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RESEARCH ARTICLE

Effects of submerged aquatic vegetation and water quality on waterfowl abundance by foraging guild

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Abstract

1. Back Bay, Virginia, has been documented as an important foraging area for waterfowl since at least the mid-1800s. Expansive submerged plant beds historically supported diverse assemblages of non-breeding waterfowl; however, coastal development and other anthropogenic influences have since led to fluctuations in submerged aquatic vegetation (SAV) and an associated decline in waterfowl abundance in the bay. To gain insight into the effects of environmental drivers on waterfowl foraging guilds, our study explores the effects of SAV frequency and water quality on the abundance of dabbling ducks, diving ducks and swans and geese in Back Bay.
2. We use 8 years of SAV, water quality, and waterfowl monitoring data collected by state and federal agencies to model the effects of salinity, turbidity, pH and percent frequency of SAV on the relative abundance of waterfowl by foraging guild in Back Bay. The appropriateness of the data and reasonability of the preliminary results were then evaluated through semi-structured interviews with 11 local informants representing state, federal and non-governmental organizations.
3. Quantitative results indicated that dabbling ducks are affected differently than other guilds by water quality and percent frequency of SAV. Thematic analysis of the interview data revealed a number of potential explanations for the model results, as well as highlighted areas of uncertainty in need of further research. In a test of face validity, participants demonstrated a significant degree of belief in turbidity, salinity and SAV as drivers of waterfowl abundance, but were not convinced by the potential effects of pH as demonstrated by the model.
4. This mixed methods study provides insights that could potentially influence the management and conservation of non-breeding waterfowl populations by challenging the assumption that particular environmental conditions serve all foraging groups equally.

KEYWORDS
foraging guild, key informants, mixed methods, submerged aquatic vegetation, water quality, waterfowl conservation

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1 | INTRODUCTION

Coastal marine ecosystems and the co-benefits they provide are profoundly threatened by the synergistic effects of climate change and other anthropogenic influences (Harley et al., 2006; Intergovernmental Panel on Climate Change, 2014, 2018; Spalding et al., 2014). Direct and ex situ impacts ranging from habitat loss to stormwater runoff lead to changes in the structure and function of coastal systems, thus affecting the myriad species that depend on them (Spalding et al., 2014). Environmental variability as a function of these influences poses an especially significant challenge for waterfowl management, as the maintenance and monitoring of migratory bird populations are affected by phenology, distributional shifts and resource availability (Nichols et al., 2011).

Submerged aquatic vegetation (SAV), or the rooted, vascular plants that colonize soft sediments in coastal, estuarine and freshwater ecosystems, is one element of aquatic environments at high risk due to direct and indirect human activity (Dennison et al., 1993; Orth et al., 2006; Patrick et al., 2017). As a vital primary producer in both aquatic and adjoining upland habitats, SAV provides a range of ecosystem services including water column filtration, sediment stabilization, and biodiversity support through habitat and food resource provision (de Boer, 2007; Hestir et al., 2016; Madsen et al., 2001; Munro & Perry, 1983; Stevenson & Confer, 1978). In Back Bay, Virginia, SAV has historically supported large populations of waterfowl, including dabbling ducks, like the American black duck (*Anas rubripes*), gadwall (*Mareca strepera*), and mallard (*Anas platyrhynchos*); diving ducks, such as bufflehead (*Bucephala albeola*) and hooded merganser (*Lophodytes cucullatus*); and swans and geese, including Canada goose (*Branta canadensis*), snow goose (*Anser caerulescens*), and tundra swan (*Cygnus columbianus*) (Gross et al., 2020; Morton & Kane, 1994; Perry et al., 2007; Settle & Schwab, 1991; Waterfield, 1951). Throughout the twentieth century, however, fluctuations in the percent frequency of aquatic vegetation in Back Bay (from 87% in 1974 to less than 1% in 1991), and the seemingly associated decline in waterfowl abundance (over 90 thousand in 1977 to less than 10 thousand in 1990) has prompted concern from natural resource managers throughout the region (Orth & Moore, 1983; Schwab et al., 1991; Morton & Kane, 1994; Moorman et al., 2017; Figure S1 in the Supporting Information).

SAV abundance and community composition are driven by a range of environmental factors including herbivory from fish and waterfowl (Gyimesi et al., 2011; Søndergaard et al., 1996; Tatu et al., 2007), competition from non-native species (Hershner & Havens, 2008), salinity (Norman & Southwick, 1991; Waterfield, 1951), turbidity (Carter & Rybicki, 1991; Van Onsem & Triest, 2018), and pH (Buapet et al., 2013; DesGranges & Darveau, 1985; Koweek et al., 2018; Roberts et al., 1985), among other variables (Chamberlain, 1948; Dennison et al., 1993; Weisner et al., 1997). Changes to aquatic conditions from direct and indirect human activity have subsequently caused the decrease of this important waterfowl resource in wintering grounds across the Atlantic Flyway (Moorman et al., 2017; Morton & Kane, 1994; Orth & Moore, 1983; Schwab, 1984; Settle et al., 1991; Sincock et al., 1965; U.S. Fish and Wildlife Service [USFWS], 2010). While historical studies of Back Bay have examined the biological associations between water quality, SAV and waterfowl independently (Schwab et al., 1991; Settle & Schwab, 1991; Sincock et al., 1965), present understanding of the potential of these factors to interact and drive waterfowl abundance remains limited.

This study takes a new approach to assess the influence of environmental drivers on waterfowl in Back Bay by providing a quantitative analysis of the interactions between three water quality characteristics (pH, salinity and turbidity) and SAV, and their effects on waterfowl abundance by foraging guild. As water niche, or feeding depth, varies between waterfowl foraging guilds, it is hypothesized that changes in SAV frequency, as dictated by shifts in water quality conditions, will impact guild abundance differently. To investigate this relationship, we use government data from wintering waterfowl aerial surveys, water quality monitoring stations, and SAV transect surveys to model three-way interactions between environmental covariates. A series of key informant interviews with local and regional wildlife and natural resource experts were later held to evaluate the face validity, or apparent soundness, of the quantitative data and to discuss the plausibility of the preliminary results (Galletta & Cross, 2013; Kallio et al., 2016; Nevo, 1985; Rykiel, 1996). Themes captured from the interview data evaluate the reasonability and frame the interpretation of the model results and provide guidance for future research needs in the region (Boyatzis, 1998; Jick, 1979; Miles & Huberman, 1994).

2 | MATERIALS AND METHODS

2.1 | Study area

Back Bay, Virginia, USA (36°36′49″ N, 75°56′40″ W) is narrowly separated from the Atlantic Ocean by sand dunes and marsh impoundments to the east, bordered by emergent wetlands and maritime forest to the north and west, and connected to Currituck Sound through Knotts Island Channel to the south (Morton & Kane, 1994; USFWS, 2010) (Figure 1). As Back Bay is situated approximately 128 km north of the nearest marine inlet, Oregon Inlet, North Carolina, the waterbody experiences no lunar tidal action; instead, water levels are dictated by the prevailing wind direction and speed (Morton & Kane, 1994; USFWS, 2010). Wind tides coupled with precipitation and watershed inputs influence the salinity levels of the bay, which has been historically characterized as oligohaline, ranging 0–3 parts per thousand (ppt) (Norman, 1991; USFWS, 2010). Responsibility for the conservation of Back Bay and its wildlife resources is divided between the USFWS, the Virginia Department of Wildlife Resources (VDWR), and the Virginia Department of Conservation and Recreation, with collaborative efforts from a variety of environmental non-governmental organizations including but not limited to Ducks Unlimited, the Back Bay Restoration Foundation, and the Atlantic Wildfowl Heritage Museum (Figure 1).

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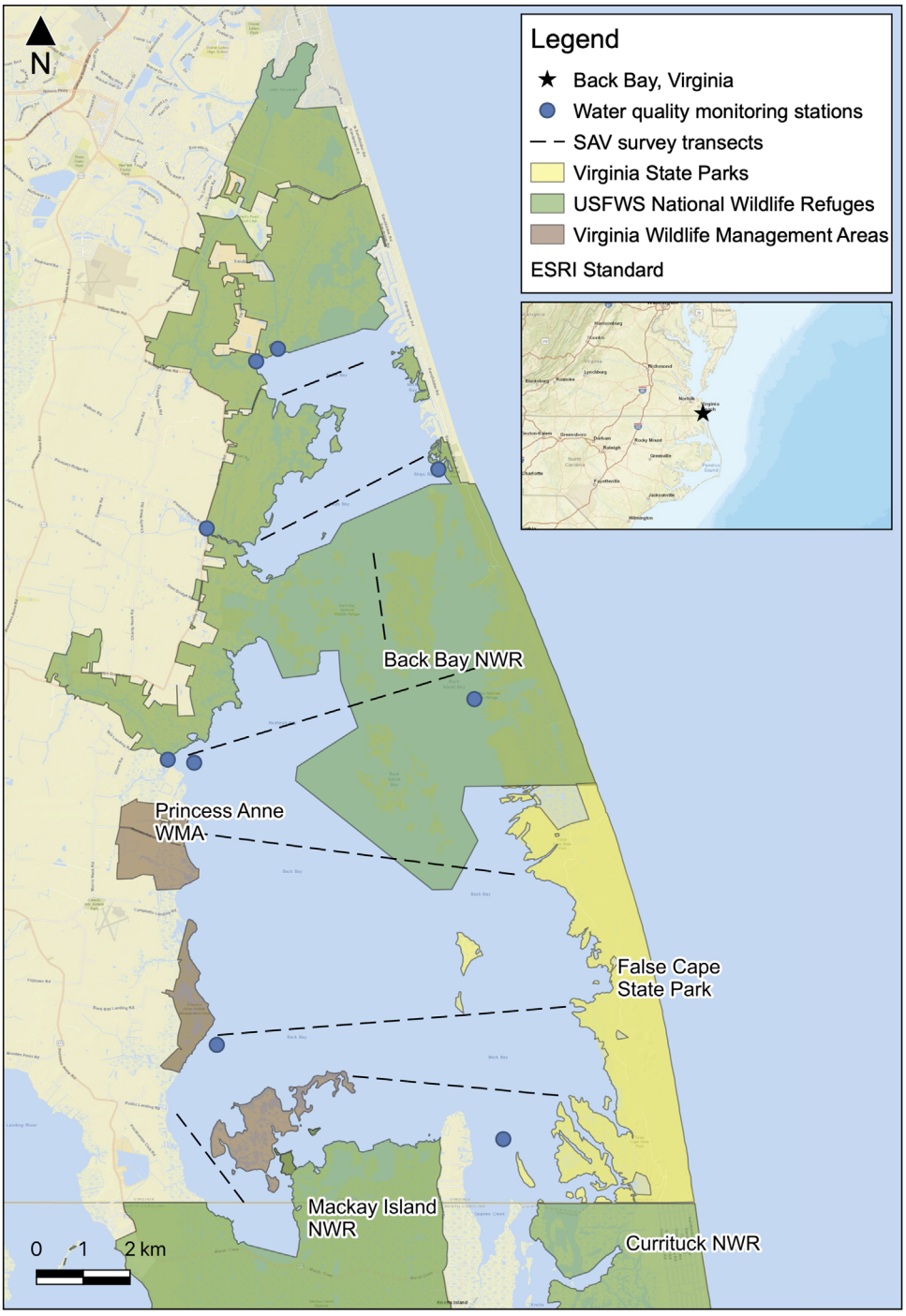


FIGURE 1 Map of protected areas, water quality monitoring stations and SAV survey transects in Back Bay, Virginia, USA, 1958–2021. State parks and wildlife management areas are owned and managed by the Virginia Department of Conservation and Recreation and the Department of Wildlife Resources, respectively. National Wildlife Refuges are owned and managed by the U.S. Fish and Wildlife Service. The Virginia Department of Environmental Quality water quality monitoring stations pictured include stream codes 5B-NWN000.00, 5B-BC000.76, 5B-MDY000.00, 5B-BKY003.47, 5B-BKY006.37, 5B-HPC000.00, 5B-SHB000.57, 5B-BKY006.48 and 5B-BKY-000.99 under organization identifier 21VASWCB. Submerged aquatic vegetation survey transects were established in 1958 (Schwab et al., 1991) and are still used today (Costanzo, 2017)

2.2 | Waterfowl aerial surveys

Aerial surveys designed to estimate wintering waterfowl abundance and distribution were conducted by the VDWR, in January of each year between 1998 and 2017, and by the Back Bay National Wildlife Refuge biologist in 2011 (January, February, March, November, December), 2012 (January, February, March) and 2013 (November, December). In both the VDWR and USFWS aerial surveys, waterfowl numbers were recorded by species in generalized locations in and around Back Bay. Mid-winter inventory flight transects were designed to provide

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complete aerial coverage of the mid-winter inventory survey unit; however, USFWS surveys placed a greater focus on the refuge and state park property (see Settle & Schwab, 1991). Count data from the refuge and state park impoundments were excluded here to retain compatibility with the SAV and water quality datasets.

Waterfowl counts by species and location were spoken into a handheld recorder (Sony ICD-BX140 4 GB Digital Voice Recorder, San Diego, USA, or similar) and later reproduced onto handwritten datasheets. Scanned copies of the original datasheets were provided by the respective agencies and electronically transcribed. While pilots varied between surveys, the VDWR and USFWS surveys were conducted by the same two biologists, one state and one federal, respectively, thus reducing the probability of observer bias (Pearse et al., 2008). While Huesmann (1999) and Eggeman and Johnson (1989) caution against using aerial mid-winter survey data, the latter identify Virginia as an Atlantic Flyway state where surveys have been conducted with consistency in methods, personnel, route coverage and survey effort. Waterfowl were categorized into guilds (dabbling ducks, swans and geese, and diving ducks) based on foraging behaviour (Table S1 in the Supporting Information). Dabbling ducks normally feed by dabbling their bills or tipping forward in water ranging in depth from 5 to 30 cm (Guillemain et al., 2000; Nelms et al., 2007; Sibley, 2000). Swans and geese feed similarly, by tipping up or grazing, foraging at water depths of 0–10 cm (Fredrickson & Reid, 1988; Gyimesi et al., 2011; Nelms et al., 2007; Sibley, 2000; Tatu et al., 2007). Diving ducks prefer water greater than 25 cm in depth, where they can dive for SAV as well as animal matter such as clams, fish and various other invertebrates (Nelms et al., 2007; Pöysä, 1983; Sibley, 2000).

2.3 | Water quality monitoring stations

Monthly water quality data for salinity, pH and turbidity collected by the Virginia Department of Environmental Quality was downloaded from the National Water Quality Monitoring Council's (NWQMC) Water Quality Portal for nine stations in and around the perimeter of Back Bay (NWQMC, 2022; Figure 1). Salinity was measured via the electrical conductivity method, and pH value in water was measured by potentiometry using a standard hydrogen electrode (NWQMC, 2020). Turbidity was measured in nephelometric turbidity units (NTU) by the nephelometric method (NWQMC, 1995). While water quality measurements were collected with consistent methodologies, variation in the time of day that the samples were taken, and the speed and direction of the wind during sampling events may have introduced variability into otherwise standardized measurement procedures.

2.4 | Submerged aquatic vegetation transects

SAV surveys in Back Bay were established in 1958 (Sincock et al., 1965) and have been surveyed annually by the VDWR since 2009 following the methods of Schwab et al. (1991) and (Costanzo 2017). During each survey event, vegetation samples were taken at 500 m intervals along eight transect lines traversing Back Bay (Figure 1). At each 500 m interval, three two-square-foot bottom samples were taken using modified oyster tongs, and species of SAV were recorded along with a visual estimate of percentage cover or density (trace, low, medium, and high) (Figure S2 in the Supporting Information). The one- or two-day sampling events were conducted annually between September and November. The annual percent frequency of SAV in Back Bay was derived from dividing the number of samples with any SAV by the total number of samples taken each year.

2.5 | Statistical analysis

All quantitative analyses were conducted in the R statistical platform with the 'lme4', 'MuMIn', 'lsmeans' and 'multcomp' packages (Version 1.1.463, 2009–2018) (Bartoń, 2019; Bates et al., 2015; Hothorn et al., 2008; Lenth, 2016). As the data were not subject to overdispersion, we used a Poisson distribution model to investigate the impact of the selected environmental drivers on waterfowl abundance by foraging guild. The water quality and SAV variables were centred and standardized before analyses to allow for direct comparison of model coefficients between variables with different units (z-scores; Gelman, 2008). A Bayesian information criterion (BIC) comparison, which penalizes more complex models by excluding terms that explain only little variability in the data, was used to evaluate three models with three-way interactions between feeding guild, SAV percentage and each water quality characteristic (pH, salinity and turbidity) (Aho et al., 2014; Table 1). The first model comprises three, three-way interactions, including all additive terms and lower order interactions. The second model builds on the first by adding an offset for the number of waterfowl surveys per year. In addition to the added offset, the third model incorporates year as a random factor. The BIC comparison indicated that the first and second models were equally parsimonious. The second model, which includes three, three-way interactions between waterfowl guild, average water quality measurements, and annual vegetation frequencies from 2010 to 2017, as well as an offset for the number of waterfowl surveys per year, was chosen to evaluate the data ($R^2_{\text{Adjusted}} = 0.46$; Table S2 in the Supporting Information). A Tukey multiple comparison of means analysis was subsequently run to assess differences between abundances across feeding guilds.

2.6 | Key informant interviews

Interview participants were selected purposively to include key informants in the Back Bay region with local or expert knowledge in waterfowl dynamics, wetland ecosystems, and related fields. Purposive sampling is a non-probability technique by which the researcher clearly defines the desired participant criteria and deliberately selects the most productive sample to answer the research question (Campbell, 1955; Marshall, 1996; Tongco, 2007). As the USFWS and VDWR frequently partner with non-profit organizations to promote the conservation of Back Bay, participants were chosen from federal agencies,

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TABLE 1 Model selection detailing the effects of water quality (pH, turbidity and salinity) and SAV on waterfowl abundance by foraging guild (dabbling, diving and swans and geese). The initial model contained three, three-way interactions between the waterfowl guild, percent frequency of SAV, and each water quality characteristic, including all additive and lower order interactions. Subsequent models included an offset for the number of waterfowl surveys per year and added year as a random factor. The most parsimonious model selected by means of the Bayesian information criteria is shown together with the null, offset, and mixed-effect models. The second model, which included an offset for the number of waterfowls each year, was selected to evaluate the data

Model No.	Explanatory variables selected			Offset	Random factor	BIC	Δ BIC
1	G × SAV × pH	G × SAV × T	G × SAV × S			69,361.65	
2	G × SAV × pH	G × SAV × T	G × SAV × S	Surveys		69,361.65	0
3	G × SAV × pH	G × SAV × T	G × SAV × S	Surveys	Year	69,366.24	4.59
Null	Total abundance					148,214.94	

Abbreviation: BIC, Bayesian information criteria; G, guild; pH: pH; S: salinity; SAV, percent frequency of submerged aquatic vegetation; T, turbidity. Surveys: Number of surveys per year.

state agencies and local environmental non-profit organizations. The preselected list of key informants was later supplemented via snowball sampling, a recruitment process through which selected participants refer qualified individuals from their professional networks (Marshall, 1996; Bernard, 2006). As there is no definitive standard for sample size in qualitative interviewing, the number of participants was reasonably maximized within the constraints of time and cost (Bryman, 2016). All interview audio was recorded using the Apple, Inc. application Voice Memos (Version 2.0), run on an encrypted 2017 MacBook Pro, and direct quotes and paraphrases from participants are cited via semi-anonymous pseudonyms (Table S3 in the Supporting Information). Data security and consent protocols were approved by the University of Oxford's Central University Research Ethics Committee prior to the initiation of this research.

Semi-structured interviews use open-ended and theoretically driven questions to collect similar types of information from each participant (Galletta & Cross, 2013; Kallio et al., 2016). The semi-structured interview guide designed for this study aimed to gauge each participant's knowledge of the study area and assess the face validity, or apparent soundness, of the quantitative data and preliminary results (Text S1 in the Supporting Information). A technical note illustrating the data sources and preliminary results was provided to each participant prior to his or her interview (Text S2 in the Supporting Information). Interview transcripts were subsequently encoded through thematic analysis, a process through which units of meaning, or codes, are assigned to the descriptive or inferential information compiled during the course of the study (Boyatzis, 1998; Braun & Clarke, 2012; Miles & Huberman, 1994). Codes were identified and clustered under broader themes or categories, resulting in the identification of the thematic patterns and recurring motifs that reflect the ideas most evident in the data (Bryman, 2016; Galletta & Cross, 2013). Face validity was then evaluated by qualitatively assessing whether the interview themes depicted a sufficient degree of belief in the accuracy and applicability of the model, given its designed purpose (Nevo, 1985; Rykiel, 1996). By implementing the trustworthiness criteria outlined by Lincoln and Guba (1985), the common shortfalls of thematic analysis, such as oversimplification and lack of cohesion, have been significantly reduced here (Goosen et al., 2007; Nowell et al., 2017).

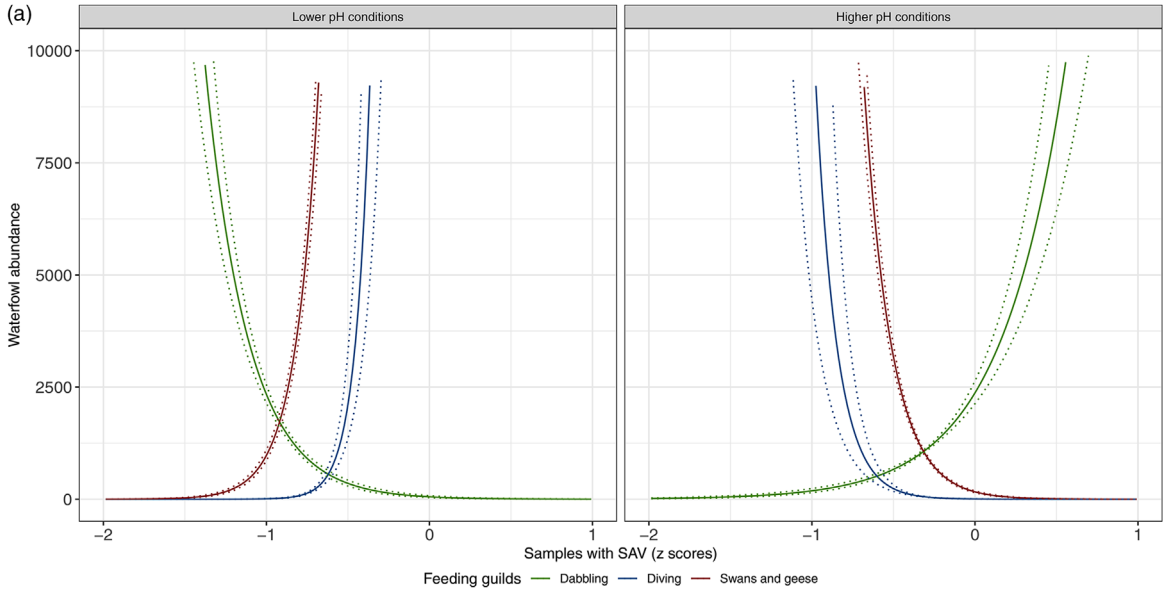
3 | RESULTS

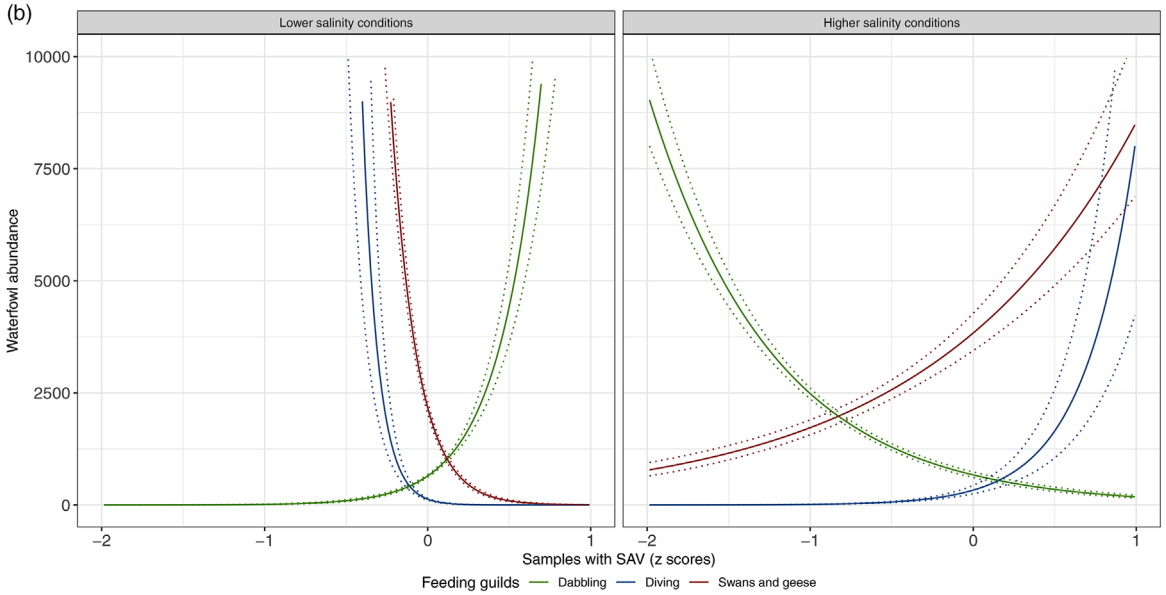
3.1 | Waterfowl abundance trends

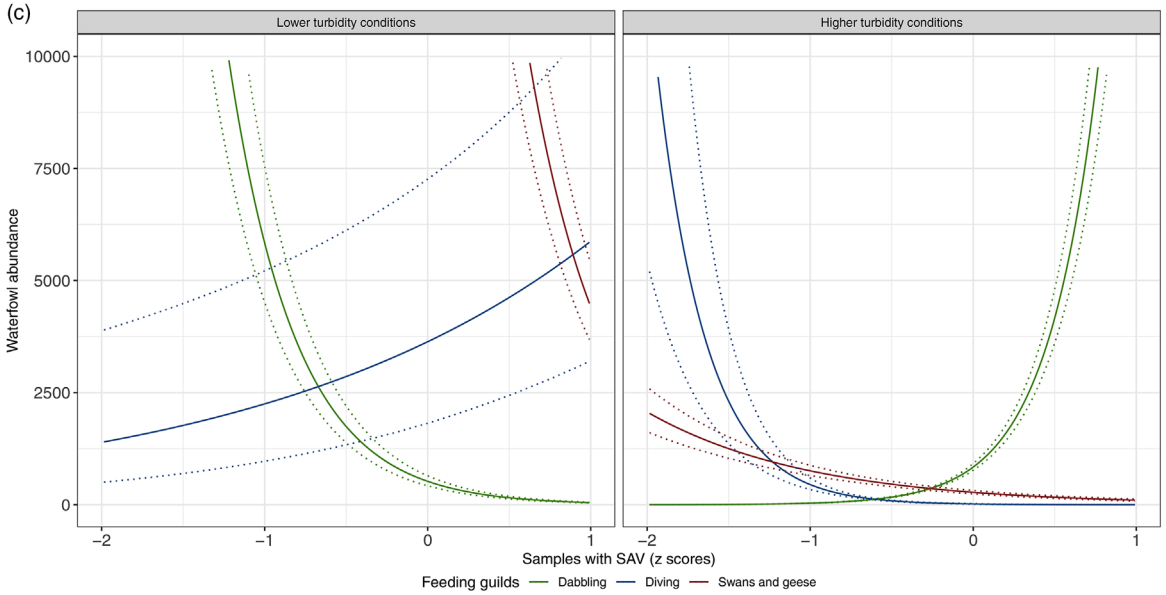
The waterfowl, water quality and SAV datasets overlapped from 2010 to 2017. During those years, total abundance of dabbling ducks ranged from 607 to 18,496 individuals, diving ducks ranged from 40 to 1762 individuals, and swans and geese ranged from 165 to 2671 (Figure S3 in the Supporting Information). Each of the three water quality variables was averaged across monthly samples each year: salinity ($\bar{x} = 1.26$ ppt, $n = 8$, SD = 0.39 ppt), pH ($\bar{x} = 7.72$, $n = 8$, SD = 0.13) and turbidity ($\bar{x} = 18.88$ NTU, $n = 8$, SD = 2.53 NTU). Although vegetation cover by species was estimated with a visual percentage in the field, the SAV unit used in the model represents the number of samples each year with any vegetation present ($\bar{x} = 28.99\%$, $n = 8$, SD = 6.61%). Correlation analysis of the possible explanatory variables was conducted to avoid including highly correlated variables that could distort model predictions (Dormann et al., 2013). All water quality characteristics (pH, salinity and turbidity) had correlation coefficients ≤ 0.70 (Figure S4 in the Supporting Information).

Abundance trends of waterfowl guilds reversed between the two pH conditions, despite a relatively narrow range (min = 7.44, max = 7.86). Where pH was slightly lower, diving duck and swan and geese abundances were projected to increase with increasing SAV, and where pH was slightly greater, the same guilds were projected to decrease (Figure 2a). The opposite is true for the dabbling ducks, whose trends contrasted the diving ducks and swans and geese in both pH scenarios. When salinity was less than 1 ppt (min = 0.58 ppt), abundances of diving ducks and swans and geese were projected to decrease with more SAV present, while dabbling duck abundance was projected to increase (Figure 2b). In more saline conditions (max = 1.72 ppt), diving duck and swan and geese abundances were projected to increase, while the abundance of dabbling ducks was projected to decrease. Again, dabblers had contrasting trends to the diving ducks and swans and geese. This pattern was consistent still in more turbid water (max = 23.09 NTU), where diving duck and swan and geese abundances were projected to decrease and dabbling ducks were projected to increase (Figure 2c). Although diving ducks appear inconsistent with swans and geese in conditions of lower turbidity (min = 14.61 NTU),

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TABLE 2 Themes identified in the analysis of semi-structured interview data from key informants with knowledge of wildlife and natural resource management in Back Bay, Virginia. Interviews were conducted between 25 June and 22 July 2019. Semi-structured interview questions were designed to explore each participant's perspective on study area trends, and investigate face validity, or the apparent aptness of the study to measure impacts to waterfowl abundance by the guild in Back Bay. The themes outlined are the result of Braun and Clarke's (2012) six-phase approach to thematic analysis

Theme	Description
I. Historical trends	Provides context to the research objectives by outlining ecological patterns documented and observed in Back Bay from the 1950s onward. Many participants cited declines in water quality and submerged aquatic vegetation and waterfowl abundance and expressed concern over the loss of important ecosystem services
II. Face validity	Outlines participants' reactions to and reflections on the datasets used in the model, in addition to the preliminary results of the model itself. This theme evaluates the face validity of the study, or whether it appears to assess what it claims to, measured by both the emotional (i.e. surprise, confusion, confidence) and technical (i.e. areas of uncertainty, assumptions, confounding factors) responses of the participants
III. Informant speculation	Discusses potential explanations for the model results based on participant site-specific or subject matter expertise. Many participants recalled observed changes in the feeding behaviours of waterfowl species, highlighted key interspecific relationships and noted landscape-level features of Back Bay which may provide further context to the results

the confidence interval for diving ducks in this scenario nearly spans the width of the trendline for swans and geese. Most markedly, dabbling duck abundance trends follow a different pattern than the other two guilds in all predicted conditions except those with lower turbidity.

3.2 | Interview themes

Semi-structured interviews were held with 11 participants, including four federal (USFWS), three state (VDWR) and four non-governmental informants (Ducks Unlimited, Back Bay Restoration Foundation and the Atlantic Wildfowl Heritage Museum), in person or over an audio or video conferencing software (Skype Version 8.48.0.51 and Vidyo Version 3.6.15) between 25 June and 22 July 2019. Together, the participants represent approximately 265 years of experience working or volunteering in wildlife conservation or a related field in the greater Back Bay and Currituck Sound areas (Table S3 in the Supporting Information). The screening phase of thematic analysis produced over 400 individual notes and annotations capturing the breadth of all interview responses (Braun & Clarke, 2012). This preliminary list was vetted and organized to consolidate duplicates and to eliminate those topics outside of the scope of the research questions. The final list of unique ideas and phrases pertinent to the research objectives comprised 34 descriptive and interpretive codes, which were then clustered into three distinct themes based on relatedness and interdependency (Table 2; Table S4 in the Supporting Information). The recurring motifs are discussed below in the context of our research objectives to provide a more comprehensive understanding of the quantitative results (Boyatzis, 1998; Bryman, 2016).

4 | DISCUSSION

Our results indicate that water quality, particularly salinity, and abundance of SAV differently affect waterfowl foraging guild abundance in Back Bay. In nearly all of the modelled conditions, dabbling duck trends were distinctly opposite to those of diving ducks and swans and geese, indicating that dabbling duck populations vary in their response to the tested environmental drivers. As this result was in some cases contrary to the expectations of interviewees, potential explanations for the results as speculated by participants arose as a key theme in the interview data.

4.1 | Historical context

Declines in SAV and the loss of its associated ecosystem services, especially resource provision for waterfowl, were the most prevalent response when participants were asked to reflect upon important ecological trends in Back Bay (Table 2, Theme I). The historical association between the percent frequency of SAV and waterfowl in Back Bay demonstrated by Settle and Schwab (1991), Sincock et al. (1965) and Costanzo (2017) (Figure S1 in the Supporting Information) was frequently recalled by key informants, who agreed that declines in SAV and degradation of marsh habitat had led to local declines in waterfowl abundance. While participant understanding of the association between SAV and dabbling ducks was consistent with Settle and Schwab's (1991) study examining this relationship in Back Bay, there were some slight disparities in reported trends of other guilds. For example, the state waterfowl biologist regarded swans and

FIGURE 2 Predicted effects of pH (a), salinity (b), and turbidity (c) and the percent of samples with SAV on waterfowl abundance by the guild (dabbling ducks, diving ducks and swans and geese) in Back Bay, Virginia, 2010–2017. Waterfowl abundance indicates the total number of individuals counted each year. Solid and dotted lines represent averages and 95% confidence intervals, respectively. The annual frequency of SAV is quantified as the standardized (*z*-scores) percent of all samples with vegetation present. High and low water quality conditions represent the ends of the range for that variable: pH (min = 7.44, max = 7.86), salinity (min = 0.58 ppt, max = 1.72 ppt), and turbidity (min = 14.61 NTU, max = 23.09 NTU)

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geese as 'pretty consistent in the bay', whereas the state migratory bird program manager noted declining numbers of snow goose (*A. caerulescens*) and tundra swan (*C. columbianus*). This discrepancy likely presented itself due to differences in a timeframe, as our data indicate that the abundance of swans and geese appear relatively stable across the most recent decade (Figure S3 in the Supporting Information). Over the longer term, however, participants agreed that waterfowl numbers in Back Bay were 'disappointing' compared to 'the old days' (Ducks Unlimited State Conservation Chair) and that the most effective defence against waterfowl resource loss is the protection of habitat, especially ecological buffers, through land acquisition (USFWS, 2010).

Nearly all participants acknowledged the significant role SAV plays in improving water quality and reducing sediment erosion and marsh loss in the bay. While some observed that the water quality in the bay had seen some improvements over the last decade, many noted that chronic declines in SAV had resulted in greater wave action and higher turbidity across the bay. Dense communities of SAV, referred to locally as a 'slick', create a source of friction against wind-driven tides, resulting in greater wave attenuation (state fisheries biologist). This important ecosystem service has been recognized not only in Back Bay (Schwab et al., 1991; USFWS, 2010) but in other aquatic systems as well (de Boer, 2007; Hershner & Havens, 2008; Hestir et al., 2016; Madsen, et al., 2001; Weisner, 1997). Educating local communities, especially recreational boaters, on the important functions of SAV was discussed by participants as one strategy for reducing disturbance to aquatic plant beds in Back Bay. Participant perception of historical and current ecological trends in Back Bay serves as important context for their interpretation of the preliminary model results.

4.2 | Face validity

In addition to exploring participant perception of ecological trends, the semi-structured interviews investigated the face validity of our study, or its aptness to evaluate the influence of environmental drivers on waterfowl abundance by the guild in Back Bay (Table 2, Theme II). By thematically analysing participants' emotional and inductive responses to the quantitative data and preliminary results, we assess qualitatively whether there is sufficient belief in the accuracy and applicability of the model in the context of the research objectives (Nevo, 1985; Rykiel, 1996). Although participants identified the use of disparate datasets and the potential for confounding environmental factors as potential limits to the data, there was consensus that the datasets used were the best available for the study area. As noted above, participants agreed that the declining patterns of SAV and waterfowl reflected in the data accurately reflected their knowledge of Back Bay and other wetland systems in the region (Carter et al., 1983; Moorman et al., 2017; Sincock et al., 1965). Given the positive correlation between dabbling ducks and SAV demonstrated by Settle and Schwab (1991), and the underlying assumption that greater SAV abundance supports waterfowl regardless of the guild, participants initially referred to the contrary results as 'strange' and 'perplexing'. As the interview progressed, however, the nature of participant responses transitioned from doubt to curiosity and conjecture. Although initially surprised by negative associations between waterfowl and SAV, and the deviating trends of dabbling ducks compared to other guilds, informants offered plausible and ecologically relevant explanations for the trends based on site-specific or subject matter expertise, demonstrating a sufficient degree belief in the plausibility of the results and the aptness of the methodology to investigate the research objectives.

4.3 | Informant speculation of observed trends

In their consideration of the preliminary model results, participants proposed potential explanations where plausible, and where implausible, indicated significant doubt. For instance, while relationships between SAV and pH have been studied in marine systems and oligotrophic lakes (Buapet et al., 2013; DesGranges & Darveau, 1985; Koweek et al., 2018; Roberts et al., 1985), interview participants were not convinced that the interaction between pH and SAV was an important driver in understanding waterfowl abundance in Back Bay. Dabbling duck abundance has historically been shown to relate positively with increased SAV coverage in Back Bay (Settle & Schwab, 1991), yet this was not the case in conditions of lower pH, according to our model. Surprisingly, dabbling duck abundance was predicted to decrease with greater frequencies of SAV in slightly more acidic conditions, where diving ducks and swans and geese were projected to increase. The narrow range of lower and higher pH conditions as defined by the model dataset reversed patterns of waterfowl abundance across the spectrum of SAV coverage, but targeted research on the influence of pH on SAV composition is needed before any conclusions or management implications may be drawn.

Based on previous studies and empirical knowledge of the system, participants agreed that salinity was likely to be a key driver of overall waterfowl abundance in Back Bay. Our model indicated that numbers of diving ducks and swans and geese decrease in lower salinity conditions when more SAV is present, and increase in tandem with SAV in higher salinity conditions. The opposite was projected for dabbling ducks, as numbers were shown to increase with more SAV in lower salinity conditions and decrease with more SAV in higher salinity conditions. In addressing the unexpected tendency of certain guilds to decrease despite more abundant SAV, many interviewees noted the importance of vegetative community composition and its relationship to waterfowl foraging behaviour. For instance, assimilable energy may provide insight into the vegetation valued by waterfowl species within each guild (Dugger et al., 2007; Fredrickson & Reid, 1988; Gross et al., 2020). Southern naiad (*Najas guadalupensis*), wild celery (*Vallisneria americana*), coontail (*Ceratophyllum demersum*), sago pondweed (*Potamogeton pectinatus*), and Eurasian watermilfoil (*Myriophyllum spicatum*) are all important waterfowl resources found in Back Bay with varying degrees of tolerance to turbidity and salinity (Carter et al., 1983; Carter & Rybicki, 1991; Chamberlain, 1948; Tiner & Rorer, 1993) and varying degrees of true metabolizable energy for waterfowl (Gross et al., 2020). Moreover, diving ducks such as bufflehead (*B. albeola*) and

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mergansers (hooded [*L. cucullatus*] and red-breasted [*Mergus serrator*]) may be more tolerant of higher salinity conditions due to their ability to dive for marine crustaceans and molluscs (Perry et al., 2007). The specific diet and energy requirements of species within and across guilds may explain the negative associations expressed by the model (Guillemain et al., 2000); however, species-specific foraging dynamics were not included in our analysis and this hypothesis, therefore, cannot be explicitly supported or contradicted here. Characterization of SAV species based on salinity tolerance or energy value constitutes an important next step in investigating the strength of this driver in Back Bay.

Informants also discussed behavioural changes in foraging behaviour and interspecific and intraspecific interactions between waterfowl as rationale for the different responses predicted amongst the guilds. For instance, swans and geese appear to have adapted to the lack of SAV in Back Bay by shifting their foraging behaviour in parallel with changes in the landscape. The state migratory bird program manager noted that, in the early data, 'swans were really tied to SAV in Back Bay … but this association has diminished over the last 20–30 years, as more land in the region has been converted to agriculture and tundra swan (*C. columbianus*) have increased their field feeding. The tendency of dabbling ducks to increase in abundance in higher turbidity conditions with greater SAV may occur as a function of reduced competition with diving ducks and swans and geese as their abundances decrease under those same conditions. When asked about the potential of food source competition between guilds, participants provided mixed responses on the reasonableness of this explanation. While informants agreed that dabbling duck abundance is more strongly correlated to SAV than are the other two groups, niche breadth and overlap may also play a role in determining guild prominence in Back Bay (Bethke, 1991; Giustino et al., 2017; Lamb et al., 2020).

While speculative responses from participants offer interesting routes for future research, the specific conclusions drawn cannot be explicitly supported within the scope of our study. What can be concluded, however, is that there is sufficient belief, derived from the analysis of government datasets and site-specific subject matter expertise, that dabbling ducks in Back Bay respond differently to changes in SAV abundance than do other guilds in high and low conditions of salinity and turbidity. As wildlife and natural resource managers continue to evaluate the threat of regional watershed changes to waterfowl populations in Back Bay, conservation measures related to water quality and SAV abundance should be approached from a guild standpoint to account for the nuanced responses between dabbling ducks, diving ducks and swan and geese.

5 | CONCLUSIONS

Research designed to reduce uncertainties associated with specific management decisions is vital for advancing waterfowl conservation. The links between waterfowl populations, habitat and human dimensions are similarly important facets of the conservation decision framework, as the establishment of like priorities across stakeholders is key in environmental management. Our research revealed that managing aquatic ecosystems for one guild of waterfowl is unlikely to suit the needs of all three. It is therefore recommended that natural resource managers across migratory flyways aim to establish conservation goals with a clear focus on which guild or guilds require the most support from local resources. Future research on the species-specific relationships between aquatic vegetation and waterfowl community composition in Back Bay may serve to further support conservation goals along the greater Atlantic Flyway.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

C.S. and L.M. conceived ideas and contributed to the acquisition and management of data. C.S., J.A-G., and Y.M. designed the methodology and analysed the data. C.S. and J.A-G. led the writing of the manuscript, with support from all co-authors. All authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.jh9w0vtbd (Sibilia et al., 2022).

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