Version of Record: https://www.sciencedirect.com/science/article/pii/S2213078022000718
Manuscript_8dfbfdd941558297bf9f8d3eaacf289f

Research Note: Recreational Boating, Sewage Production, and Potential Implications for Phosphorus Loading in Lake Champlain

Kristine F. Stepenuck[a], Eric D. Roy[b], Katherine Helmer[c], and James Sleigh[d]

[a] Rubenstein School of the Environment and Natural Resources and Lake Champlain Sea Grant, The University of Vermont, 81 Carrigan Dr, Burlington, VT 05405, USA, kris.stepenuck@uvm.edu

[b] Rubenstein School of the Environment and Natural Resources, Dept. of Civil and Environmental Engineering, and Gund Institute for Environment, The University of Vermont, 81 Carrigan Dr, Burlington, VT 05405, USA, Eric.Roy.1@uvm.edu

[c] Rubenstein School of the Environment and Natural Resources, The University of Vermont, 81 Carrigan Dr, Burlington, VT 05405, USA, katherine.re.helmer@gmail.com

[d] Rubenstein School of the Environment and Natural Resources, The University of Vermont, 81 Carrigan Dr, Burlington, VT 05405, USA, james.c.sleigh@gmail.com

Corresponding author: kris.stepenuck@uvm.edu

Declaration of Interest

Declaration of interest: none

Acknowledgments

The authors wish to thank the marinas and boaters that participated in the surveys, and the marinas that allowed our students and staff on-site to conduct the surveys. Mike Wichrowski, Colleen Hickey, Mike O'Brien, Lori Fish, and Mark Malchoff, who provided review and input into survey design.

Funding was made available to the University of Vermont through an interagency agreement with the National Oceanic and Atmospheric Administration (NOAA) National Sea Grant College Program Award NA18OAR4170099 to the Lake Champlain Sea Grant Institute.

Highlights

- Powerboats (60%) and sailboats (39%) were most common at Lake Champlain marinas.
- 65% of Lake Champlain boaters at marinas spoke English and 35% spoke French.
- On average, Lake Champlain boaters slept on boats an estimated 31 nights per year.
- Lake Champlain boaters produced about 2,916 m^3 (770,340 gallons) of sewage annually.
- Marinas pumped out about 3,001 m^3 (792,692 gallons) of sewage annually.
- $10 was most often (45%) identified as the most reasonable pumpout cost.
- Phosphorus from improper sewage disposal was <0.01% of annual phosphorus sources.

Abstract

The impacts of recreational boating on lake ecosystems are often not well characterized, including for Lake Champlain (US/Canada) where excess watershed phosphorus loading drives cyanobacteria blooms. Improperly disposed boater-generated sewage has not been considered as a source of phosphorus in total maximum daily load models or implementation plans for the Lake. Surveys of marinas and boaters informed sewage production estimates by marina-using boaters. Annual boater-generated sewage volume was estimated to range between 2,445 and 5,184 m^3. These volumes allowed estimation of potential phosphorus contributions to Lake Champlain by improperly disposed sewage at varied rates of discharge. Such contributions were negligible compared to known Lake Champlain phosphorus sources, suggesting use of Clean Water Funds to reduce phosphorus inputs may not be warranted. Nonetheless, due to potential for pathogen contamination, continued financial support through other means was recommended to allow marinas to operate and maintain pumpout facilities at rates reasonable to boaters.

Keywords: recreational boating, sewage, marinas, phosphorus, Lake Champlain

1. Introduction

Impacts of recreational boating on the environment are multifaceted and cascading. It can cause physical impacts to aquatic habitats (Venohr et al., 2018; Whitfield & Becker, 2014). It is a known pathway for aquatic invasive species transport (Hunt, Morris, Drake, Buckley, & Johnson, 2019), altering aquatic food webs (Barcelo-Serra, Cabanellas, Palmer, Bolgan, & Alós, 2021) and impacting livelihoods (e.g., commercial fishing) and recreation (e.g., diving, fishing) (Iburg et al., 2021; Whitfield & Becker, 2014). Recreational boating is also known to impact water quality via marine paints, pathogen contamination, and plastic decomposition (Burgin & Hardiman, 2011; Whitfield & Becker, 2014). Cyanobacteria blooms also have potential to be influenced by recreational boating. However, while sewage inputs are a recognized risk to freshwater quality, rarely have researchers attempted to quantify such inputs.

The study of recreation ecology provides a theoretical framework upon which the impacts of a multitude of types of recreational activities on the environment, including recreational boating, can be assessed. Recreational ecology posits that there are a variety of environmental consequences of voluntary outdoor activities (Monz, Pickering, & Hadwen, 2013). Understanding such impacts can inform management activities. This concept forms the basis of the research study described within this research note.

Lake Champlain is used for recreation by more than 64,000 boaters via boat landings each year (Lake Champlain Basin Program, 2021). The lake, which lies between Vermont and New York in the United States and Quebec, Canada, extends 193 km (120 mi), and spans a width of 19 km (12 mi; Lake Champlain Basin Program, 2021). Areas of the lake are impaired by phosphorus, which drives cyanobacteria blooms. This puts human and animal health at risk (Lake Champlain Basin Program, 2021) and has caused declines in property values (Associated Press, 2015). As the lake plays a major role in the region's tourism economy (Voigt, Lees, & Erickson, 2015) and provides drinking water to thousands (Lake Champlain Basin Program, 2021), significant investments have been made to improve water quality. In 2015, the Vermont Clean Water Act and Clean Water Fund were created. In 2016, a Total Maximum Daily Load (TMDL) focused on phosphorus reduction was approved by the US Environmental Protection Agency for twelve segments of Lake Champlain within Vermont (USEPA, 2016). An implementation plan identified thousands of projects to reduce phosphorus inputs (Vermont, 2016) using Clean Water Funds (Vermont, 2020).

One potential source of phosphorus not accounted for in the TMDL or its implementation plan is sewage produced by recreational boaters on Lake Champlain that is improperly disposed from marine toilets or direct human discharges (e.g., over the edge). Lack of knowledge of phosphorus contributions from this source prohibits use of Clean Water Funds to support sewage pumpout facility operation. In turn, this directs pumpout costs to boaters, which has resulted in reduced use of such facilities elsewhere.

Although sewage discharge to Lake Champlain is prohibited throughout the waterbody in Canada (Government of Canada, 2012) and the United States (USEPA, 1975), not all boaters may comply. A study of US power and sail boaters conducted in the late 1990s suggested highest compliance with use of pumpout facilities by boaters on freshwater lakes as compared to coastal waters (Baasel-Tillis & Tucker-Carver, 1998). Reported non-compliance in lakes ranged from 1% to 15%. Historically, recreational boaters in the Chesapeake Bay reported limited use of sewage pumpout facilities due to inconvenience, lack of pumpout facilities, lack of knowledge of laws that prohibited sewage dumping, and decision making that failed to consider environmental impacts (Cottrell, 2002). Recent anecdotal evidence from Rhode Island suggests that marina pumpout facilities that charged even a modest price of $5 were used significantly less than when services were provided at no cost (personal communication, Mike Wichrowski, Vermont Fish and Wildlife Department, March 28, 2018). In 2014, the State of Connecticut began offering free pumpouts. Annual pumpout data demonstrated a statistically significant ($p<0.05$) increase in volume of sewage pumped out after free pumpouts began (t-test on unpublished data received through personal communication with Kate Hughes Brown, Connecticut Department of Energy and Environmental Protection, December 22, 2020).

Very little research has been conducted about recreational boating on Lake Champlain. The last study that assessed motor and/or sail boating on the lake was conducted in 1992, which compared results to a similar study carried out in 1980 (Bulmer, 1993). As such, goals of this research were to: 1) assess characteristics and practices of Lake Champlain marina-using boaters; 2) estimate annual sewage volume produced by boaters; and 3) estimate phosphorus inputs to Lake Champlain from potentially improperly disposed boater-generated sewage. This research note describes methods used to collect data to address these goals via surveys of boaters and marinas, shares survey results, and makes management recommendations.

2. Materials and Methods

2.1 Survey Design

Between August 2018 and August 2019, surveys were conducted with recreational boaters that used marinas on Lake Champlain (hereafter, boaters), and with marina, yacht club and resort owners or operators (hereafter, marinas). For the boater survey (Supplemental files 1 and 2), marinas on the lake and the first 16 km (10 miles) of the Richelieu River (to which the lake drains) were randomly selected. One Quebec marina, seven Vermont marinas, and eight New York marinas agreed to have their customers be invited to participate. Three marinas declined to participate and three did not respond to requests. Separately, marinas were asked to identify the number of moorings (a floating ball to which a boat can tie up) and slips (a docking space for a single boat) available and the percent rented for the season (Supplemental file 3). They were also asked to estimate the percent of season-long rentals with toilets, and the total volume of sewage pumped out each year. The study was approved through the University of Vermont Institutional Review Board (Study 19-0028).

The boater survey was offered in both English and French. Postcards at marinas advertised the survey, which was available online. In addition, intercept surveys were conducted of boaters at marinas. Information collected included the volume of the marine toilet holding tank (if any), the estimated number of pumpouts per year, the average percent filled the tank was at pumpout, the type and length of boat, the number of days spent boating on Lake Champlain each season, the average number of people per excursion, the estimated number of hours per trip, and the estimated number of overnights on the vessel per year.

2.2 Data Analysis

Survey results were entered into Qualtrics, and SPSS was used for analyses. The volume of sewage produced by Lake Champlain boaters was estimated in three ways to aid in validation of results. First, the Lincoln-Petersen equation (Powell & Gale, 2015) was used to estimate the population of boats with toilets on Lake Champlain that used marinas (Supplemental file 4). Separately, the average volume of sewage produced per boat per year was estimated using the volume of each boat's holding tank, the average percent the holding tank was filled at pumpout, and the number of pumpouts per year. The product of these was used as an estimate of the average volume of sewage produced. Second, the estimated number of nights spent in boats and estimated average number of people per boat were used to determine a per capita estimation of sewage volume and a standard sewage volume produced per day. Third, the volume of sewage pumped out at the marinas was estimated based on marina survey responses.

2.3 Nutrient Loading Estimations

To determine the total annual phosphorus (P) mass entering boat toilets, average per capita total phosphorus (1.6 grams P per person per day; USEPA, 2002) contributions from toilets to residential wastewater were multiplied by the total number of boating person-days. Boating person-days were calculated using the estimated average number of people per boat, estimated number of nights spent on boats, and the estimated boat population with toilets. Other phosphorus sources to boat sewage (e.g., graywater) were assumed to be negligible. Estimated phosphorus mass entering boat toilets was then divided by the estimated total boat sewage volume to determine concentration in mg P per L for comparison with raw wastewater total P concentrations reported in the literature (Lowe et al., 2010).

To estimate the annual mass of phosphorus that may be loaded from improper sewage disposal to Lake Champlain by boaters, low (2%), medium (4%), and high (12%) percentages of excreted P that is disposed overboard were assumed based on reported overboard disposal frequencies of sewage from a past survey of boaters in U.S. waterbodies (Baasel-Tillis & Tucker-Carver, 1998).

3. Results

3.1 Boating Characteristics and Habits

A total of 273 boaters were surveyed, 35% francophones and 65% anglophones. The majority (60%) operated power boats, while 39% operated sailboats. Operators of one pontoon boat and two cruisers also responded to the survey (1%). Boaters heralded from 36 homeports in five US states and two Canadian provinces. The largest percent (24%) spent between 31 and 40 days per year on Lake Champlain (Figure 1). In any single trip, 42% spent more than 24 hours on the lake before returning to shore. Almost a third (28%) spent four to six hours on the water, while fewer spent <1-3 hours (16%) or seven to 24 hours (15%) out before returning to shore. On average, boaters spent 31 nights per year on the lake (n = 239).

Almost half (49%) boated alone or with one other person, while 42% had three to four people in the boat, and 9% had five to eight people on board during each trip (n = 267). On average, 2.8 people were aboard per trip.

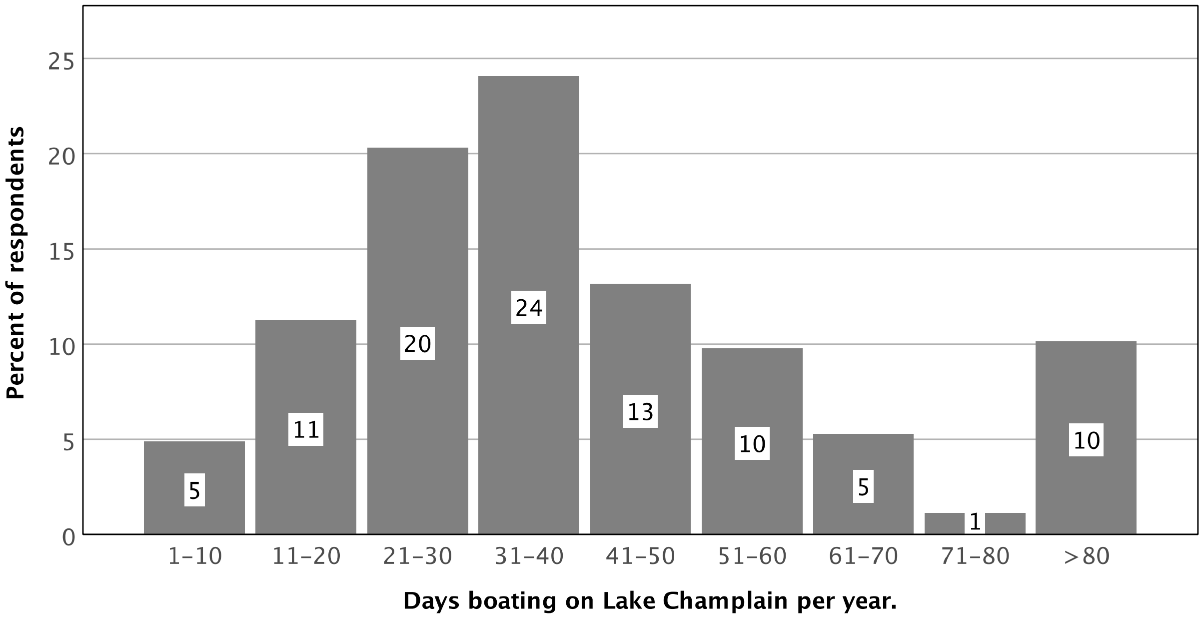

Figure 1. Number of days boaters reported boating on Lake Champlain per year (n = 266 during 2018-19. Percent of respondents is indicated for each bar in the chart.

Most (89%) had some type of toilet on board (n=271). Nearly all (94%) had installed toilets with a holding tank. A few had portable toilets (5%) or composting toilets (1%). While nearly a quarter of boaters (24%) did not know the size of their holding tank (n = 240), known volumes ranged from less than 27 L (6 gallons) to more than 372 L (72 gallons). Thirty-eight percent had tanks less than 113 L (25 gallons) and 34% had tanks 113-327 L (72 gallons). Four percent had tanks larger than 327 L. It was estimated that the average toilet holding tank volume was 127 L (28 gallons).

3.2 Use of Pumpout Facilities

Most boaters (89%) used pumpout facilities on Lake Champlain an estimated nine times per year when holding tanks were about 65% full. The number of pumpouts ranged from never (2%) to more than 40 times per year (0.8%) with most pumping out one to five times per year (Figure 2). The majority (63%) pumped out their tanks when they were more than 50% full (n = 235).

In general, boaters had no issues in finding (97%) or using (92%) sewage pumpout facilities. However, three indicated marinas they used previously had stopped offering the service, and two others lacked knowledge of pumpout facility locations. Challenges reported included: user error; long wait times; facility closed upon arrival; out of date equipment; equipment malfunctions; high cost per pumpout; and water depth inhibiting access.

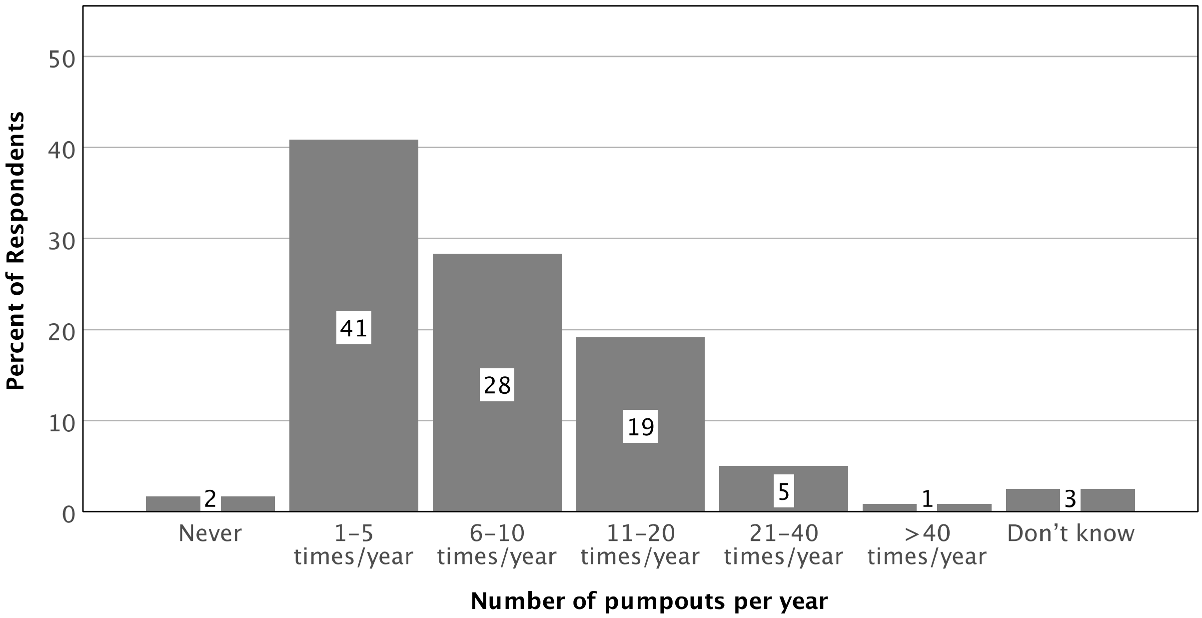

Figure 2. Number of pumpouts per year reported by Lake Champlain boaters (n = 240). Percent of respondents indicated for each bar in the chart.

Most boaters (45%) were willing to pay $10 per pumpout. One in five wanted pumpouts to be free or included with other marinas costs (e.g., part of mooring fee). Another 20% wanted to pay $7.50 or less, and the remaining boaters were willing to pay more than $10.

3.3 Boat Population and Sewage Production Estimates

Thirty-seven of 41 marinas were surveyed. Others were unable to be reached in person, by phone or via email. Responding marinas had 4198 slips and 817 moorings available. Of those, an estimated 3392 slips (81%) and 672 moorings (82%) were rented for the season. About half (49%) of marinas estimated that 76-100% of seasonal rentals had some type of toilet.

These marina estimates were paired with boater survey results to estimate the population of boats with toilets that used marinas on Lake Champlain (Powell & Gale, 2015). The low population estimate was 2910 ± 76 boats (Supplemental file 4). The average estimate was 3470 ± 91 boats, and the high estimate was 4028 ± 106 boats.

The volume of sewage produced by Lake Champlain boaters ranged from 0 to about 6.6 m^3 (1,449 gallons; n = 162). On average, 1009 L (222 gallons) of sewage were produced per boat per year. This was determined using the number of times each holding tank was filled per year and multiplying that by the volume of each tank. An average across all boats was then calculated. Combining the total number of boats that used marinas on Lake Champlain with the estimated average number of gallons of sewage per year produced by boat, it was estimated that the total annual volume of sewage produced by boats was between 2,445 m^3 (646,020 gallons) and 3,385 m^3 (894,216 gallons), with an average estimate of 2,916 m^3 (770,340 gallons; Table 1).

Sewage produced on Lake Champlain was estimated using a standard sewage volume of 45 L (10 gallons) per slip per day (North Carolina, 2018). Estimated low, mid and high estimates for number of boating nights were used to determine a range of gallons of sewage produced (Table 1). The low, average and high number of boating nights were determined to be 27, 31, and 34 nights, respectively.

Table 1. Estimated annual sewage volume produced by boats on Lake Champlain that use marinas based on pumpouts reported by boaters, boater nights, and sewage volume pumped out by marinas.

Category	Estimate	Sewage produced annually in m^3 (gallons)
Pumpouts reported by boaters	Low	2,445 (646,020)
	Mid	2,916 (770,340)

	High	3,385 (894,216)
Boater nights	Low	2,974 (785,700)
	Mid	4,072 (1,075,700)
	High	5,184 (1,369,520)
Sewage volume reported by marinas	Low	2,612 (689,988)
	Mid	3,001 (792,692)
	High	3,389 (895,396)

The volume of sewage produced annually by Lake Champlain boaters was also estimated based on the volume of sewage marinas reported pumping out annually. Seven of 27 marinas that offered pumpout services (26%) provided estimates. The volume of sewage pumped out each year at reporting marinas ranged from 14 m^3 (3600 gallons) per year to 291 m^3 (77,000 gallons). Total volume of sewage reported to be pumped out annually from these marinas was 780 m^3 (206,100 gallons). Extrapolating from the 26% of reporting marinas, the volume of sewage pumped out annually was estimated at 3001 m^3 (792,692 gallons) ± 389 m^3 (102,704 gallons; Table 1).

Potential phosphorus (P) contributions to Lake Champlain by improper sewage disposal were small as compared to other phosphorus sources to the lake. Estimated boating person-days were calculated at the low end to be 219,996, on average to be 301,196, and at the high end to be 383,466. Based on the assumed excretion rate to toilets of 1.6 g P per person per day, this corresponded to 352, 482, or 614 kg P (776, 1062, or 1353 lb P) excreted by boaters each year in total. Using the estimated phosphorus mass excreted for the average boater population estimate and the mid estimate for sewage volume produced based on reported boater nights, the calculated P concentration of sewage would be approximately 118 mg P L^{-1}.

Potential phosphorus contributions from overboard discharge of human urine and feces ranged between 0.007 t/yr (16 lb/year) and 0.074 t/yr (162 lb/yr; Table 2). For purposes of comparison with reported phosphorus inputs to Lake Champlain, these overboard discharge values translate to between 0.001% and 0.008% of the estimated 921 metric tons of phosphorus in total entering Lake Champlain annually from all measured sources (Lake Champlain Basin Program, 2018).

Table 2. Estimated potential phosphorus (P) inputs from overboard discharge of human urine and feces into Lake Champlain annually in pounds (lbs) and metric tons (t).

	Low estimates of phosphorus inputs[1]		Medium estimates of phosphorus inputs[2]		High estimates of phosphorus inputs[3]	
Boat Population estimate	Phosphorus (lb/yr)	Phosphorus (t/yr)	Phosphorus (lb/yr)	Phosphorus (t/yr)	Phosphorus (lb/yr)	Phosphorus (t/yr)
Low	16	0.007	31	0.014	93	0.042
Mid	21	0.010	42	0.019	127	0.058
High	27	0.012	54	0.025	162	0.074

[1]Assuming 2% overboard discharge

[2]Assuming 4% overboard discharge

[3]Assuming 12% overboard discharge

4. Discussion

Boating habits on Lake Champlain have rarely been assessed. As such, potential contributions from improperly disposed boater-generated sewage were not accounted for in phosphorus-focused Total Maximum Daily Load calculations nor the implementation plan to reduce phosphorus inputs to the lake. This study assessed habits of boaters on Lake Champlain to estimate sewage production and potential phosphorus inputs, and to make management recommendations.

The estimated concentration of 118 mg P L^{-1} in sewage produced by boaters based on person-days was high compared to literature values for modern single residential source onsite raw wastewater, which only range up to 32 mg P L^{-1} (Lowe et al., 2010). However, this is not surprising because marine toilet water is less diluted by low nutrient water than residential wastewater. Previous studies of source-separated blackwater from vacuum toilets have reported 70-89 mg PO_4-P L^{-1} (Sun, Mohammed, & Liu, 2020) and total P concentrations of 150-220 mg P L^{-1} (de Graaff, Temmink, Zeeman, & Buisman, 2010), providing evidence that our methods for estimating phosphorus mass and sewage volume in this study are reasonably accurate.

Estimated potential phosphorus inputs from improperly disposed boat sewage was negligible in comparison to other sources of phosphorus to Lake Champlain. In total, 921 metric tons (t) of phosphorus enters the lake each year (Lake Champlain Basin Program, 2018). The largest sources are agriculture (352 t), forest (184 t), developed lands (147 t) and wastewater treatment plants (55 t). Calculated potential phosphorus inputs from improperly disposed recreational boater sewage represented not more than 0.008% of known annual phosphorus inputs to the lake. Even if 50% of boat sewage was improperly disposed by boaters directly and overboard from holding tanks (which is not advisable, nor legal), the percent of known phosphorus loading to the lake would be only about 0.03%.

Nonetheless, if boater sewage on Lake Champlain was improperly disposed into the lake, pathogen contamination could result particularly in areas with high boat congregation and limited flushing, such as at marinas (ENSR International, 2005). This can be discouraged through education and supporting pumpout facilities (ENSR International, 2005).

Almost half of boaters felt that a pumpout fee of $10 was reasonable, while one in five believed pumpouts should be free. As of 2021, 32 of 43 Lake Champlain marinas offered pumpout services (Epical, 2021). Only nine marinas offered free pumpouts. In fact, 49% of Lake Champlain marinas either charged more than $10 or did not offer pumpout services (Epical, 2021). While compliance to use pumpout facilities has been reported to be high on inland freshwater lakes in the US (Baasel-Tillis & Tucker-Carver, 1998), limited pumpout facilities and excessive costs may hinder compliance with sewage discharge regulations. Challenges with use of facilities described by Lake Champlain boaters, such as long wait times and facilities in need of upgrades, have been demonstrated to hinder pumpout use in other locations (Smith, 2014; USFWS, 2012).

This study had a variety of limitations. First, numerous estimates were used to calculate the sewage produced annually by Lake Champlain boaters. Minor modifications to future surveys to ask for numeric responses rather than responses to range categories (e.g., ask boaters to report number of days boating vs. to select from choices with defined ranges of days) would not significantly extend response times and could strengthen sewage production estimates. In addition, to assess accuracy of responses, a random subset of boaters could be asked to allow researchers to measure holding tank volume and sewage volume. Second, boaters with toilets that used landings or private docks were generally excluded resulting in underestimation of sewage production by boaters. Future research should assess habits of these boaters. Third, not all marinas were surveyed. Thus, the number of slips, moorings and boats that used marinas on Lake Champlain were underestimated.

5. Conclusions and Management Recommendations

Lake Champlain boaters that used marinas, represented primarily by powerboaters and sail boaters, spent considerable time in their boats each year as compared to other locations with longer boating seasons (Sidman et al., 2006). Due to the small potential contribution of phosphorus from boater-produced sewage, use of Clean Water Funds to minimize phosphorus inputs to Lake Champlain may not be warranted. However, pathogen inputs to the lake could be minimized by directing sufficient alternative funds to support sewage pumpout facilities to allow such services to be offered free or at rates reasonable to most boaters. Adequate and maintained facilities can reduce wait times and ensure operational equipment and access by vessels with varied draughts. As Lake Champlain boaters commonly spend more than 24 hours away from shore, a traveling pumpout vessel could increase convenience and help ensure compliance with regulations (e.g., Friends of Casco Bay, 2019; Hoedemaker, 2019). Further, communications about pumpouts should be available in English and French due to strong boater representation from each language group on the lake. Providing critical information in users' primary language can increase potential for safety (Uekusa, 2019) and compliance. Future research should consider potential sewage inputs from boaters that use ramps and private docks to access the lake.

References

Associated Press. (2015, July 25). Lake Champlain property values hurt by algae. *Boston Globe*. https://www.bostonglobe.com/metro/2015/07/25/lake-champlain-property-values-hurt-algae/5ZETKX3qngMcOkE9T7ObMP/story.html

Baasel-Tillis, P., & Tucker-Carver, J. (1998). Garbage and sewage disposal from recreational boats. *Environmental Health, 61*(4), 8–18.

Barcelo-Serra, M., Cabanellas, S., Palmer, M., Bolgan, M., & Alós, J. (2021). A state-space model to derive motorboat noise effects on fish movement from acoustic tracking data. *Scientific Reports*, *11*(1), 1–13. https://doi.org/10.1038/s41598-021-84261-2

Bulmer, S. K. (1993). *Lake Champlain Boat Study*. Vermont Department of Forests, Parks and

Recreation.

Burgin, S., & Hardiman, N. (2011). The direct physical, chemical and biotic impacts on Australian coastal waters due to recreational boating. *Biodivers Conserv*, *20*, 683–701. https://doi.org/10.1007/s10531-011-0003-6

Cottrell, S. (2002). Predictive model of responsible Environmental behaviour: Application as a visitor-monitoring tool. *Monitoring and Management of Visitor Flows in Recreational and Protected Areas Conference Proceedings*, 129–135. Conference Proceedings edited by A. Arnberger, C. Brandenburg, A. Muhar. http://mmv.boku.ac.at/refbase/files/cottrell_stuart-2002-predictive_model_of.pdf

De Graaff, M. S., Temmink, H., Zeeman, G., & Buisman, C. J. N. (2010). Anaerobic treatment of concentrated black water in a UASB reactor at a short HRT. *Water*, *2*(1), 101–119. https://doi.org/10.3390/w2010101

ENSR International. (2005). *Mitigation Measures to Address Pathogen Pollution in Surface Waters: A TMDL Implementation Guidance Manual for Massachusetts*. USEPA New England Region 1. https://www.mass.gov/doc/implementation-guidance-manual-for-watershed-specific-pathogen-tmdl-reports-0/download

Epical. (2021). *Pumpout Nav App*. Pumpout Nav Admin Platform. http://oberon.abag.ca.gov:8080/cvadmin/#/login

Friends of Casco Bay. (2019). *Our pumpout boat is taking care of business.* Friends of Casco Bay: Casco BAYKEEPER. https://www.cascobay.org/our-pumpout-boat-is-taking-care-of-business/

Government of Canada. (2012). *Vessel pollution and dangerous chemicals regulations.* Justice Laws Website. https://laws-lois.justice.gc.ca/eng/regulations/sor-2012-69/page-14.html

Hoedemaker, B. (2019). *A summer boat ride on a mobile sewer.* Washington Sea Grant. https://wsg.washington.edu/a-summer-boat-ride-on-a-mobile-sewer/

Hunt, L. M., Morris, D. M., Drake, D. A. R., Buckley, J. D., & Johnson, T. B. (2019). Predicting spatial patterns of recreational boating to understand potential impacts to fisheries and aquatic ecosystems. *Fisheries Research*, *211*, 111–120. https://doi.org/10.1016/j.fishres.2018.11.007

Iburg, S., Izabel-Shen, D., Austin, Å. N., Hansen, J. P., Eklöf, J. S., & Nascimento, F. J. A. (2021). Effects of Recreational Boating on Microbial and Meiofauna Diversity in Coastal

Shallow Ecosystems of the Baltic Sea. *mSphere*, *6*(5). https://doi.org/10.1128/msphere.00127-21

Lake Champlain Basin Program. (2018). *2018 State of the Lake.* https://www.lcbp.org/news-and-media/publications/state-of-the-lake/

Lake Champlain Basin Program. (2021). *2021 Lake Champlain State of the Lake and ecosystems indicators report*. https://sol.lcbp.org/

Lowe, K. S., Tucholke, M. B., Tomaras, J. M. B., Conn, K., Hoppe, C., Drewes, J. E., … Munakata-Marr, J. (2010). *Influent constituent characteristics of the modern waste stream from single sources*. Water Environment Research Foundation. IWA Publishing. Alexandria, VA. https://doi.org/10.2166/9781780403519

Monz, C. A., Pickering, C. M., & Hadwen, W. L. (2013). Recent advances in recreation ecology and the implications of different relationships between recreation use and ecological impacts. *Frontiers in Ecology and the Environment*, *11*(8), 441–446. https://doi.org/10.1890/120358

North Carolina, State of. (2018). 15A NCAC 02T .0114 North Carolina Wastewater Design Flow Rates. http://reports.oah.state.nc.us/ncac/title 15a - environmental quality/chapter 02 - environmental management/subchapter t/15a ncac 02t .0114.pdf

Powell, L. A., & Gale, G. A. (2015). Chapter 8: Estimation of population size: closed populations. In *Estimation of parameters for animal populations: a primer for the rest of us* (pp. 91–102). Caught Napping Publications. Lincoln, NE. https://larkinpowell.wixsite.com/larkinpowell/estimation-of-parameters-for-animal-pop

Sidman, C., Grant, F. S., Swett, R., Fik, T., Fann, S., & Grant, F. S. (2006). *A Recreational Boating Characterization for Sarasota County*. Florida Sea Grant. https://www.flseagrant.org/wp-content/uploads/flsgps06001.pdf

Smith, A. (2014). *Clean Vessel Act Plan for Proper Sewage Disposal for Virginia. Marine Resource Report No. 2014-3.* Virginia Institute of Marine Science, College of William and Mary. https://doi.org/10.21220/m2-pf49-eb57

Sun, H., Mohammed, A. N., & Liu, Y. (2020). Phosphorus recovery from source-diverted blackwater through struvite precipitation. *Science of The Total Environment*, *743*, 140747. https://doi.org/10.1016/j.scitotenv.2020.140747

Uekusa, S. (2019). Disaster linguicism: Linguistic minorities in disasters. *Language in Society*, *48*(3), 353–375. https://doi.org/10.1017/S0047404519000150

USEPA. (1975). *Vermont Marine Sanitation Device Standard*. https://www.epa.gov/sites/default/files/2015-09/documents/40_fr_42240.pdf

USEPA. (2002). *Onsite Wastewater Treatment System Manual.* https://www.epa.gov/sites/default/files/2015-06/documents/2004_07_07_septics_septic_2002_osdm_all.pdf

USEPA. (2016). *Phosphorus TMDLs for Vermont Segments of Lake Champlain.* https://www.epa.gov/sites/default/files/2016-06/documents/phosphorus-tmdls-vermont-segments-lake-champlain-jun-17-2016.pdf

USFWS, U. S. F. and W. S. (2012). *Clean Water needed: Clean Vessel Act Protects Alaska's Coastal Waters.* In: *Celebrating the Wildlife and Sport Fish Restoration Program 75 years of Conservation and Partnership Success*. https://www.nbbd.com/godo/minwr/75Years-WildlifeRestoration.pdf

Venohr, M., Langhans, S. D., Peters, O., Hölker, F., Arlinghaus, R., Mitchell, L., & Wolter, C. (2018). The underestimated dynamics and impacts of water-based recreational activities on freshwater ecosystems. *Environmental Reviews*, *26*(2), 199–213. https://doi.org/10.1139/er-2017-0024

Vermont, State of. (2016). *Vermont Lake Champlain Phosphorus TMDL Phase 1 Implementation Plan.* https://dec.vermont.gov/sites/dec/files/wsm/erp/docs/2016%20Draft%20Phase%201%20Implementation%20Plan.pdf

Vermont, State of. (2020). *Clean Water Board.* Agency of Natural Resources: Department of Environmental Conservation. https://dec.vermont.gov/water-investment/cwi/board

Voigt, B., Lees, J., & Erickson, J. (2015). *An Assessment of the Economic Value of Clean Water in Lake Champlain*. *Technical Report No. 81.* The Lake Champlain Basin Program and New England Interstate Water Pollution Control Commission. http://www.lcbp.org/wp-content/uploads/2013/03/81_VoigtEconomicsFinalReport1.pdf

Whitfield, A. K., & Becker, A. (2014). Impacts of recreational motorboats on fishes: A review. *Marine Pollution Bulletin*, *83*(1), 24–31. https://doi.org/10.1016/j.marpolbul.2014.03.055