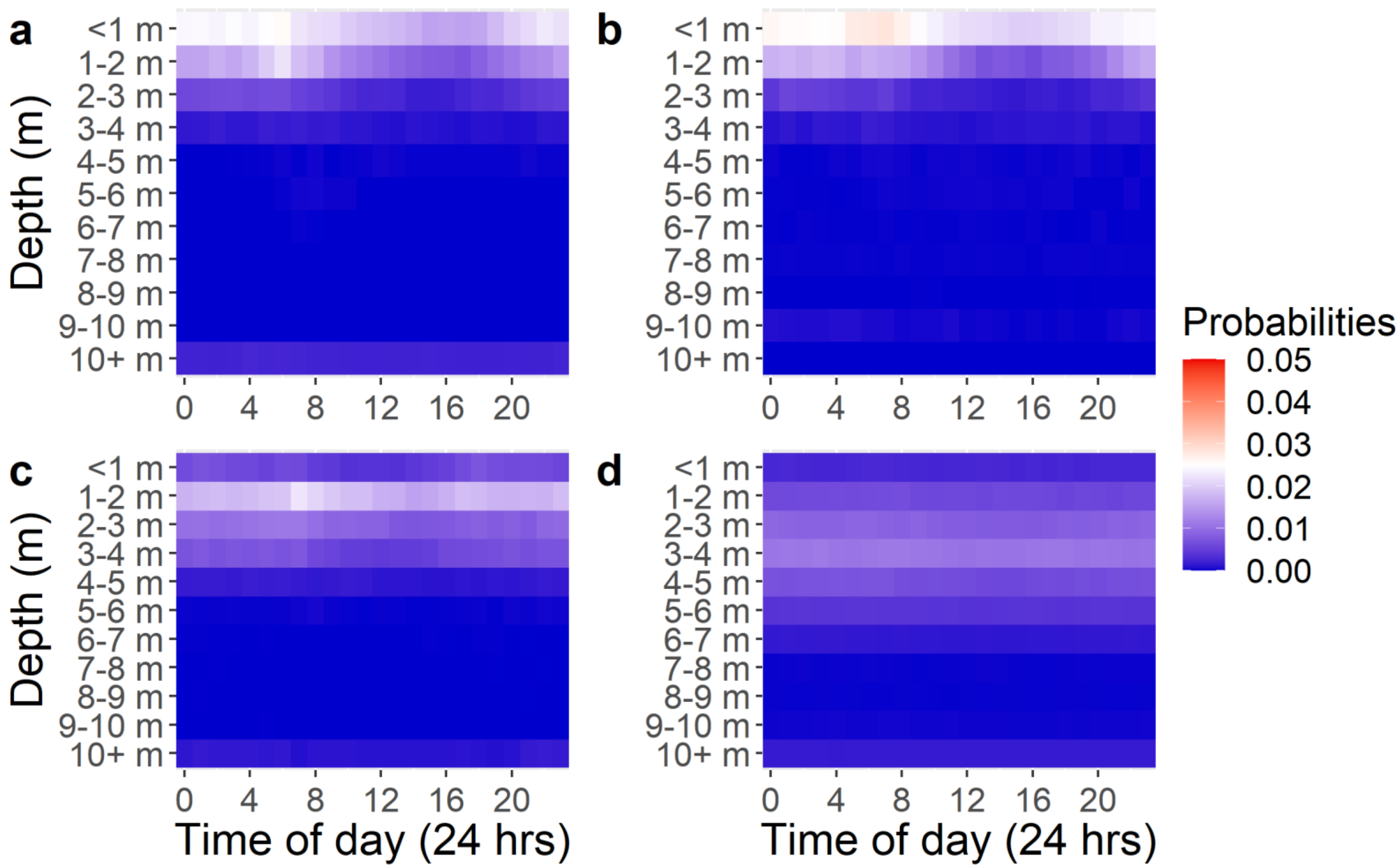

Figure 11. Mean detection probability at depth (m) and time of day (hours) for Largemouth Bass in Toronto Harbour during a) spring, b) summer, c) fall, and d) winter.

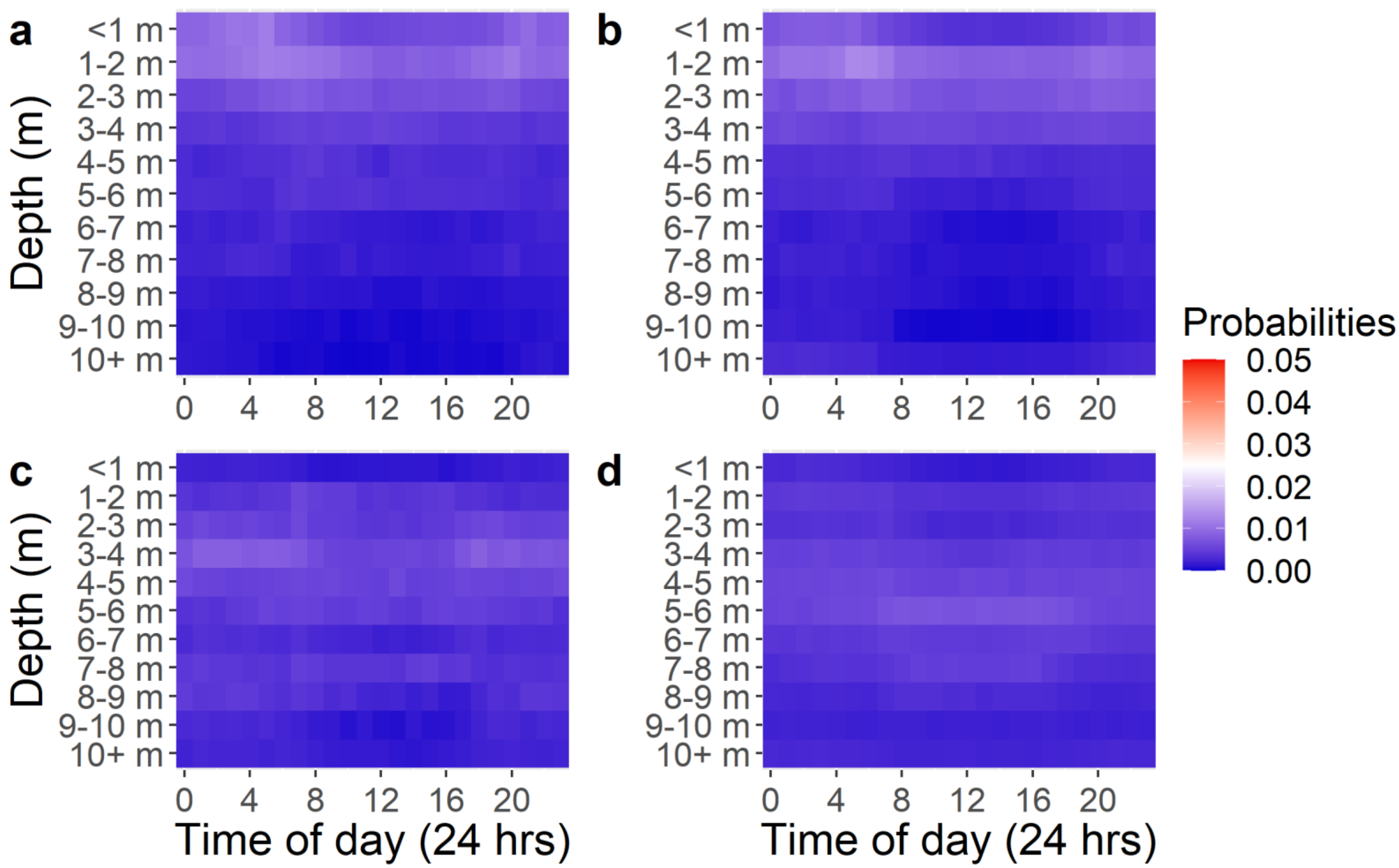

Figure 12. Mean detection probability at depth (m) and time of day (hours) for Northern Pike in Toronto Harbour during a) spring, b) summer, c) fall, and d) winter.

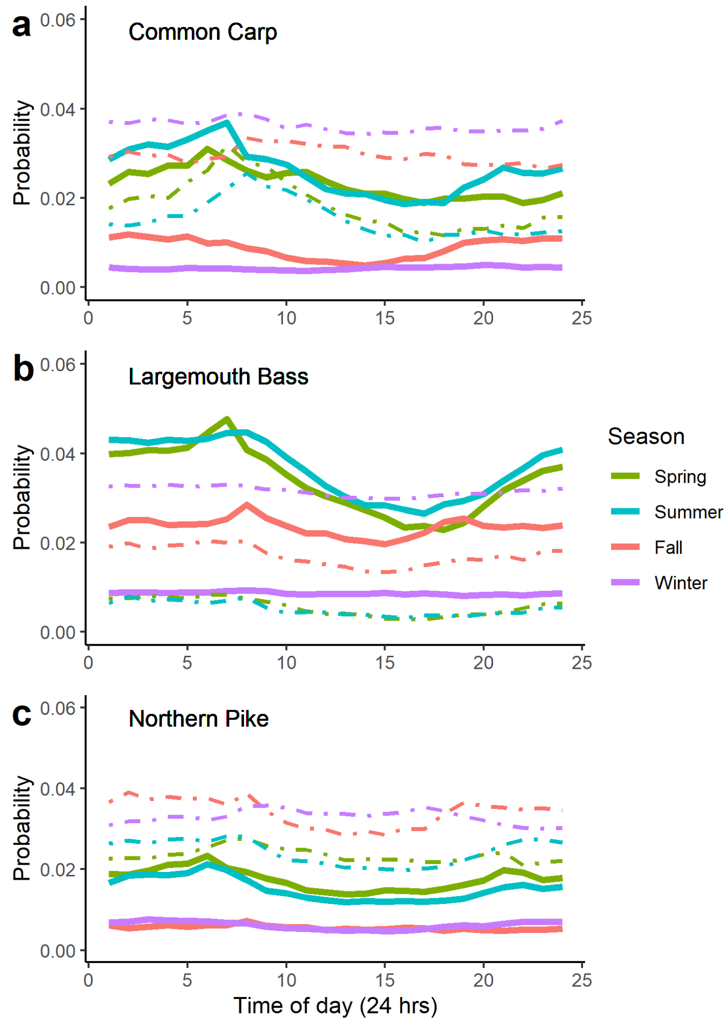

Figure 13. The cumulative detection probability at depths ≤2 m (solid lines) and >2 (dashed lines) by the time of day (hours) across seasons in Toronto Harbour for acoustic tagged a) Common Carp, b) Largemouth Bass, and c) Northern Pike.

APPENDIX A

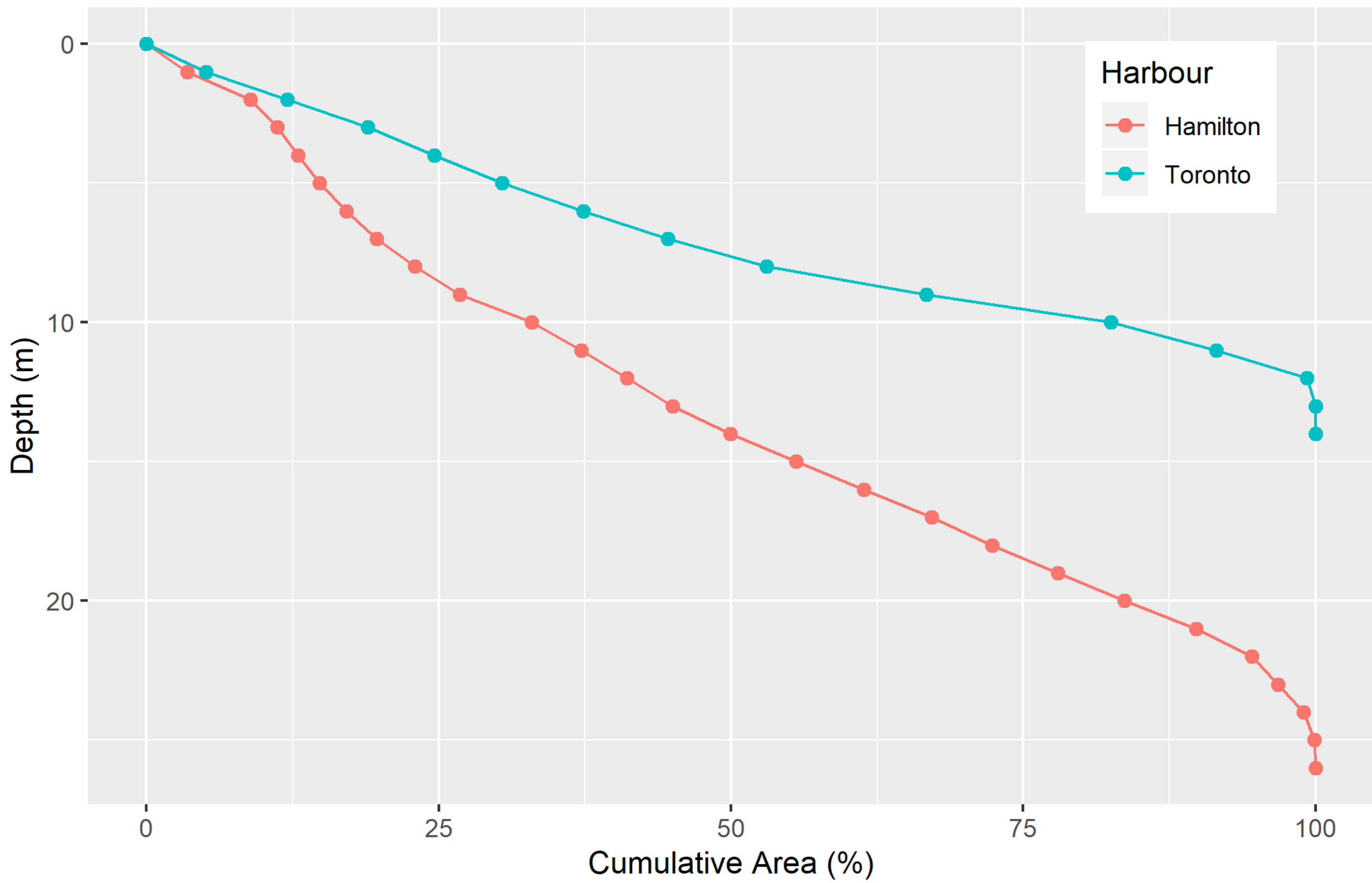

Figure A 1. Hypsometric curve for depth (m) and area in Hamilton and Toronto harbours in Lake Ontario. Based on digital elevation maps of both harbours and using the Lake Ontario mean water level of 74.8 m above sea level measured by Canadian Hydrographic Services over the duration of the study (2010-2018).

APPENDIX B

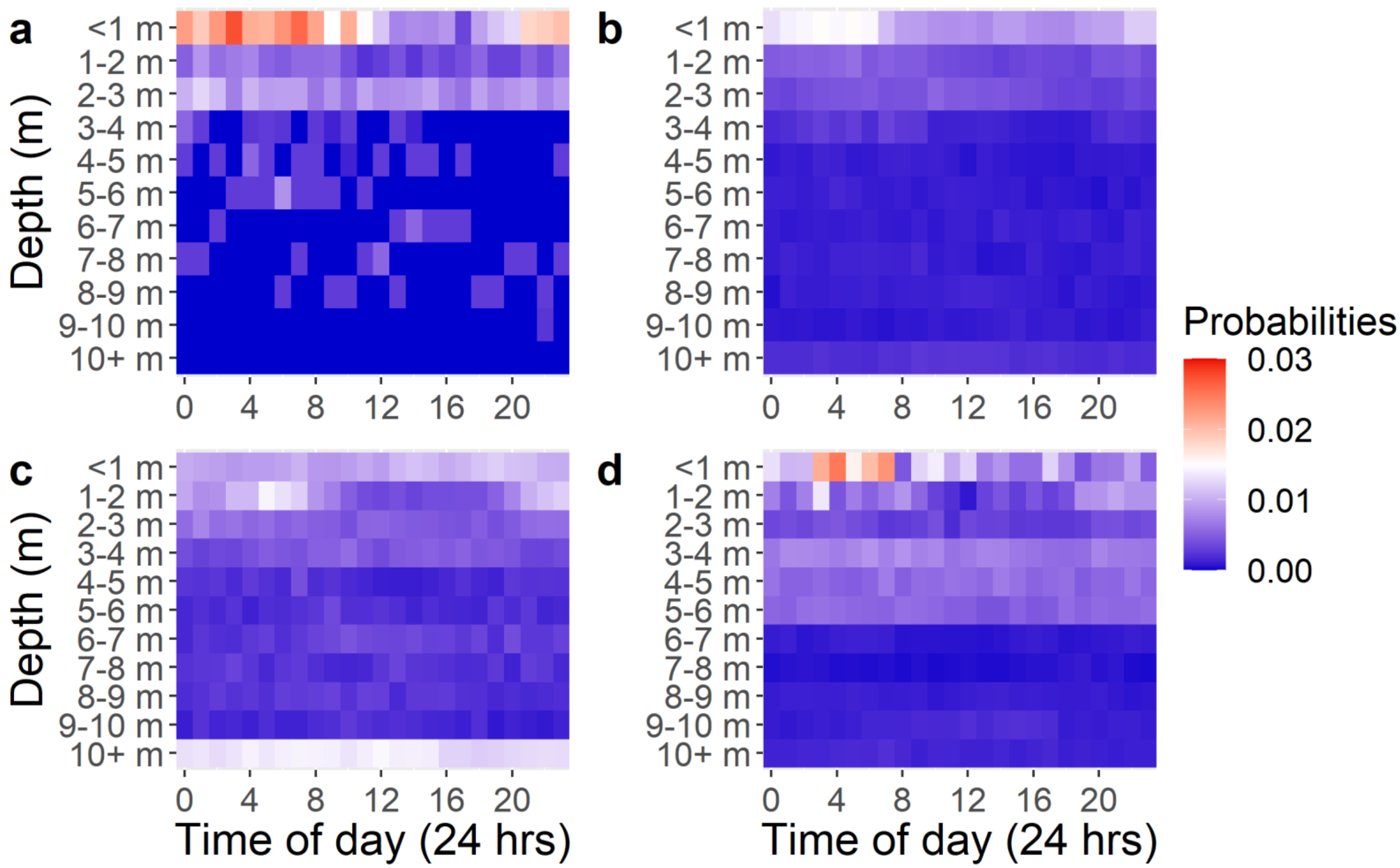

Figure B 2. Standard deviation of the detection probability at depth (m) and time of day (hours) for Common Carp in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

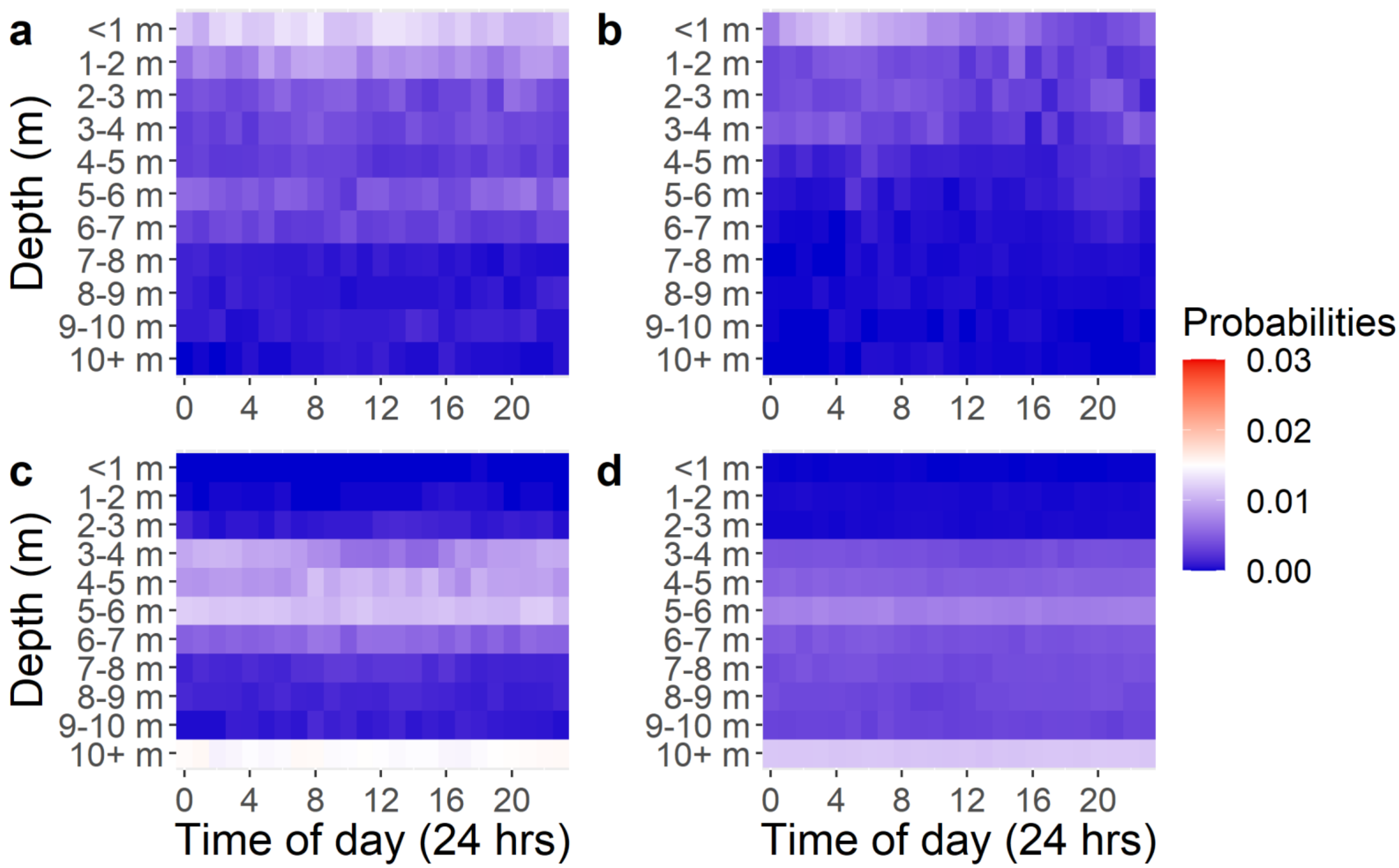

Figure B 3. Standard deviation of the detection probability at depth (m) and time of day (hours) for Freshwater Drum in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

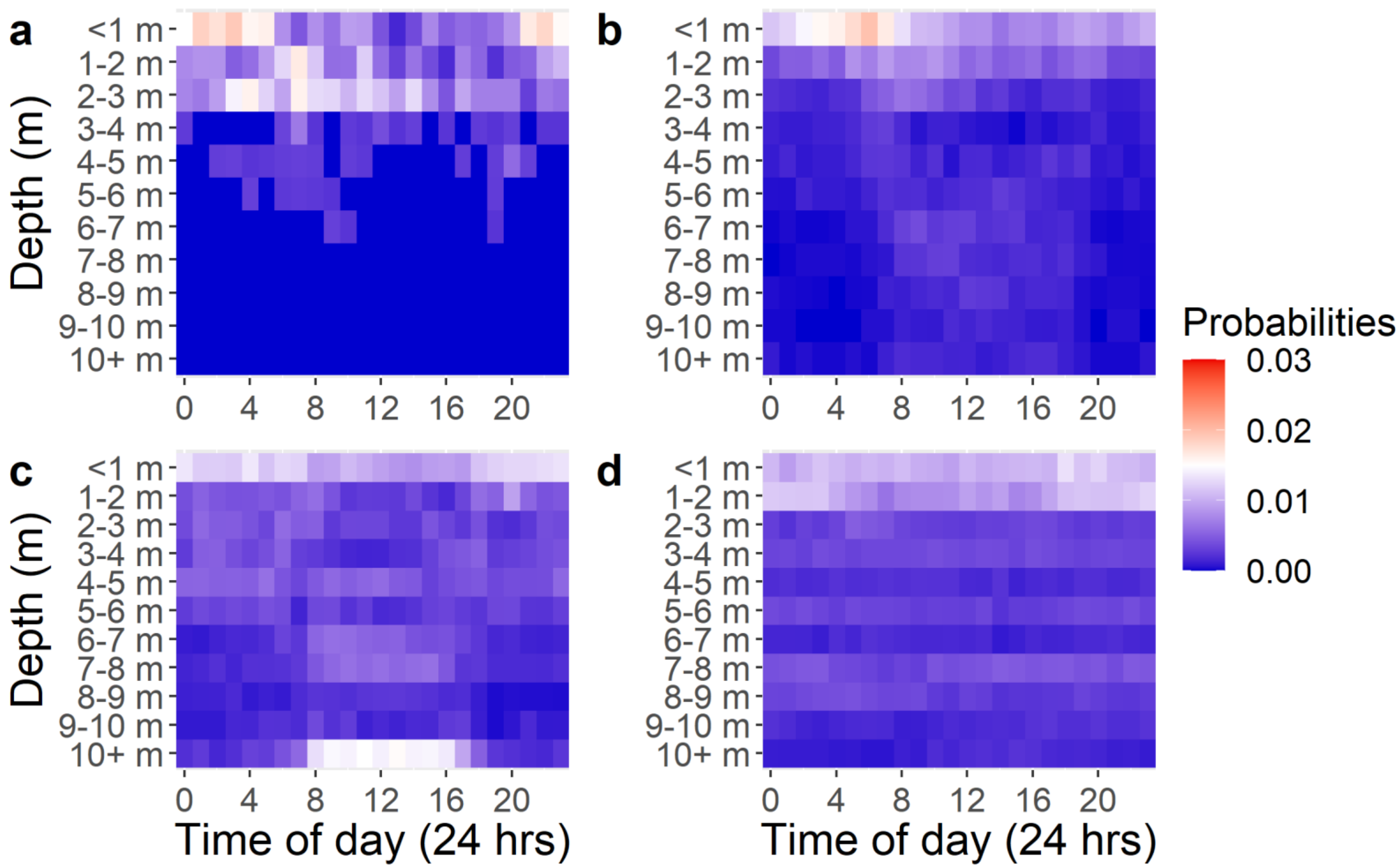

Figure B 4. Standard deviation of the detection probability at depth (m) and time of day (hours) for Goldfish in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

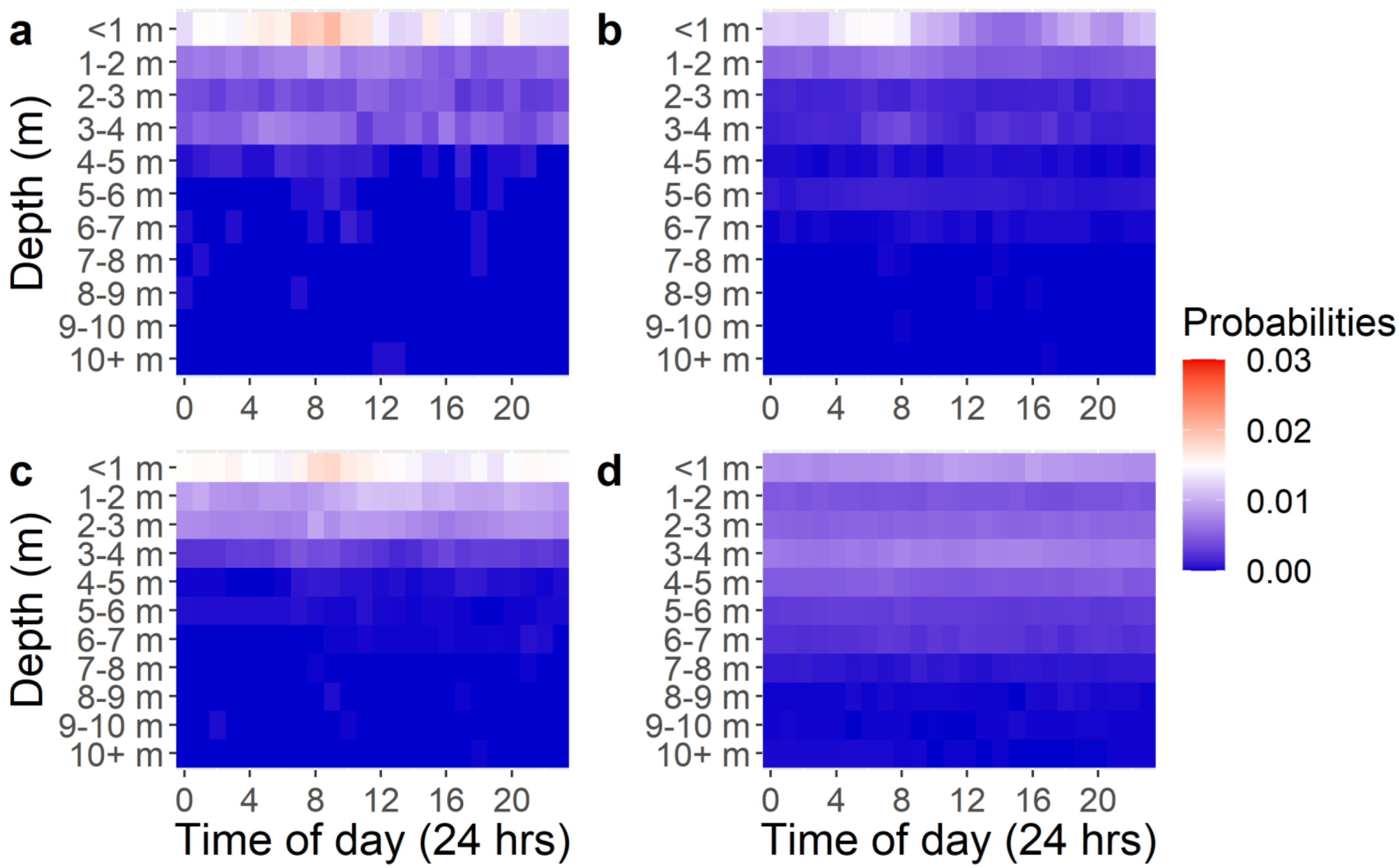

Figure B 5. Standard deviation of the detection probability at depth (m) and time of day (hours) for Largemouth Bass in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

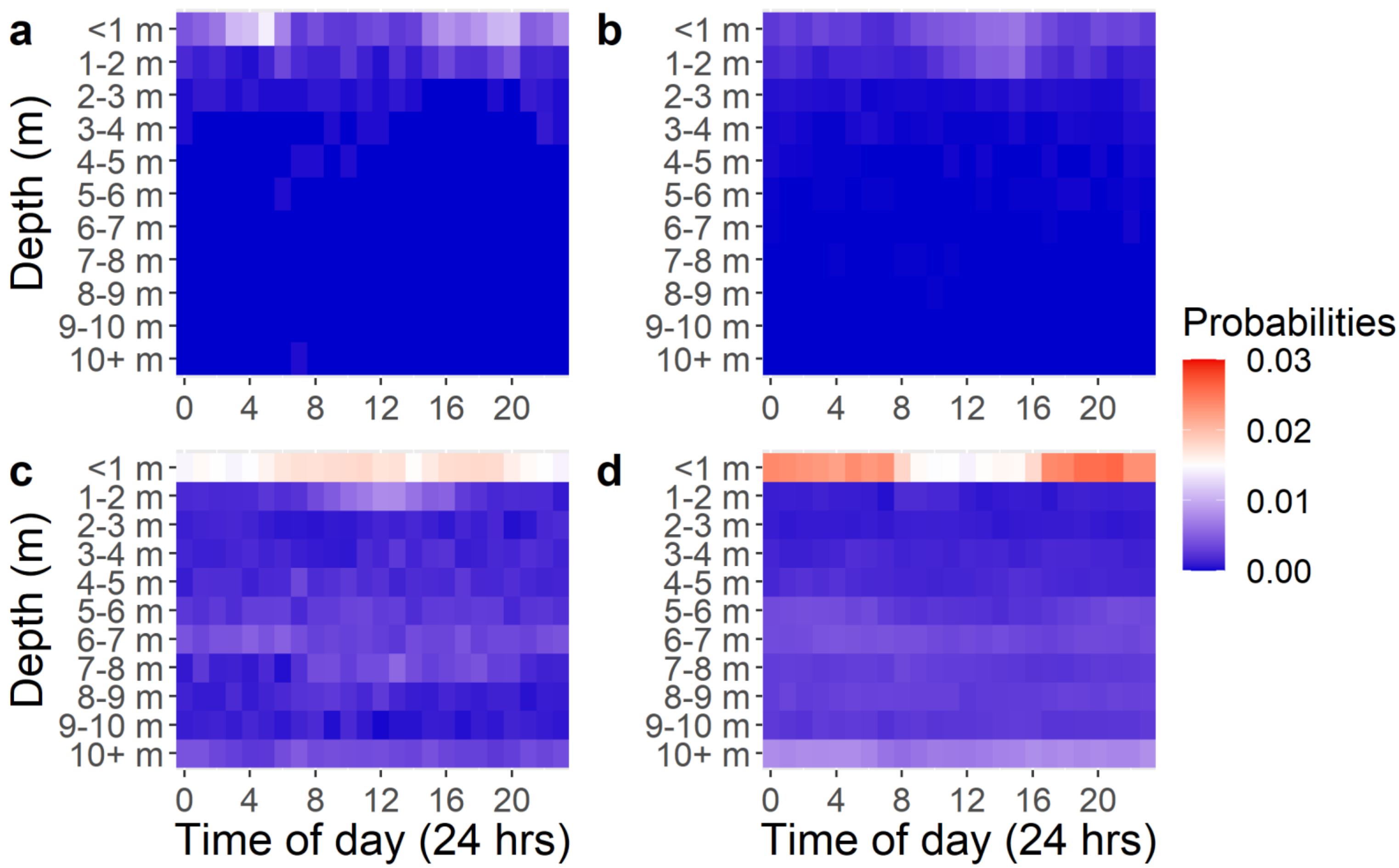

Figure B 6. Standard deviation of the detection probability at depth (m) and time of day (hours) for Longnose Gar in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

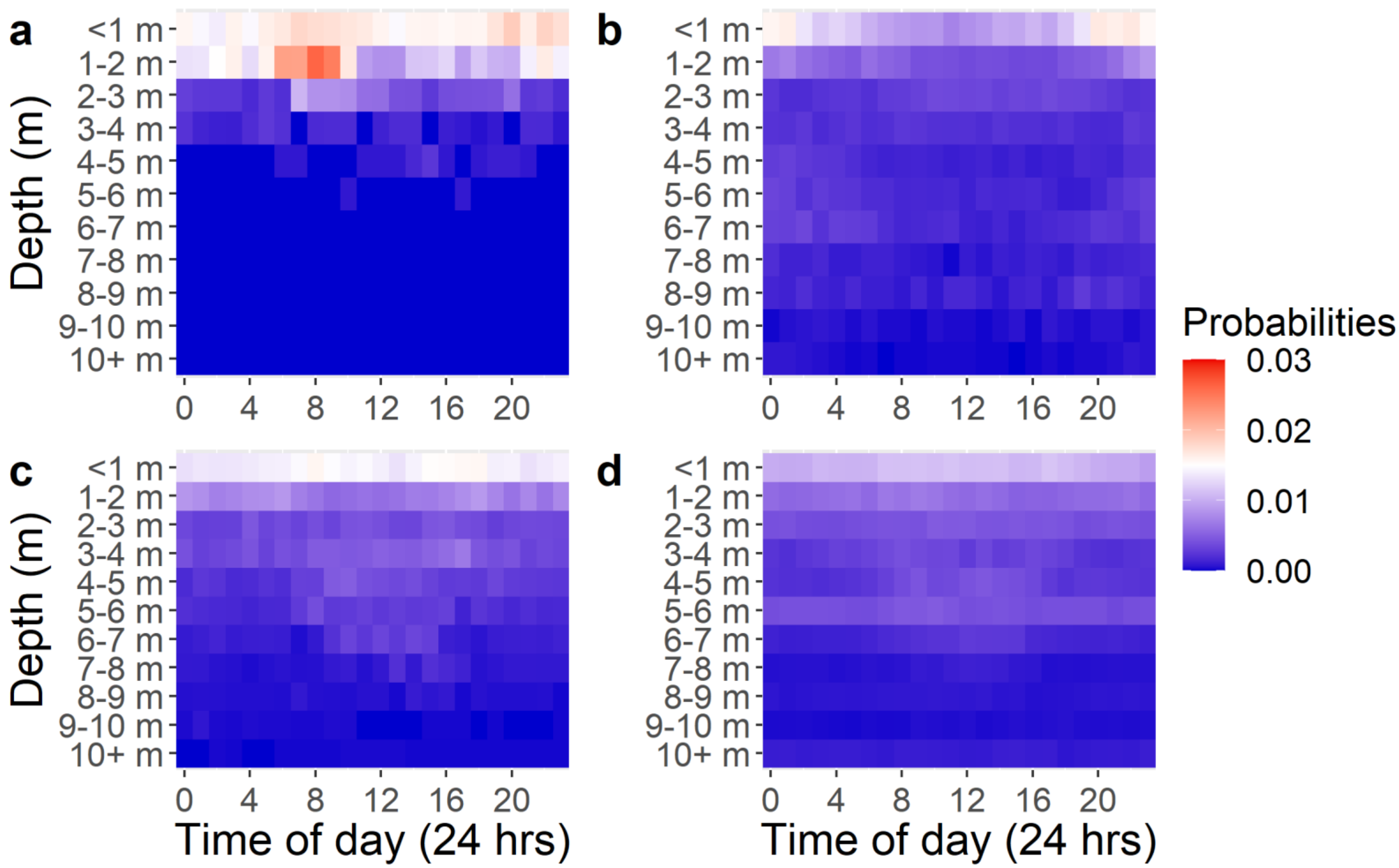

Figure B 7. Standard deviation of the detection probability at depth (m) and time of day (hours) for Northern Pike in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

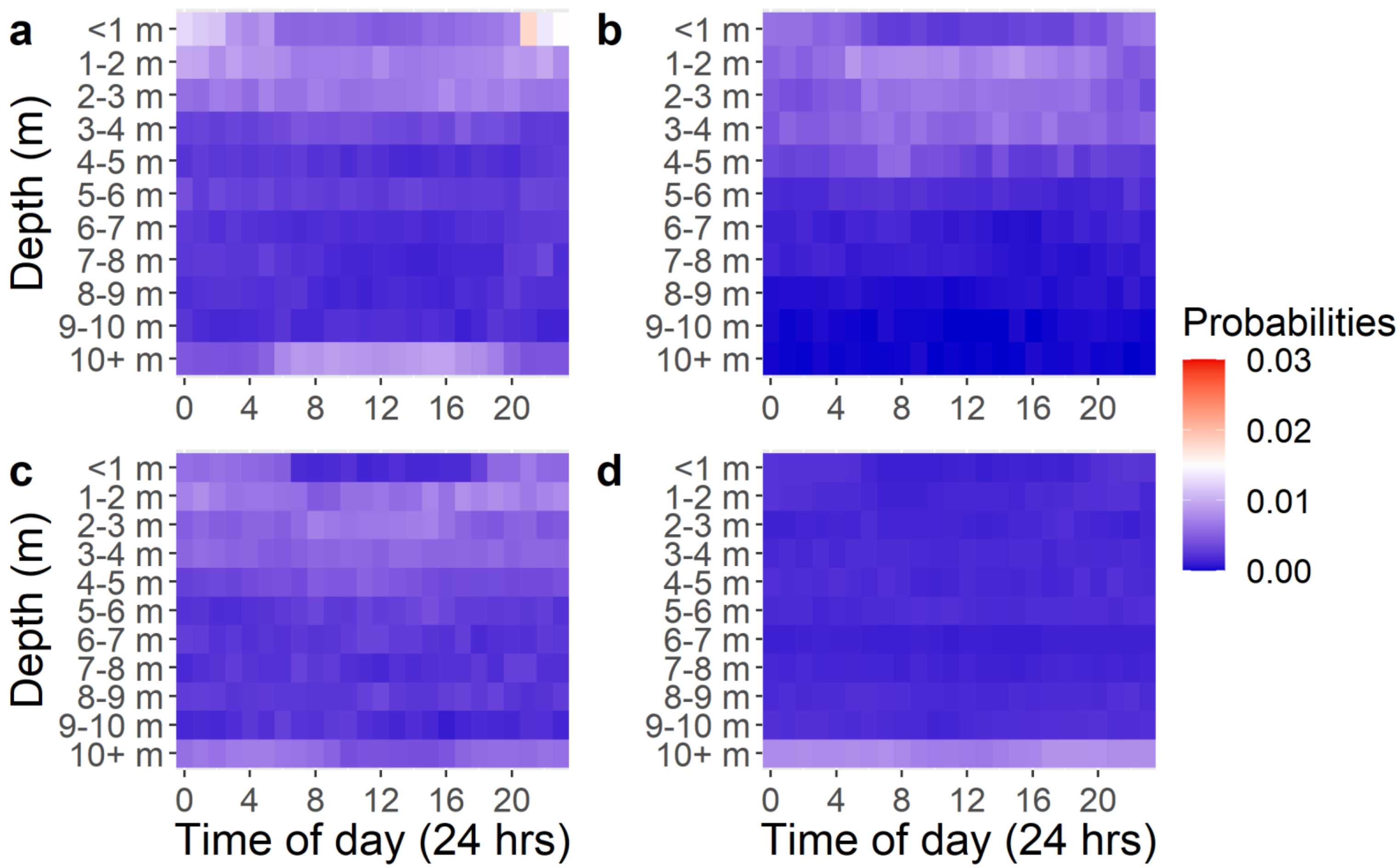

Figure B 8. Standard deviation of the detection probability at depth (m) and time of day (hours) for Walleye in Hamilton Harbour during a) spring, b) summer, c) fall, and d) winter.

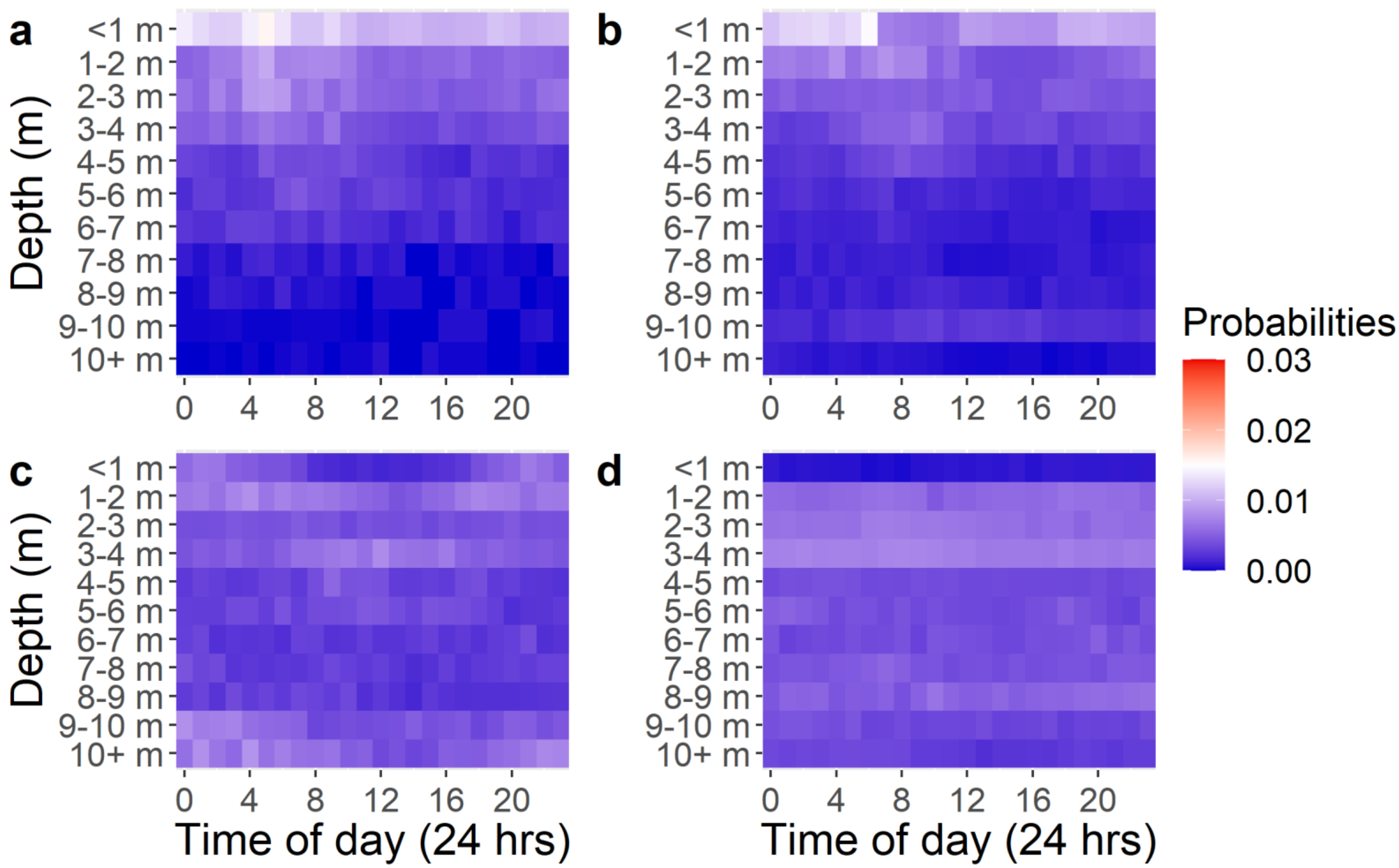

Figure B 9. Standard deviation of the detection probability at depth (m) and time of day (hours) for Common Carp in Toronto Harbour during a) spring, b) summer, c) fall, and d) winter.

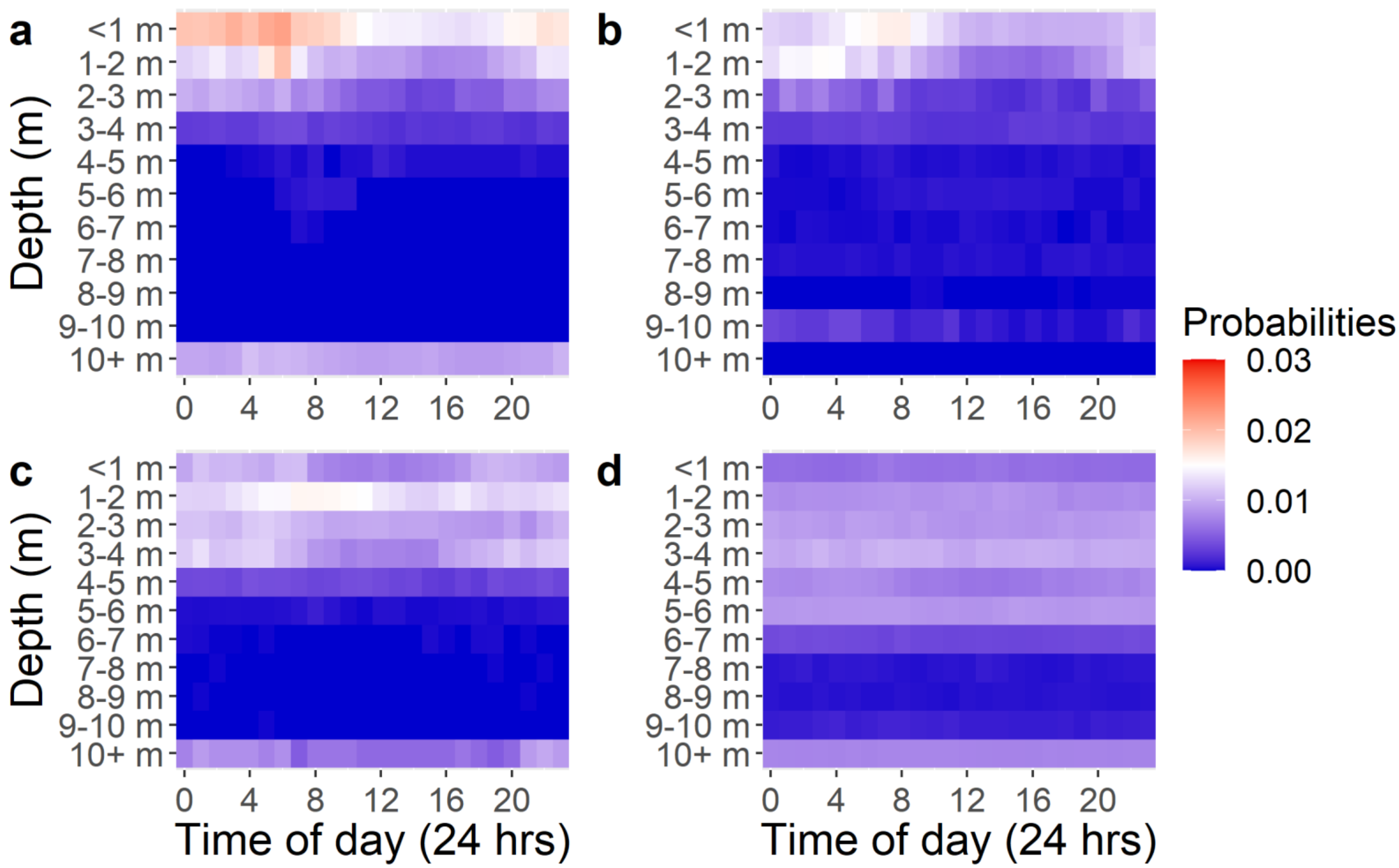

Figure B 10. Standard deviation of the detection probability at depth (m) and time of day (hours) for Largemouth Bass in Toronto Harbour during a) spring, b) summer, c) fall, and d) winter.

Figure B 11. Standard deviation of the detection probability at depth (m) and time of day (hours) for Northern Pike in Toronto Harbour during a) spring, b) summer, c) fall, and d) winter.