Norton Sound red king crab stock assessment

Appendix A: History of Acceptable Biological Catch buffers and rationales, risk table, and ecosystem considerations

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History of Acceptable Biological Catch buffers and rationales

Table 1: History of Acceptable Biological Catch (ABC) buffers and buffer justifications for the Norton Sound red king crab stock. Source: Crab Stock Assessment and Fishery Evaluation (SAFE) Report Introductions, https://www.npfmc.org/library/safe-reports/.

Year	ABC buffer	Justifications
2021	40%	- status of the stock (few legal males in the system) - overfishing limit based on legal crab rather than retained size of crab
2022	40%	- natural mortality and size-at-maturity are borrowed from other stocks - impact of seasonal movement on survey estimates - uncertainty in stock vs. survey areas - shortage of discard data on which to base estimates of total catch mortality - absence of standardized CPUE for 2020 and 2021 - discrepancies in Alaska Department of Fish & Game and National Oceanic and Atmospheric Administration Northern Bering Sea survey estimates - some parameters at bounds - overestimation of proportion of large crab - very high natural mortality in largest size class - retrospective patterns - new information on barren females in surveys not presented
2023	30%	- same justifications as for 2022 with the exception of the concern about information on barren females, which was not mentioned in 2023
2024	30%	- natural mortality and size-at-maturity are borrowed from other stocks - impact of seasonal movement on survey estimates - uncertainty in stock vs. survey areas - lack of information about discards - overestimation of the abundance of the largest male crab - use of a higher natural mortality value for larger males in order to correct for this overestimation rather than using a size-independent natural mortality - retrospective pattern in model-estimated mature male biomass
2025	30%	- natural mortality and size-at-maturity are borrowed from other stocks - impact of seasonal movement on survey estimates - uncertainty in stock vs. survey areas - shortage of discard data on which to base estimates of total catch mortality - estimates of total catch mortality rely on ad hoc methods to estimate discards - overestimation of the proportion of large crab - whether high estimate for M in largest size class is reasonable remains unresolved

Risk table

Introduction

The following table was used to complete the draft risk table.

	Assessment-related considerations	Population dynamics considerations	Environmental/ ecosystem considerations	Fishery performance
Level 1: No concern	Typical to moderately increased uncertainty/minor unresolved issues in assessment	Stock trends are typical for the stock; recent recruitment is within normal range	No apparent environmental/ ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: major concern	Major problems with the stock assessment; very poor fits to data; high level of uncertainty; strong retrospective bias	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns	Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 3: extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable	Stock trends are unprecedented; more rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. The four types are stock assessment, population dynamics, environmental/ecosystem, and fishery performance considerations. Examples of concerns relevant for each consideration type include the following (Dorn and Zador 2020):

1. Assessment considerations: data-input concerns such as biased ages, skipped surveys, or the lack of fishery-independent data; model fit concerns such as poor fits to fishery or survey data or the inability to simultaneously fit multiple data inputs; model performance concerns such as poor convergence, multiple minima in the likelihood surface, or parameters hitting bounds; estimation uncertainty concerns such as poorly-estimated but influential year classes; retrospective bias in biomass estimates.
2. Population dynamics considerations: decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.
3. Environmental/ecosystem considerations: adverse trends in environmental/ecosystem indicators or ecosystem model results; changes in ecosystem productivity, prey abundance or availability, predator abundance, or productivity.
4. Fishery performance: fishery CPUE showing a pattern different from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in fishery opening duration.

Summary and ABC recommendations

The assessment authors recommend using the same ABC buffer as in 2025, 30%. While ongoing concerns in the "Assessment-related considerations" category lead to a risk level 2, those concerns have not changed since the previous assessment, and one of the key concerns may be addressed if one of the models using a spatiotemporally standardized index of abundance is chosen for harvest specifications. All other categories were scored as risk level 1. Data collected in Norton Sound in 2026 showed water pH values below 8, which are known to reduce survivorship for juvenile Bristol Bay red king crab. However, further research is needed to determine where juvenile Norton Sound red king crab are located, the water pH values at these locations, and whether the impact of pH values below 8 on juvenile survivorship is similar between the Norton Sound and Bristol Bay red king crab populations.

Table 2: Summary of risk-table considerations and concern levels for Norton Sound red king crab.

	Assessment-related considerations	Population dynamics considerations	Environmental and ecosystem considerations	Fishery performance
	Level 2: increased concern	**Level 1: normal**	**Level 1: normal**	**Level 1: normal**
long term or persistent	Natural mortality and size-at-maturity are borrowed from other stocks. Estimates of total catch mortality rely on ad hoc methods to estimate discards due to shortage of discard data. The impact of crab seasonal movement on survey estimates is unknown. The area historically used for estimating stock abundance from survey data may not capture the full range of the stock. Overestimation of the proportion of large crab is corrected for by estimating a higher M for large males but whether this approach is reasonable remains unresolved.	Stock trends appear to be typical for the stock. Recruitment has been low but increasing since 2022.	In general, there is a lack of a mechanistic understanding for the direct and indirect effects of ecosystem indicators on the survival and productivity of NSRKC. Prey conditions for pelagic crab were favorable in 2025 and 2026. Indirect evidence of prey for benthic crab stages was poor in 2025. Competition for pelagic prey resources was average in 2026 and low for benthic prey resources in 2025. Pelagic predation pressure was above average in 2023-2026 from jellyfish and average from pollock in 2025-2026. Benthic predation pressure from Pacific cod was below average in 2025. Modeled pH continues to decline.	Fishery-informed indicators are included in the assessment. Catch per unit effort was above the average for the period following implementation of super-exclusive fishery regulations (1994-present) in 2022-2026.
	no change	**no change**	**no change**	**no change**
current	If one of the models using a spatiotemporally standardized index of abundance is chosen for harvest specifications, this would address the concern about the mismatch between the stock range and the area over which abundance is estimated. A new concern is that no new fishery-independent survey data were available in 2026.	Mean weight in the summer commercial fishery retained catch was the highest in the time series. The % of males in the retained catch in the largest size bin was the highest in the time series at 34% and had previously exceeded 20% only in 1981 and 1982. Drivers of this pattern are unknown but could include reduced natural mortality on large males or greater availability of large males to the fishery due to changed movement patterns.	Summer SSTs were near-average January-June 2026; July and August SSTs were above average; September SSTs returned to average. The EBS shelf had an extensive cold pool in summer 2026. Both modeled and measured pH in Norton Sound were low in 2026, which could negatively impact juvenile survivorship.	While the ABC was exceeded in 2026, this was due to a larger than expected catch in the time between the fishery closure annoucement and the fishery closure. The risk of overfishing is not expected to be greater than normal in future years.

Details

Assessment considerations

Historical considerations: Risk level 2: increased concern

Current considerations: no change

As noted in the ABC buffer justifications for 2022-2025, uncertainty exists about the overlap between the stock and survey areas. The ADF&G and NOAA NBS trawl survey abundance estimates that were used in the 2025 stock assessment model were calculated over a spatial area that encompasses much of the historical harvest but likely not the complete distribution of the stock, meaning that survey abundance estimates may not accurately capture stock abundance. Work on developing a model-based index that unites information from the ADF&G and NOAA NBS trawl surveys while predicting abundance over an area that better represents the stock distribution is presented in Appendix B, but has not yet been included in a stock assessment model accepted for harvest specifications. If one of the models using a spatiotemporally standardized index of abundance is chosen for harvest specifications, this would address concerns about the mismatch between the stock range and the area over which abundance is estimated.

Other recurring concerns for the assessment include the lack of information about discards in the directed fisheries due to the lack of observers, and the use of a higher natural mortality value for large males in order to correct for the model's overestimation of the abundance of the largest male crab. Planned work on spatiotemporal model-estimated size compositions may help to address the historical overestimation of large male crab abundance.

Population dynamics considerations:

Historical considerations: Risk level 1: normal

Current considerations: no change

Recruitment estimates for the most recent years were low relative to the historical time series but have been increasing since 2022. The collection of fishery-independent survey data in 2027 would reduce uncertainty about a potential increase in recruitment. Average weight for the summer commercial fishery retained catch was the highest in the time series at 3.7 lb and size compositions are atypical for the time series, most closely resembling those from 1980-1982. The increased relative abundance of large male crab could be due to factors including reduced natural mortality on the larger size classes or increased availability of large males to the commercial fishery due to alterations in movement patterns. Currently available data do not allow for discrimination between these possibilities. The collection of fishery-independent survey data in 2027 would be helpful in understanding the unusually high relative abundance of large males in the population.

Environmental/ecosystem considerations:

Historical considerations: Risk level 1: normal

Current considerations: no change

Ecosystem indicators are organized into several categories to capture the scope of considerations available in the ESR:

Environmental Processes: During winter 2025-2026 (Dec 2025 - Mar 2026), the Aleutian Low Pressure Index was weak, which tends to result in fewer storms and weaker winds (Overland & Wang 2026, in Siddon 2026, in press). Sea ice extent was below average through February 2026 (ice advanced over residual warm SSTs), then winds from the Arctic during March/April led to record ice extent (for 6 weeks), but ice was thin (Thoman 2026, in Siddon 2026, in press). Sea-ice thickness in the Bering Strait and Norton Sound was above average in 2026. Bering Strait shifted to thicker ice in 2021, while ice thickness in Norton Sound has been more variable, but average to above average since 2020 (Thoman 2026, in Siddon 2026, in press). Along-shelf winds in May-August 2026 favored off-shelf transport. Norton Sound red king crab larvae are present in the water column as swimming zoeae from mid-April to mid-June, therefore off-shelf transport may have dispersed

pelagic crab stages away from suitable benthic habitat (Hennon 2026, in Siddon 2026, in press). Summer sea surface temperatures (SSTs) were near-average January-June 2026; July and August SSTs were above average, but not warm enough to trigger marine heatwave status; September SSTs returned to average (Callahan and Lemagie 2026, in Siddon 2026, in press). Summer bottom temperatures in Norton Sound were >2°C based on MOM6 modeled temperatures (no observed survey temperatures are available for 2026) (Kearney 2026, in Siddon 2026, in press). The summer 2026 cold pool extent was > 1 SD above the time series mean and was the largest 2°C cold pool since 2012 (Rohan 2026, in Siddon 2026, in press). The NMME ensemble forecasts as of October 8, 2026 for November 2026 to January 2027 show cool SST anomalies over much of the SEBS shelf and NBS (-0.5 - 0°C) (Lemagie 2026, in Siddon 2026, in press; forecast will be updated for final ESR).

Modeled pH continued to decline in 2026, driven by strong low pH values near the Yukon River delta and in Norton Sound. Corrosive bottom waters could negatively impact NSRKC growth, shell hardening, and survival (Pilcher et al., 2026, in Siddon 2026, in press).

In 2026, ADF&G staff collected pH data from water samples in the field (Jenefer Bell, ADF&G, unpublished data), which could help corroborate and validate the modeled pH results. Samples were collected at station 2, east of Nome, and station 6, west of Nome (Figure 1), using a HOBO® pH and temperature data logger. Measured pH was consistently below 8 at both stations, though closer to 8 at station 2 than at station 6 (Figures 2 and 3). Laboratory research on Bristol Bay red king crab indicated that survivorship is lower among juveniles raised at pH 7.8 compared to those raised at pH 8.04, while no juveniles raised at pH 7.5 survived longer than 3 months (Long et al. 2013). The authors are unaware of similar experiments conducted using Norton Sound red king crab, and the possibility remains that Norton Sound red king crab have different responses to pH than Bristol Bay red king crab. However, these laboratory results combined with the pH data collected in 2026 raise concerns about the survivorship of juvenile red king crab in Norton Sound, and further research on this topic is needed.

Prey: Diatom abundance anomalies, based on the Continuous Plankton Recorder, remained positive from 2023 through 2025 (Ostle & Batten 2026, in Siddon 2026, in press), indicating above-average feeding conditions for pelagic crab stages. Satellite chlorophyll data showed an early spring bloom associated with ice retreat. Spatially, large areas with ice associated blooms occurred over the shelf; ice associated blooms tend to lead to higher deposition of algae to the seafloor, indicating good feeding conditions for benthic crab stages (Nielsen 2026, in AFSC Spring PEEC 2026; Gann & Callahan 2026, in Siddon 2026, in press). No direct metrics of benthic prey are available. Yellowfin sole are small-mouthed benthic foragers and can serve as a proxy for benthic prey conditions. In 2025 (most recent bottom trawl survey in the NBS), yellowfin sole biomass was >1 SD below the time series mean (2010, 2017, 2019, 2021-2023, 2025) (NBS Report Card in Siddon 2026, in press) and their condition (based on length-weight residuals) was below average (Prohaska & Rohan 2026, in Siddon 2026, in press), which suggests poor benthic prey conditions in the NBS in 2025. Taken together, feeding conditions for pelagic crab stages have been favorable in 2025 and 2026. Indirect evidence of prey for benthic crab stages were poor in 2025.

Competitors: Abundances of small and large copepods in the NBS were average in late summer 2026, suggesting pelagic competition for prey resources was average in 2026 (Kimmel et al. 2026, in Siddon 2026, in press). In 2025, yellowfin sole biomass was > 1 SD below the time series mean (2010, 2017, 2019, 2021-2023, 2025) (NBS Report Card in Siddon 2026, in press) which suggests competition for benthic prey resources remained low in 2025.

Predators: Jellyfish biomass in the NBS has been above average from 2023 through 2026 (Domke et al., 2026, in Siddon 2026, in press) suggesting above average pelagic predation pressure. Pollock biomass was average in the 2025 NBS survey (NBS Report Card in Siddon 2026, in press) but, in 2026, the southern Bering Sea index for pollock increased 58% from 2025 (SEBS Report Card in Siddon 2026, in press). Pacific cod biomass was below average in the 2025 NBS survey (NBS Report Card in Siddon 2026, in press) but, in 2026, the southern Bering Sea index increased 17% from 2025 (SEBS Report Card in Siddon 2026, in press). Pacific cod condition in the NBS in 2025 was just below average (Prohaska & Rohan 2026, in Siddon 2026, in press).

Fishery performance:

Historical considerations: Risk level 1: normal

Current considerations: no change

Total fishing mortality in 2026 was 338,628 lb (0.154 kt), above the ABC of 298,000 lb (0.135 kt) but below the OFL of 426,000 lb (0.193 kt). Crab per pot lift (catch per unit effort, CPUE) in the summer commercial fishery was down 11% from 2025, and was 10% below the time series mean. The Guideline Harvest Level (GHL) of 268,000 lb was exceeded by 16.8%. An unexpected increase in catch at the end of the 10-day fishery, during the period between the fishery closure announcement on 23 June 2026 and the closure at noon on 25 June 2026, contributed to this overage. The OFL was not exceeded so overfishing did not occur. The risk of overfishing in future years is not thought to be elevated.

Literature cited

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Figures

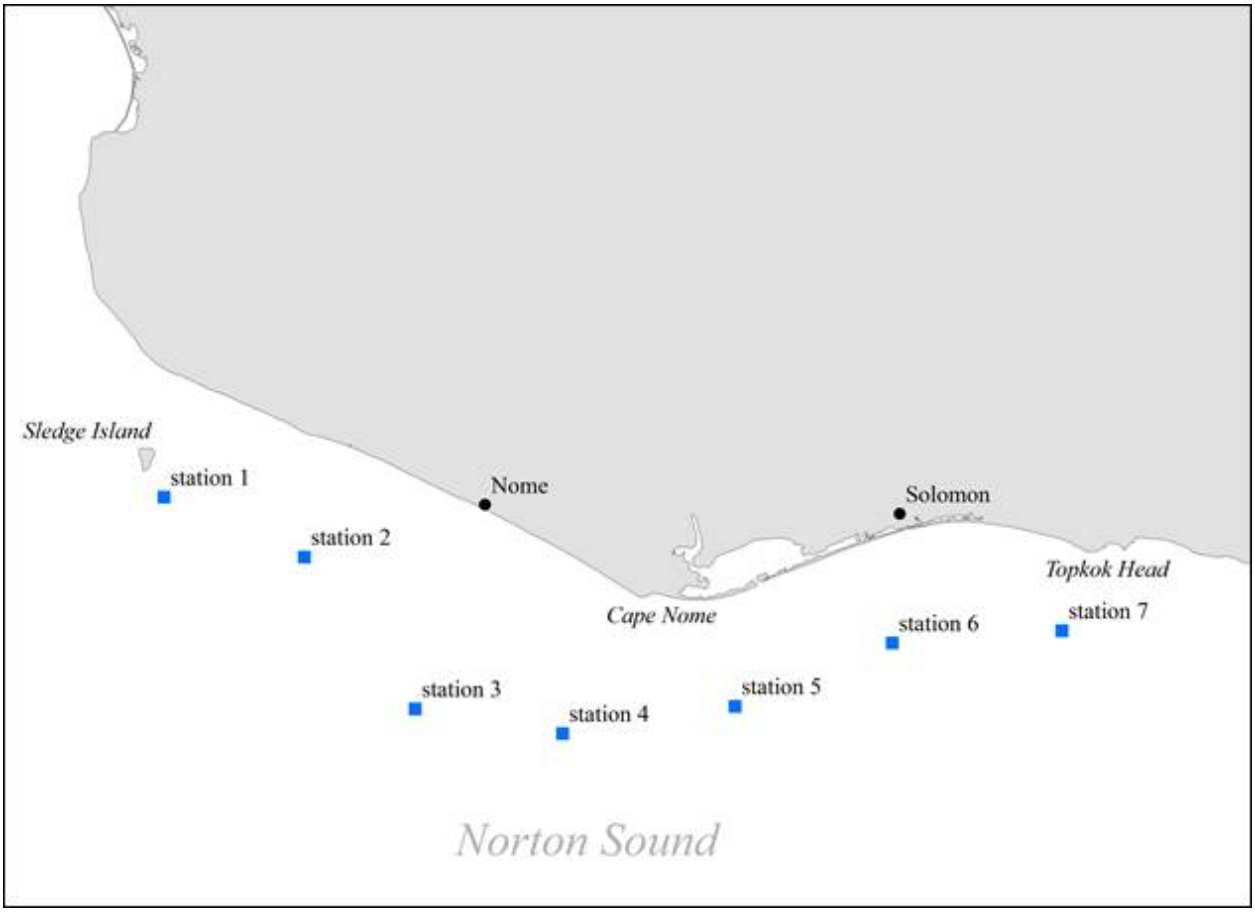


Figure 1: Stations at which ADF&G collected data relevant to Norton Sound red king crab in 2026. Water pH was measured at stations 2 and 6.

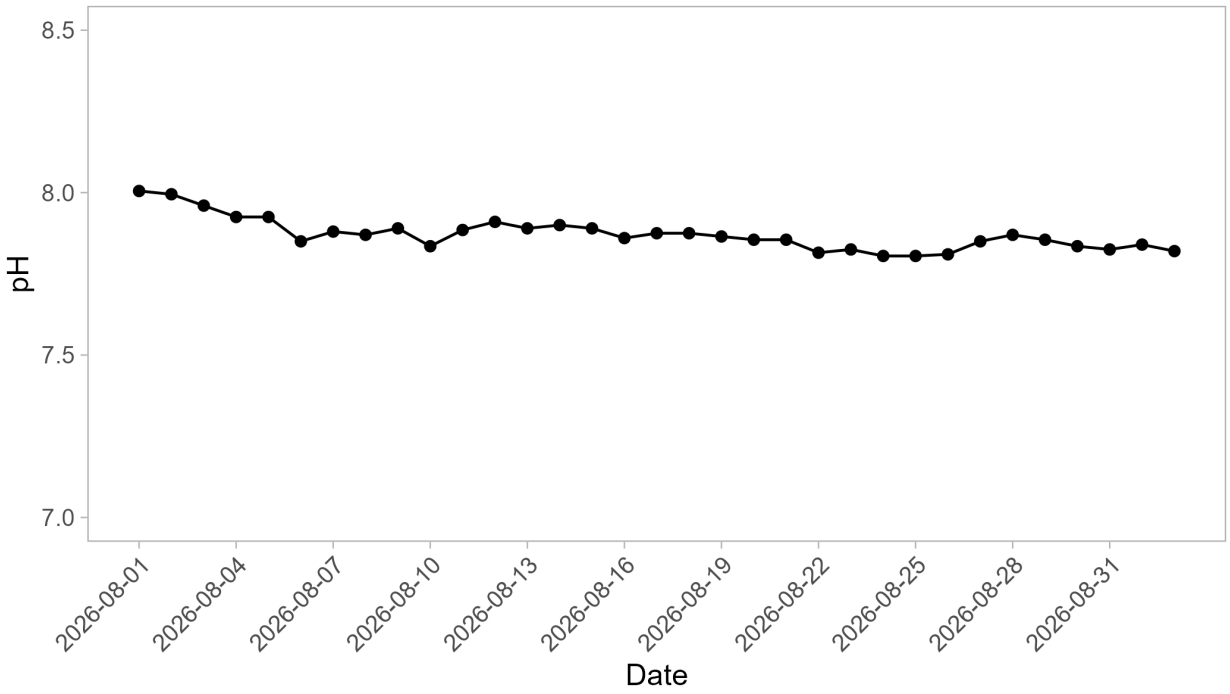


Figure 2: pH measurements collected by ADF&G staff in 2026 in Norton Sound at station 2.

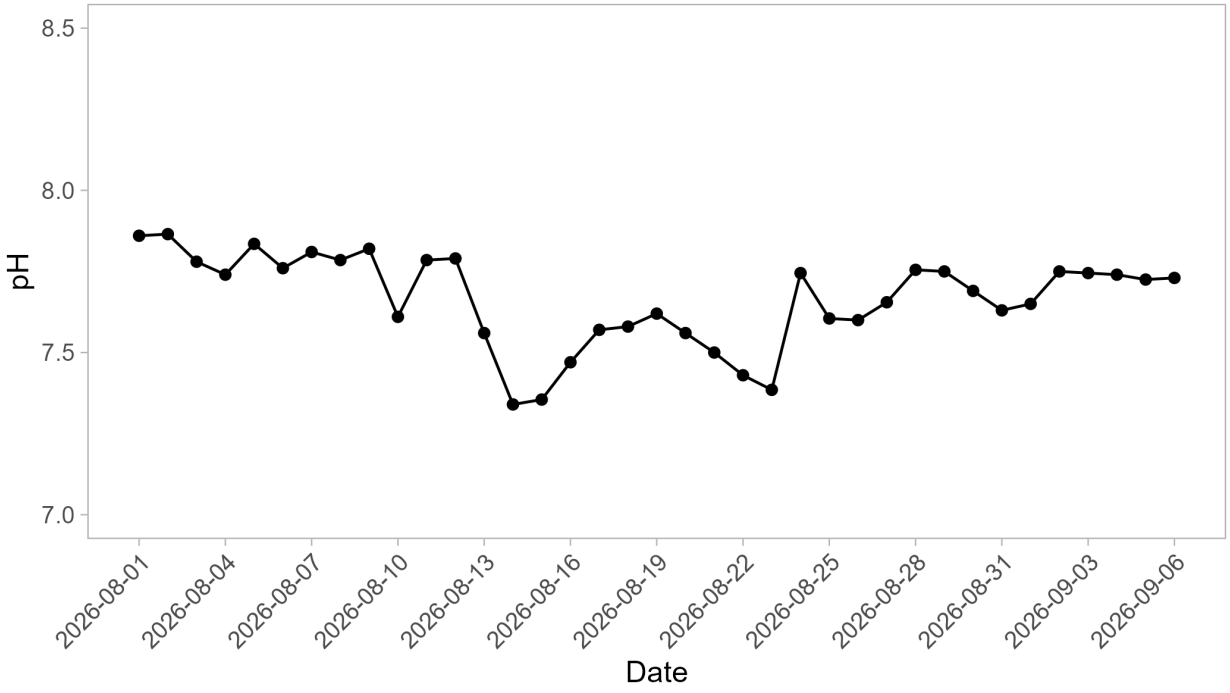


Figure 3: pH measurements collected by ADF&G staff in 2026 in Norton Sound at station 6.