2021 State of the Damariscotta River Estuary Report

Local knowledge of trends in the shellfish resource and human activity in the Damariscotta River Estuary

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Presented to the Damariscotta-Newcastle Joint Shellfish Committee
October, 2021

Land Acknowledgement

The Darling Marine Center recognizes that it is located in South Bristol along the Damariscotta River in the homeland of the Wabanaki Tribal Nations, where issues of water and territorial rights, and encroachment upon sacred sites, are ongoing. The historic Walinakiak Abenaki Tribe and other tribal peoples of the Pemaquid Peninsula area are connected to the modern, consolidated Abenaki Tribal Nation in Quebec and other Wabanaki Tribal Nations—the Passamaquoddy, Penobscot, Maliseet, and Micmac—through kinship, alliances, and diplomacy. The Darling Marine Center recognizes that the Wabanaki Tribal Nations are distinct, sovereign, legal and political entities with their own powers of self-governance and self-determination.

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Other Acknowledgements

We thank M. Lutkus and the staff of the Town of Damariscotta, the Damariscotta-Newcastle Joint Shellfish Committee, B. Marsh, and the Bremen Shellfish Committee, as well as M. Williams and S. Swett of the University of Maine. This work was supported by The Broad Reach Fund: Maine Shellfish Restoration and Resilience Project through an award to the Town of Damariscotta, the NOAA Saltonstall-Kennedy Program through award NA17NMF4270198 to HL and JS, a Diana Davis Spencer Scholars Program award to SR, and friends and donors of the UMaine Darling Marine Center.

** Shared first authorship.*
Cover photo: View of the Chadbourne intertidal area, looking south from the Damariscotta River's western shore, just south of Jack's Point in Newcastle. Photo by Kara Pellowe.

Executive Summary

This project emerged from questions identified by the members of the Damariscotta-Newcastle Joint Shellfish Committee and the Bremen Shellfish Committee and a shared interest in the stewardship of town-managed shellfish resources. Specifically, these municipal leaders requested information on the current status of wild shellfish resources and information on how these resources, and the many human uses of the estuaries, are changing through time. The project represents a partnership between the towns of Damariscotta and Newcastle and the University of Maine Darling Marine Center that began in 2019 (Pellowe & Leslie, 2019). With additional support from the Broad Reach Shellfish Restoration and Resilience Fund, the project expanded in 2020 to include the town of Bremen and the Medomak River Estuary.

This work was supported by multiple sponsors, including local donors to the Darling Marine Center and grants from the Broad Reach Fund, Diana Davis Spencer Partnerships for a Sustainable Maine program, National Science Foundation (NSF), and National Oceanic and Atmospheric Administration (NOAA). In kind support from the Towns of Damariscotta and Bremen, and UMaine's Darling Marine Center also have been vital to our work in the last 18 months.

With this study, we aimed to answer the following questions:

1) What areas are most important for the wild shellfish fishery and farmed shellfish production in Damariscotta River Estuary, and why?
2) How and where do people in the estuaries interact, particularly those involved with aquaculture and the commercial softshell clam fishery?
3) What biological and social changes have estuary users observed and what is driving those changes?

To answer these questions, we conducted a mapping study to document local knowledge about the abundance and diversity of wild-caught shellfish and the spatial distribution of different activities in each estuary. Here we report on the results of the Damariscotta River Estuary study. We found that a wide variety of recreational and commercial activities co-occur in the estuary, particularly in the upper river (see Figure 2, page 5). The upper river also is where clams and other wild-harvested shellfish are most abundant (see Figure 6, page 16). The 28 participants in our study - including harbor masters, shellfish harvesters, aquaculture farmers, conservationists, lobster fishermen and other marine-dependent business owners, and residents who live and recreate on the estuary - have observed substantial changes through time in the magnitude and type of activities that people engage in on and around the waters of the Damariscotta River estuary. These changing patterns of use present both challenges and opportunities for future stewardship of the estuary. As scientists and citizens, we look forward to working with the Joint Shellfish Committee and other community members to support integrated and thoughtful stewardship of the estuary into the future.

Motivation

Intertidal shellfish resources in Maine are co-managed by coastal towns and the Maine Department of Marine Resources (Webber et al., 2021). Towns are responsible for managing the shellfish resources and issuing licenses through their shellfish committees. The towns of Damariscotta and Newcastle jointly manage the intertidal shellfish resources of the Damariscotta and Sheepscot River estuaries. In 2019, the Damariscotta-Newcastle Joint Shellfish Committee initiated a collaboration with scientists at the University of Maine Darling Marine Center to fill data gaps and learn more about the status of the shellfish resource in the Damariscotta River Estuary. They wanted to learn how the shellfish, and the many human uses of the estuary, have changed through time.

To support this objective, UMaine scientists, in collaboration with local harvesters, launched a survey in 2019 of upper river shellfish populations and gathered local knowledge about changes through time. In 2020, due to COVID-19 restrictions, the research team pivoted to documenting local users' ecological knowledge of the estuary using participatory mapping, focusing on abundance, distribution, and diversity of shellfish species, as well as the diversity and spatial distribution of activities. In addition to supporting the integration of local knowledge data and environmental data, this project also highlighted the value of long-term monitoring to inform understanding and management of this rapidly changing estuary system. This project identifies areas where differing species and human activities overlap, which is important for identifying and understanding areas of conflict among user groups in a changing and increasingly crowded estuary. Focusing more broadly than on a single species will help managers weigh tradeoffs among different uses and manage the entire estuary ecosystem in a more integrated, ecosystem-based manner.

Study Area

The Damariscotta River is a 19-mile (30 km) long estuary in midcoast Maine. It is surrounded by seven towns: Boothbay Harbor, Boothbay, Edgecomb, Newcastle, Nobleboro, Damariscotta, Bristol, and South Bristol (Figure 1). The head of the estuary is at the Damariscotta Mills Dam, where Damariscotta Lake empties into Great Salt Bay (Figure 2). Great Salt Bay is a large, shallow salt pond separated from the rest of the river by a constriction and reversing falls between Route 1 and the bridge connecting the towns of Damariscotta and Newcastle (McMahon, 1999). Damariscotta Lake is the primary source of freshwater into the estuary, which is classified as a tidally dominated estuary because the influence of tides is much stronger than the fresh water (Chandler, 2016; McAlice, 1977). The Damariscotta River has several narrow points that separate it into basins and trap water in the upper river, allowing it to warm up. There are many possible division points in the estuary, but the three major ones are, from north to south: at the mouth of Great Salt Bay, Glidden Ledges (between the upper and mid river sections), and Fort Island Narrows (between the mid and lower river sections (Figure 2).

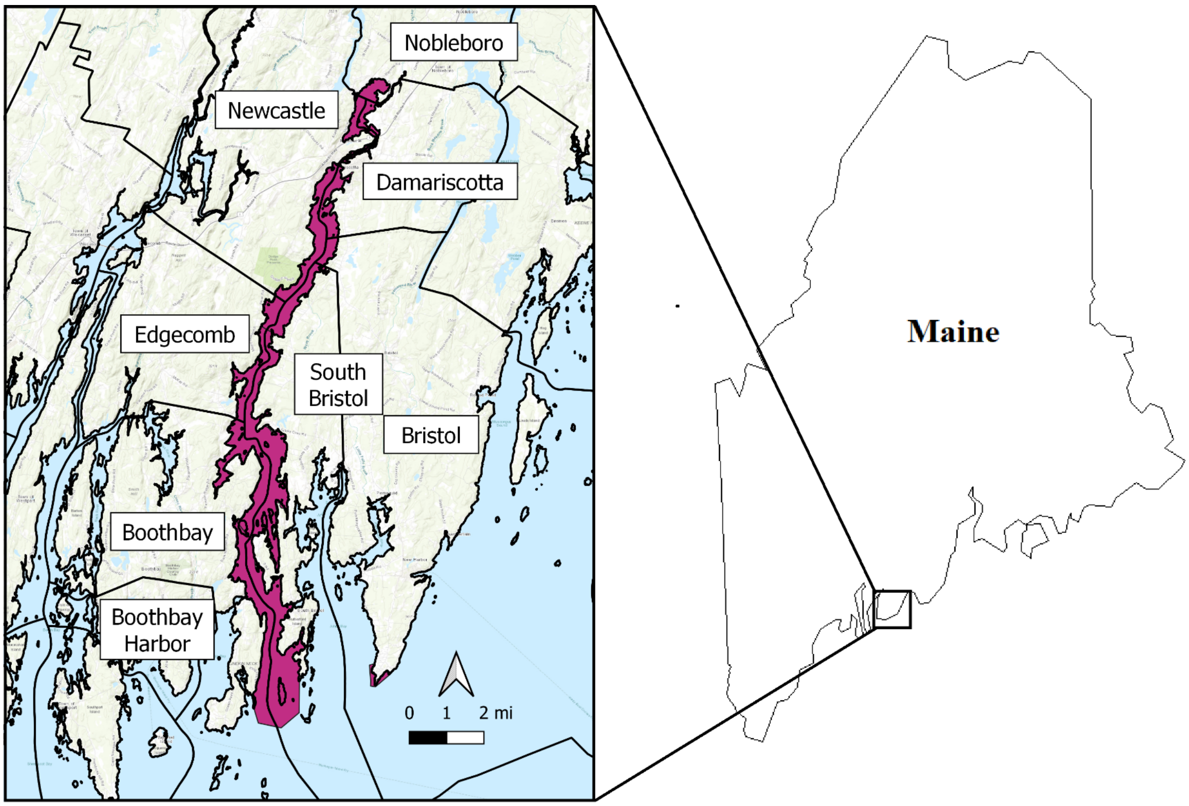

Figure 1: Damariscotta River Estuary and surrounding towns.

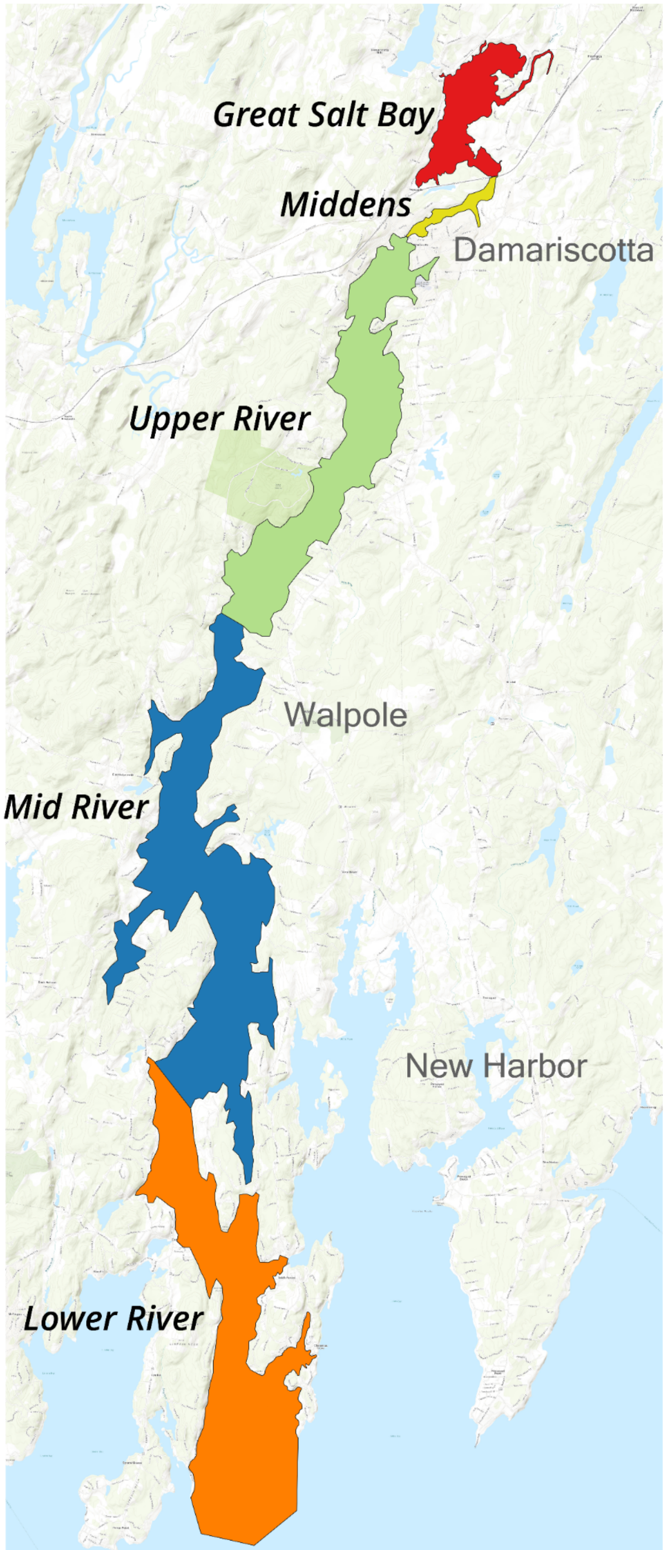

Figure 2: Major basins and areas in the Damariscotta River.

The estuary has moderate to high salinity (19-32 ppt) in the upper section of the river, and full-strength salinity (35 ppt) in the mid and lower portions (Maine EPSCoR, 2019). Great Salt Bay experiences the largest salinity fluctuations - between 1 and 26 psu (McAlice, 1993). The constrictions separating the basins slow the flow of water leaving the estuary and it can stay in the upper river for four to five weeks in the summer (McAlice, 1977). Late summer water temperatures in the upper DRE reach 68-77 °F (20-25 °C), while the lower river reaches 59-68 °F (15-20 °C) (Maine EPSCoR, 2019). This makes the Damariscotta River a very good location for growing some species of shellfish, including softshell clams (*Mya arenaria*), American oysters (*Crassostrea virginica*), and quahogs (*Mercenaria mercenaria*).

The Damariscotta River Estuary is composed of a variety of different marine habitats. The bottom is primarily soft mud and extensive mudflats can be found in the upper river and in protected coves (Anderson et al., 1981; Anderson & Mayer, 1986; Chandler, 2016; Shipp, 1989). Other habitats include eelgrass beds, rocky intertidal, rocky bottom, and salt marshes. Great Salt Bay is distinct from other parts of the river because it is shallow, warmer, and less salty than the rest of the estuary (Chaves, 1997; McMahon, 1999; Petrie, 1975). Most of the Great Salt Bay is a state-designated marine shellfish preserve and is closed to most harvesting (Maine Legislature, 2001). The Damariscotta River has three main intertidal habitat zones: one from Great Salt Bay to the Damariscotta-Newcastle Bridge, the second from the bridge to Miller Island (1.2 km downriver from UMaine's Darling Marine Center), and a third zone from Miller Island to Inner Heron Island at the mouth of the river (Chaves, 1997). The first habitat zone is brackish and has more salt marsh coverage than the rest of the river; the second zone has large intertidal mudflats and experiences a range of salinities; and the third zone has a rocky shore and is primarily marine, with salinities usually over 30 ppt (Chaves, 1997).

The Damariscotta River is home to a wide variety of marine species; see Chaves, 1997 and McMahon, 1999 for detailed descriptions of habitats and species in the river. In this study, participants mentioned commercial species including oysters (American and European), softshell clams, razor clams, quahogs, lobster, crabs, worms, scallops, and elvers. Clams, oysters, and lobsters were discussed most frequently. Participants also discussed non-commercial species including striped bass, mackerel, wild birds, seals, and eelgrass. In total, 83 unique species were mentioned by study participants, highlighting the wide diversity of animal life in the Damariscotta River.

Commercial fishing is common in the Damariscotta River, specifically for American and European oysters, softshell clams, quahogs, razor clams, lobster, menhaden (pogy), alewives, scallops, elvers, and seaweed. Previously, people fished for sea urchins and peekytoe crabs (*Cancer irroratus*). Aquaculture farms grow American oysters, blue mussels, and kelp. Commercial fishing and aquaculture contribute considerably to the local economy. In 2020, the value of publicly available landings of quahogs, softshell clams, razor clams, and lobster from ports in Damariscotta, Boothbay, and South Bristol totaled $5,638,554 (Maine Department of Marine Resources, 2021). Additionally, the 2019 dockside value of oyster aquaculture in Maine was approximately $9.7 million, and 68% of that harvest came from the Damariscotta River (Maine Department of Marine Resources, 2020).

The Damariscotta River is also a popular tourism and recreation destination. Kayaking and paddle boarding are increasingly popular, particularly in the upper river. Likewise, hiking and wildlife viewing from the conserved lands on the shores is popular and became more so during the COVID-19 pandemic (Rice et al., 2020). Recreational motor boating is common throughout the river. The River Tripper, which docks in the Damariscotta village by the Damariscotta-Newcastle bridge, runs daily wildlife and oyster farm tours in the summer, as well.

Methods

Study Participants

A total of 28 people participated in the study, which took place between October 2020 and January 2021. Participants included harbor masters, shellfish harvesters, aquaculture farmers, conservationists, lobster fishermen, other marine-dependent business owners, and residents who live and recreate on the rivers. All individuals needed to have been active and have experience on the river within the last three years to participate. Our study focused on activities like recreational boating or aquaculture (which we refer to as "general use") and commercial shellfish harvesting (which we refer to as "shellfish").

We had 17 participants complete the general use component of the study and 11 complete the shellfish component of the study. All but one of the shellfish survey participants were commercial shellfish harvesters; the other was a recreational harvester. See Table 3 for a breakdown of participant information.

Survey Type	# Participants	Male	Female	Average age	Average years of experience
Use	17	14	3	59	31
Shellfish	11	10	1	55	35

Table 3: Participant demographic information for the Damariscotta River.

Data Integration

Both interviews and maps were used to collect data for this study. Used together, maps and interviews become a powerful tool and are methods that simultaneously support each other. For example, maps - like those shown in Figures 2 and 3 - help to ground interviews in a place and facilitate discussion of specific geographic locations. Interviews provide opportunities to ask clarifying questions about maps and create space for open ended questions that help researchers learn about things that may not have been initially considered in the study. Our plan is to integrate the local knowledge data we have collected with existing environmental data. Overall, maps and interviews are important tools to document local knowledge and can be used to study change in the Damariscotta River Estuary by framing spatial and temporal shifts in shellfish resources, species composition, and human uses of the estuary. For a detailed description of the methods we used, please see Appendix I.

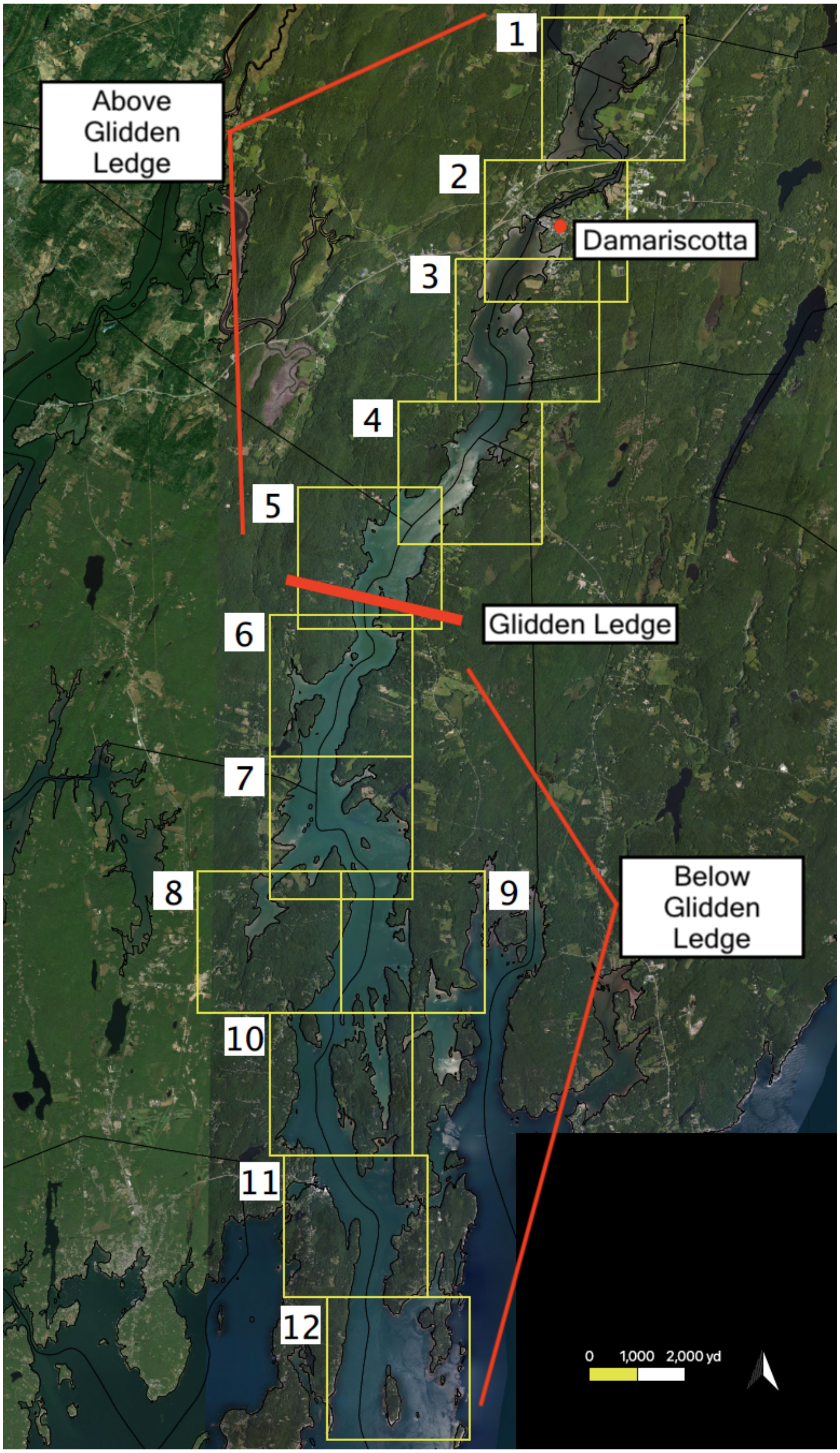

Figure 3: Upper and Lower sections of the Damariscotta River Estuary. Glidden Ledge divides the Damariscotta into two sections (as delineated by the red lines) with distinct characteristics. The numbered squares (1-12) denote the sections of the river where participants were asked to share their knowledge.

Results

Overview of Activities

The Damariscotta River Estuary is a unique estuary ecosystem that is home to a diversity of commercially important marine species and vibrant wildlife. It is also an ecosystem that supports a great range of human uses, from recreational activities to commercial industries and marine livelihoods. According to study participants, much of the river activity and use are concentrated in the upper river, near the Damariscotta-Newcastle bridge and Hog Island (Figure 5). Below we describe the types of activities identified through the local knowledge mapping study.

Commercial Fishing

The Damariscotta hosts several commercial fisheries that help to support local coastal economies. According to participant interviews, the two most cited fisheries include the lobster fishery (*Homarus americanus*) and the shellfish fishery targeting softshell clams (*Mya arenaria*), razor clams (*Ensis directus*), quahogs (*Mercenaria mercenaria*), and wild oysters (both European and American/Eastern oysters, *Mytilus edulis* and *Crassostrea virginica*). Other species that are targeted commercially include scallops (*Placopecten magellanicus*), worms (*Glycera dibranchiata and Nereis diversicolor*), crabs (*Decapods gen.*), Atlantic menhaden (or pogey, *Brevoortia tyrannus*), periwinkles (*Litorina*), and historically, green urchins (*Strongylocentrotus droebachiensis*).

Study participants observed commercial shellfishing primarily above Glidden Ledge, with only some activity occurring below Glidden Ledges (Figure 3). Other commercial fishing, like lobstering, was observed more frequently below Glidden Ledges, although commercial fishing activity was common throughout the whole river. Bait fishing, targeting menhaden/pogeys, was noted throughout the whole river and below Glidden Ledges (Figure 3).

According to Maine Department of Marine Resources landings data for 2019-2020, lobsters were the species with the highest landings by volume in the Damariscotta, followed by oysters (largely from aquaculture), menhaden, softshell clams, quahogs, crabs, and razor clams (Table 4). From 2019-2020, the number of lobster harvesters ranged from 85-89, 24-31 for oysters, 8-9 for quahogs, 25-42 for softshell clams, 3 for menhaden, and 6 for razor clams. Lobster was the highest value fishery, as well (Table 4).

Year	Species	Avg Annual Live Pounds Weight	Avg Annual Value	# Of Harvesters (range, among yrs.)
2019-2020	American Lobster	1,090,070	$ 5,049,279.59	85-89
2019-2020	Eastern / American Oyster	976,380	$ 2,553,218.62	24-31
2019-2020	Quahog / Hard Clam	30,054	$ 77,184.36	8-9
2019-2020	Softshell Clam	26,991	$ 55,577.90	25-42
2019-2020	Atlantic Menhaden	36,100	$ 9,783.10	3
2019-2020	Atlantic Clam Razor	579	$ 2,138.50	6

Table 4: *Average landings and values for fisheries in the Damariscotta River Estuary from 2019-2020. Averages were taken to account for fluctuations between years. The ports of Damariscotta, Newcastle, and Edgecomb were included in the totals for all species, excluding lobster. Lobster weight, value, and harvester number came from DMR landings data for South Bristol only. It should be noted that aquaculture accounts for most oyster landings and value. Data source: Maine DMR Landings webpage portal (https://mainedmr.shinyapps.io/Landings_Portal/).*

Aquaculture

In the Damariscotta, as of spring 2021, there are 29 active or pending aquaculture leases totaling approximately 162 acres (Table 5). Seventeen aquaculture farms manage these leases. There are 69 total active limited purpose aquaculture or LPA sites on the river currently. Study participants noted that aquaculture activity was most common above Glidden Ledges but was observed throughout the whole river. According to estimates provided by local experts and participants of the Damariscotta aquaculture industry, approximately 87-92 people are employed by aquaculture operations in the estuary.

Number of Farms (A/P/S/E)	Number Aquaculture Leases (S and E)	Total Lease Acreage	Total LPA Sites (A)	# Of People Employed (*estimated average for 2020-2021*)
17	29	~ 162	69	87-92

Table 5: *Information on aquaculture in the Damariscotta. Data were pulled from the State of Maine webpage on May 25, 2021, when the data had been last updated on April 30, 2021. Active (A) and Pending (P) sites were included in the totals. Each unique lease holder name was counted as an individual farm for these totals. Both Standard (S) and Experimental (E) leases were included in lease number total and total lease acreage. Data source: Maine DMR ArcGIS (https://maine.hub.arcgis.com/datasets/mainedmr-aquaculture-aq-leases/explore?location=43.969520%2C-69.377924%2C13.00) and personal communication with Dana Morse of Maine Sea Grant (August, 2021).*

Recreational Boating & Fishing

The Damariscotta is a waterway buzzing with active recreational boating and fishing use. The river is used for many forms of recreational boating including kayaking, motorboating, sailing, paddle boarding, and other recreational vessels like jet skis. Recreational fishing primarily targets striped bass (stripers, *Morone saxatilis*), as well as other species. The river is also commonly used for hunting, mainly of ducks.

Study participants observed extensive recreational boating activities, particularly kayaking, above Glidden Ledges. However, boating activity, including sailing and kayaking, was also observed throughout the entire river (Figure 4). Recreational fishing activities were commonly observed in the upper river, above Glidden Ledges, and more generally throughout the whole river (Figure 4).

Tourism & Sightseeing

Tourist activities in Damariscotta center around enjoying the river's wildlife and public trails and learning about local oyster aquaculture operations. Specifically, participants mentioned The River Tripper (a recreational tour boat), observing wildlife, swimming, and hiking as the primary tourist activities on or near the river. Study participants noted that tourism activity was most common above Glidden Ledges but does occur throughout the whole river (Figure 4).

Research

There is a long history of marine research activity in the Damariscotta, ranging from efforts led by professional research institutions to community scientists (*learn more about the history of Damariscotta marine research in this storymap by Britsch and Leslie (2021:* https://arcg.is/jLqfq). The Damariscotta is home to several marine research, conservation, and management institutions, including the University of Maine Darling Marine Center, Bigelow Laboratory for Ocean Sciences, Coastal Rivers Conservation Trust, and Maine Department of Marine Resources, among others.

The Darling Marine Center and Bigelow Laboratory for Ocean Sciences together employ well over 150 individuals, in Walpole and East Boothbay, respectively. These institutions provide a range of river-related employment, from employees who work to support the functioning of the facilities on the banks of the estuary, to employees and students whose research centers on the estuary and other coastal and marine ecosystems.

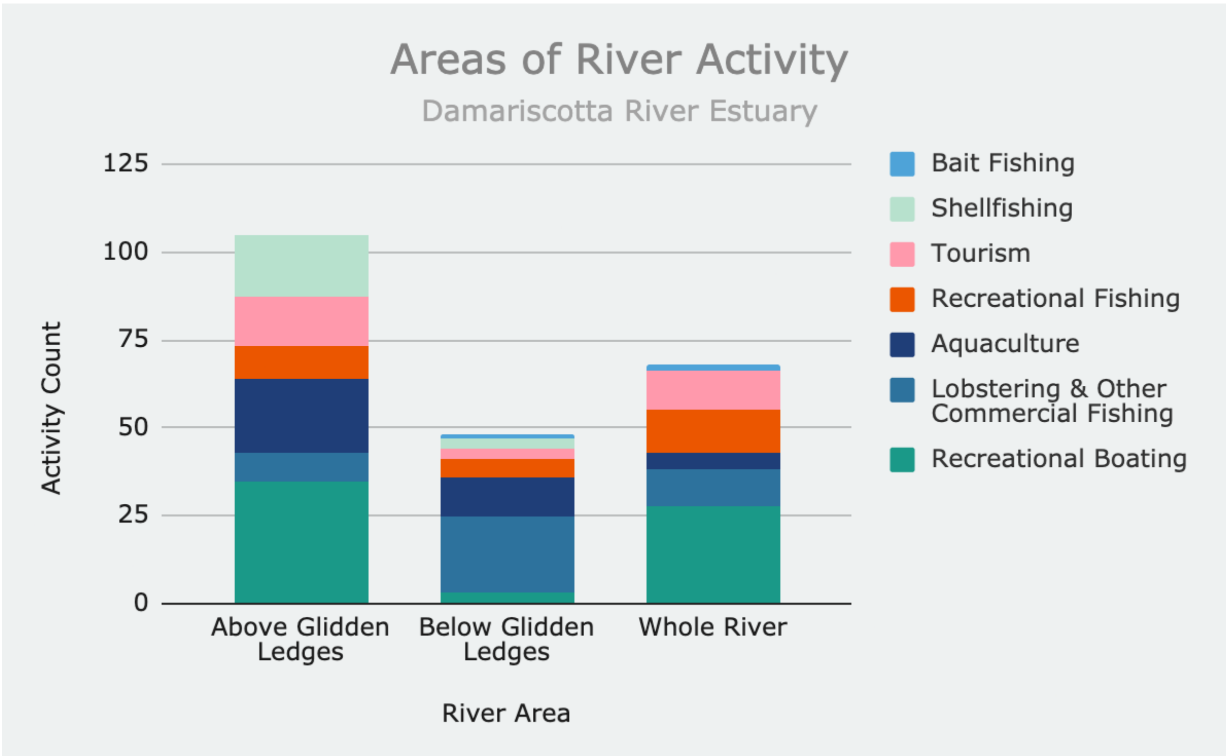

Figure 4: Count of the locations of different activities on the Damariscotta River mentioned by participants.

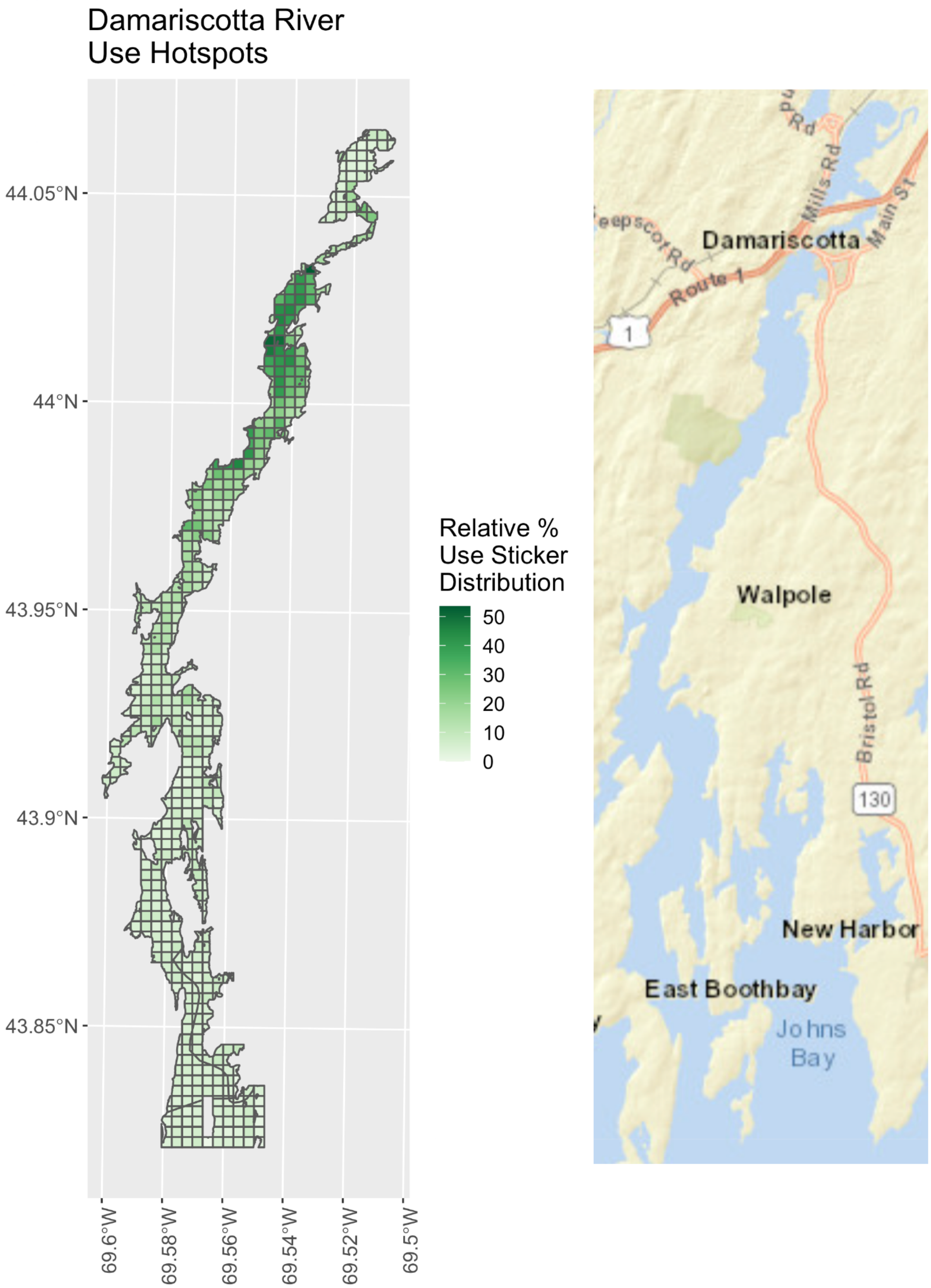

Figure 5: The map on the left shows the distribution of the intensity of human activities in the estuary. We describe how we generated these data in Appendix I. The map on the right is for reference.

Overview of Shellfish Resources in the Damariscotta River Estuary

Maine's intertidal shellfish populations help to support coastal livelihoods and have historically been Maine's second or third most valuable commercial marine fishery (Webber et al., 2021)). In 2020, 6.5 million pounds of softshell clams were landed with a value of $15.7 million in Maine, making it the second highest earning fishery in the state (Maine DMR, 2021b). Regardless, the shellfish fishery is changing and facing new challenges. Warming waters, increases in predator populations, and decreasing waterfront access are factors that are affecting the shellfish resource and fishery (Beal et al., 2018, 2020; Pershing et al., 2015). Therefore, improved knowledge about the state of the shellfish resource in the Damariscotta River Estuary and potential challenges facing the industry is essential for sustainable use and stewardship.

Commercially Targeted Shellfish Species

According to participant interviews with harvesters (n=11), commercial shellfish harvesters in the Damariscotta primarily target wild oysters (*Crassostrea virginica*), softshell clams (*Mya arenaria*), quahogs (*Mercenaria mercenaria*), and razor clams (*Ensis directus*). These species can be found from the low to the high intertidal zone and live in various habitats, ranging from rocky substrates to softer mud (Table 6).

Species	**Habitat**	**Distribution**
American Oyster	Attached to rock or other substrates, often under seaweed or on rocky, shell, and gravel areas of shore.	Upper intertidal zone or low intertidal zone.
Quahog	Sandy, rocky shore. Lives closer to the surface than soft shells.	Mid to low intertidal zone.
Softshell Clam	From soft mud to sandy, rocky areas.	Upper to low intertidal zone.
Razor Clam	Sandy areas or softer mud.	Low intertidal, almost sub-tidal.

Table 6: Habitat and distribution information for shellfish species in the Damariscotta based on interview data (total n=11).

Shellfish Predators & Threats to the Shellfish Fishery

Participants observed the following potential shellfish predators in the Damariscotta: green crabs (*Carcinus maenas*) and other crabs, ribbon worms (milky ribbon worm, *Cerebratulus lacteus*), and boring snails (*Euspira heros*). Participants pointed to aquaculture activity and the introduction of oysters, as well as decreased access (both physical walk-in access to shore and the barrier of license access) and predation pressure as the three most pressing threats to the shellfish fishery.

Shellfish Abundance, Distribution & Diversity

Overall, study participants observed that the Damariscotta, on average, has areas of low and medium clam abundance (Figure 6). Areas with the greatest clam abundance were concentrated around the section of the river near Goose Ledges and Hog Island. It should be noted that many of the study participants were Damariscotta-Newcastle license holders, and therefore are most familiar with softshell clam abundance within the bounds of these two municipalities. This area in the upper river was also identified as a location with the highest shellfish species richness (Figure 7).

Estuary Changes & Trends

The Damariscotta has experienced changes through time that have altered its physical habitat and characteristics, species composition, and human uses. The interview portion of this study offered important information about how this system is changing and the intensity and direction of these changes (see Figure 8 for a summary of these results).

In the Damariscotta, aquaculture activity was the greatest net increase observed by participants, followed by coastal development, motorboating activity, tourism/sightseeing, and kayaking/paddle boarding. Participants also observed a net increase in activity related to the wild oyster fishery. Diminished river access and navigability were the greatest net decreases, according to participants. This was followed by a decrease in the softshell clam fishery, both in fishery activity and harvestable softshell clam populations, and a smaller net decrease in lobstering and other commercial fishing activities.

Study Caveats & Limitations

It should be noted that the study participants were most familiar with, on average, six out of the 12 total river sections (Figure 3). Therefore, observations about activity may not be comprehensive for the entire river. Additionally, 48% of the participants were most familiar with the area above Glidden Ledge and only filled out river sections 1-5, while 52% were familiar with areas spanning both above and below Glidden Ledge. None focused exclusively on the area below Glidden Ledge (Figure 3). As a result, there may be an observation bias towards activities occurring above Glidden Ledge due to a limited number of participants most knowledgeable about the lower portion of the river.

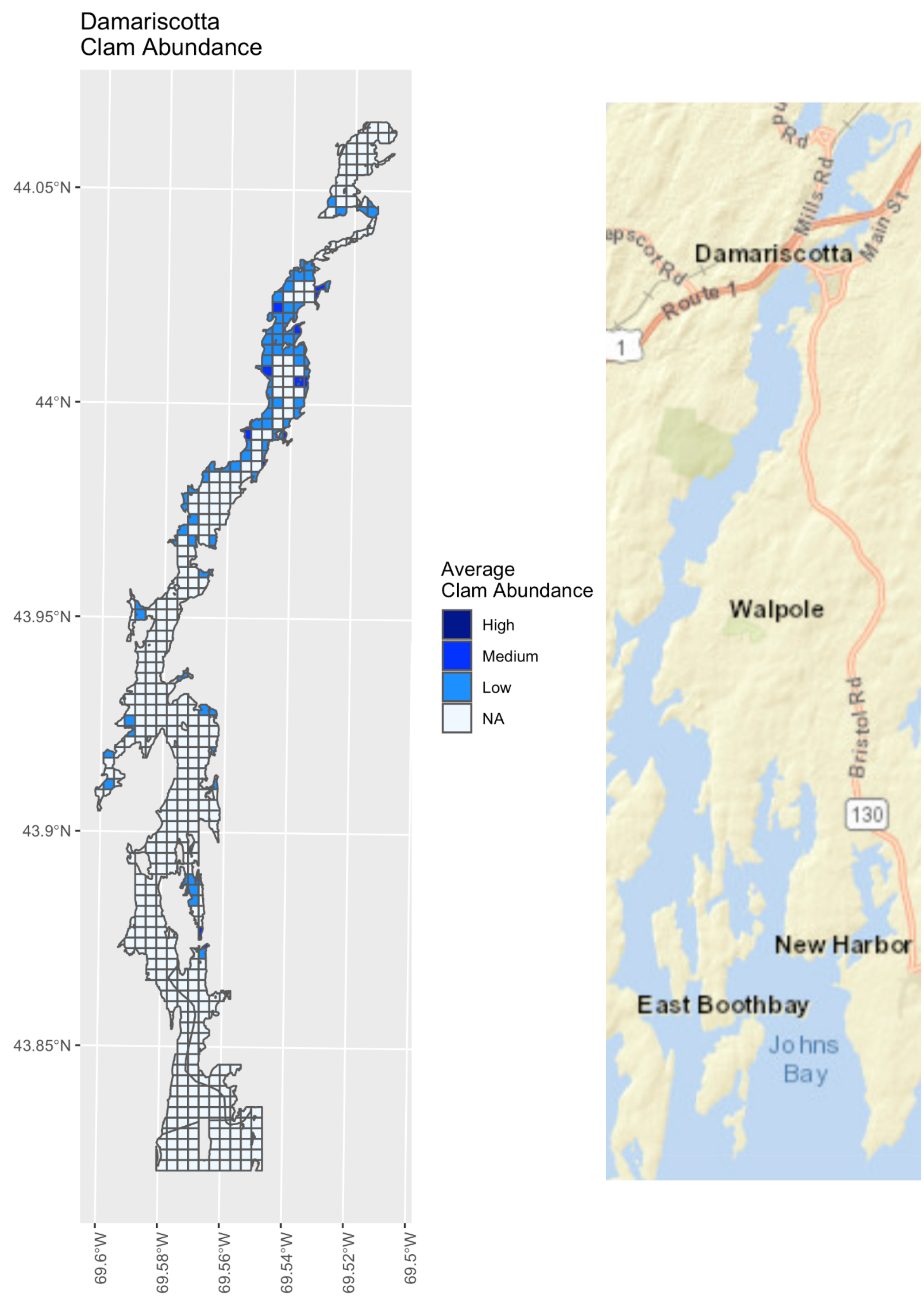

Figure 6*:* The map on the left synthesizes local knowledge of current clam abundance. Participants (n=11) identified areas with high, medium, and low softshell clam abundance. For detailed methods, see Appendix I. The map on the right is for reference.

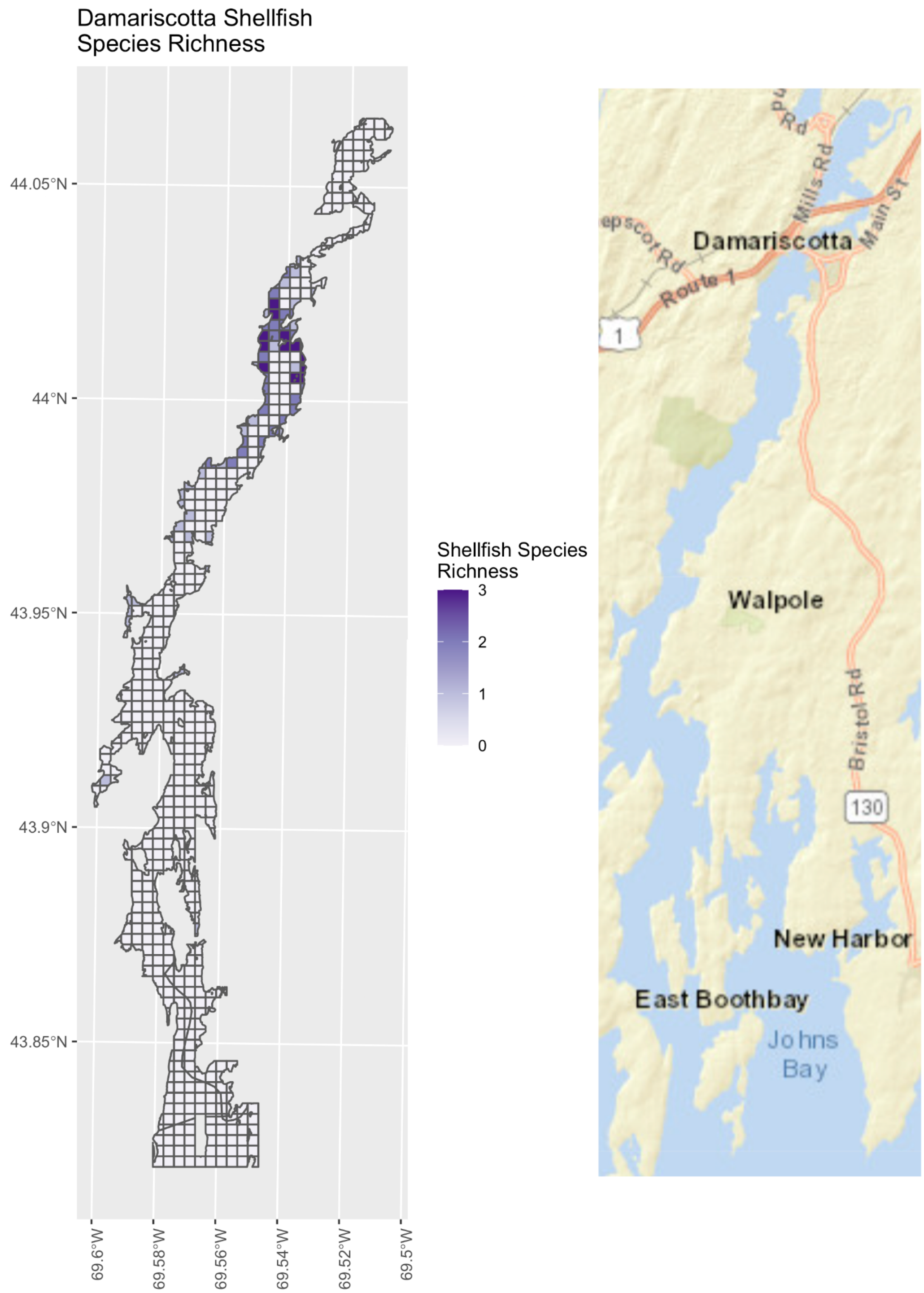

Figure 7*:* The map above (left) shows the shellfish species richness, or number of shellfish species, observed by study participants. Species included softshell clams, wild oysters, razor clams, and quahogs. Only shellfish species that were observed by three or more participants for a particular grid were included in this map. For example, a shellfish species richness score of 3 means that three shellfish species were observed by three or more people in a particular area.

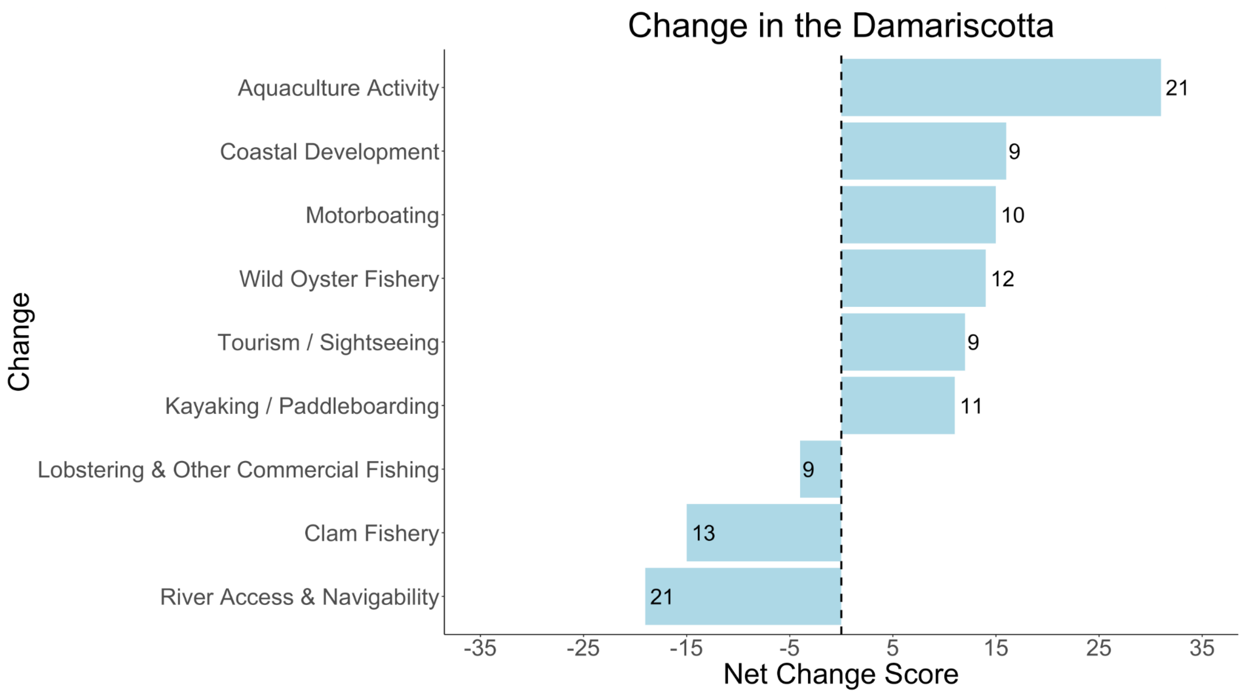

Figure 8: Changes identified by study participants (n=28). The bars show the magnitude (longer bars indicate more significant change) and direction of net change (increase=right of 0; decrease=left of 0) documented by the local knowledge study. For example, if an increase in kayaking was mentioned three times and a decrease in kayaking was mentioned once, the bar would have a value of positive two, taking the sum of these positive and negative values. The number at the end of each bar shows the total number of participants who identified each change and contributed to the net value shown. Each participant contributed one or more mentions to the total net change scores.

Conclusions

This study provided a snapshot of the human activities and how they interact with the ecology of the Damariscotta River Estuary. We also documented, thanks to deep local knowledge, how the social and ecological features are changing through time. We found that this estuary supports a variety of commercial and recreational activities, many of which overlap spatially. We also documented that the upper river is a hub for boating, aquaculture, and wild shellfish harvesting (Figures 5-7).

We interpret our findings with caution and believe that they will be strengthened with additional study in collaboration with harvesters and others in future years. Study participants were most familiar with, on average, six out of the 12 total river sections (Figure 3). Moreover, 48% of participants were most familiar with the area above Glidden Ledge and only completed information for river sections 1-5, while 52% were familiar with areas spanning both above and below Glidden Ledge. No participants focused exclusively on the area below Glidden Ledge (Figure 3). As a result, there may be an observation bias towards activities occurring above Glidden Ledge Additional observations throughout the estuary and particularly below Glidden Ledge are warranted.

This study highlights how important local knowledge is to understanding complex coastal marine ecosystems like the Damariscotta. Study participants observed both fast and slow changes in the estuary, including changes in the abundance of harvested populations, like the softshell clam, and shifts in the type and intensity of human use activities, like sailing and aquaculture. Local knowledge, generated and shared by the individuals who know the estuary best, can contribute to understanding of what is happening in the estuary at temporally and spatially fine scales, the scale at which people are interacting with this dynamic ecosystem.

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Appendix 1: Study Methods

Local knowledge mapping study

We used maps to gather information about overlapping species and human uses in the Damariscotta River Estuary. These were then followed by interviews with all participants.

Participant Recruitment

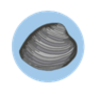
We divided the study into two types: USE, which was oriented towards human use activities like recreational boating or aquaculture, and SHELLFISH, which was oriented towards commercial shellfish harvesting (See Appendix Table 1 for a breakdown of types of participants in each study). All participants needed to have experience with the rivers and be active on the river within the last 2-3 years.

	Study Type	
	USE	**SHELLFISH**
Participants include:	Recreational users	Commercial shellfish harvesters
	Lobster fishermen	Recreational shellfish harvesters
	Aquaculture farmers	Commercial marine worm harvesters
	Harbor masters	Shellfish committee members
	Harbor committee members	
	Local business owners and employees	

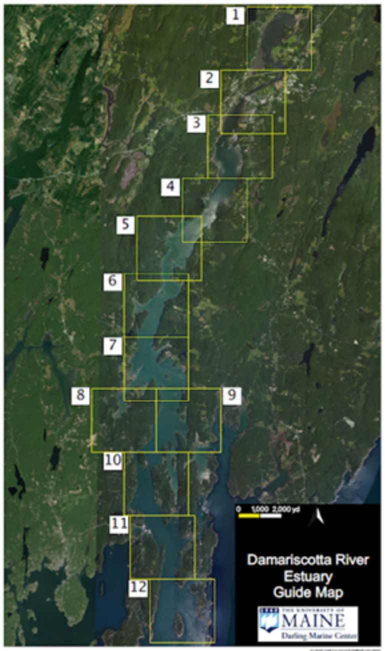
Appendix Table 1: Descriptions of potential participants for each study type.

We identified participants using town recreational and commercial shellfish license lists, state commercial shellfish, lobster, and worm harvesting license lists, and our prior knowledge of people involved in the aquaculture industry, environmental conservation, and waterfront businesses. We prioritized contacting people who live and work in Damariscotta, Newcastle, and Bremen, but also contacted participants from other towns surrounding the estuaries, including Bristol, South Bristol, and Waldoboro. During the initial recruitment phone call, participants were asked about their knowledge and activity on the estuaries; this information was used to determine whether they got stickers related to the USE or SHELLFISH. No map packets were sent unless a potential participant agreed to participate in the study.

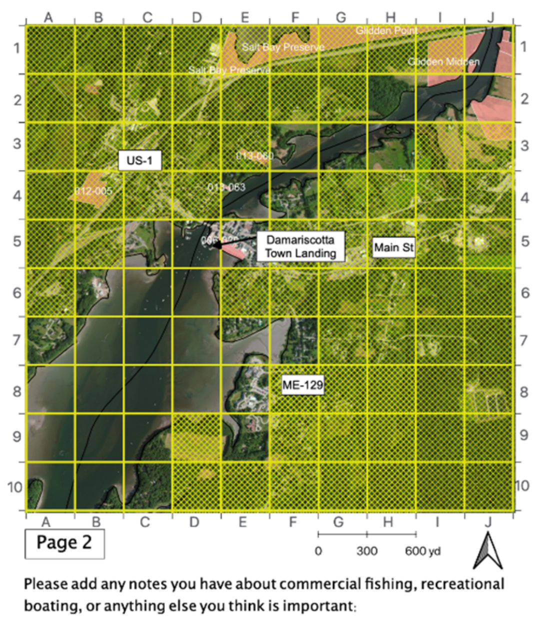
Due to COVID-19 restrictions, we mailed the maps to participants, who filled them out by placing stickers representing different species or uses onto the maps and returned them in the mail. We sent our participants a map packet, stickers corresponding to either shellfish or general use activities, and areas of significant change (Appendix Table 2), and a pen for writing notes. We also sent an overview map showing the entire estuary (Appendix Figure 1) with boxes representing individual pages in the map packet, which divided the river into smaller, zoomed-in sections. We overlaid a grid on each of these map packet pages to help with sticker placement and data entry (Appendix Figure 2). Terrestrial areas and areas with less than 25% water coverage were hashed out to reduce confusion.

Survey type:	**Image**	**Description**	**Survey Type:**	**Image**	**Description**
Use		Aquaculture	**Shellfish**		Softshell clam abundance (low)
		Recreational Fishing			Softshell clam abundance (medium)
		Sailing			Softshell clam abundance (high)
		Tourism & Sightseeing			Razor Clams
		Kayaking			Quahog/Hard Clams
		Area of Significant Change			Wild Oysters
					Marine Worm Digging
					Area of Significant Change

Appendix Table 2: Stickers for the two types of surveys (use and shellfish, left and right, respectively) for the participatory mapping study. Participants received only one version of the study. **(**Sticker Size: 0.5”).

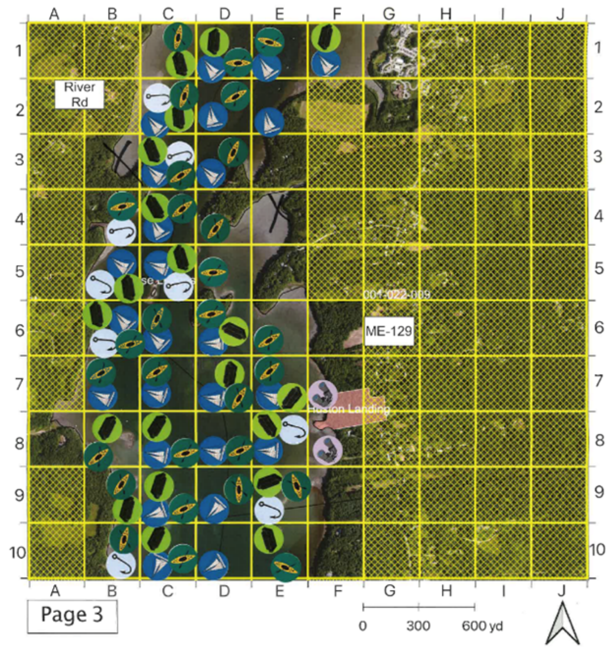


Appendix Figure 1: Guide map of the Damariscotta River estuary. Each numbered box represents a different page in the map packet.



Appendix Figure 2: Example of a page the Damariscotta River estuary map packet. The unfilled grid cells will be filled with stickers, while the boxes hashed out in yellow will not be filled. All remaining pages in both map packets are similar.

Participants were sent stickers associated with common intertidal shellfish in the estuary or different human uses (Appendix Table 1). They were instructed to 1) place stickers onto the unfilled grids in the map packet to represent where different shellfish or uses occurred, 2) write an 'X' mark to indicate that no activity occurred in a grid square, or 3) write a '?' mark to indicate that they did not know which activities occurred in that place. Participants were encouraged to write notes on the map to provide additional context and identify species or activities that were not represented in the stickers. Participants were asked to fill out entire map pages but were allowed to only fill out the map sections they felt most comfortable with. Participants filled out an average of 6.5 pages with a range of 1-12 pages completed (See Appendix Figure 3 for an example of a completed map page).



Appendix Figure 3: Example of a filled in map page from a Damariscotta River Estuary "Use" study.

Local Knowledge Interviews

We used semi-structured interviews to clarify responses to the mapping exercise and learn about changes that have occurred in the estuaries over time. This interview process was approved by the University of Maine Institutional Review Board (IRB) (#2020_06_16_Risley). These interviews were completed after the maps were finished and were an opportunity to debrief the mapping exercise, provide additional context to the maps, and learn about change in the estuary over time. These interviews took place over the phone and were between 30-60 minutes. Participants were asked if they knew what caused the changes they have observed, their responses to those changes, and if there were other factors the study should consider understanding use and change on the river. We also asked participants if we missed any species or activities in the estuaries. The follow-up interviews were scheduled to take place shortly after the mapping study was completed; they were usually scheduled during the initial recruitment process for a date about two weeks after participants were expected to receive the maps. This was intended to serve as a deadline for map completion and we did not do the interview until the participant finished the map. Participants were instructed to text or email pictures or scans of the maps to the researchers before the interview so that researchers had a digital copy of the completed map, and the participant had the paper map to reference in the interview. The combination of the mapping study and follow-up interview were intended to add context to the maps, generate common local hypotheses about drivers of change in the estuaries, and help identify study topics and locations for future research in the estuaries.

Analysis

Map data

The maps were created using QGIS (Version 3.12). Each individual map page covered an area that was 3000 x 3000 yards, and each of the grid cells within the map page covered an area of 300 x 300 yards. We assigned each grid cell a unique identifier and calculated the centroid, which was the value pulled into spreadsheets and used to recreate the maps later in R.

As maps were returned, each individual map was digitized, and the sticker information was manually added to a spreadsheet. Individual maps were then aggregated to show the overlap of information for the river. This data was then turned into maps. To preserve confidentiality, grid cells with fewer than three stickers of a given type were not shown on the final maps. We needed to have more than three stickers of a given type for that data to be shown on the final map.

The aggregated maps of sticker data were used to create maps showing the density of stickers for USE, SHELLFISH, and individual activities or species like softshell clams (e.g., Figured 5-7). We also asked participants about the relative density of softshell clams (high, medium, or low), and this information was converted into maps to show the spatial distribution and density of clams or other species and activities in the river. This data was also compiled with existing databases like the Maine Department of Marine Resources aquaculture lease map, to show both individual and overlapping activities in the estuary. All maps were made in R (Version 1.2.0553).

The shellfish maps were used to identify areas of high shellfish density for forthcoming community science shellfish monitoring initiative. These maps will help scientists target future fieldwork and will help the towns understand the distribution of their shellfish resources, as well as how they have changed over time. Additionally, understanding how activities overlap will help managers at both the state and municipal levels anticipate use conflicts in heavily used areas and manage the estuary as an ecosystem instead of managing individual species or uses.

Interview data

The interviews were recorded and then transcribed. We used the online audio transcription service otter.ai for the initial transcription and then manually corrected the interviews. We analyzed the interviews using NVIVO (MLB: Pro 12, SCR: Version 2). MLB and SCR designed the codebook and coded four interviews together for practice. Their intercoder reliability was >90% in nearly all nodes. After the initial coding was complete, we pulled the information about specific topics, like species in the estuary, and added that information to spreadsheets for a second round of coding and to build tables.

We analyzed river activities by counting each participant who mentioned a specific activity, and then grouping those activities into more general categories. We also counted each mention of the location of a specific activity and then grouped these locations into three broad categories: ‘Above Glidden Ledges’, ‘Below Glidden Ledges’, and ‘Whole River’. The tables related to the shellfish resource were generated by summarizing participant descriptions of shellfish habitat and distribution. Only characteristics that were identified by three or more participants were included in these summaries.

Figures relating to changes identified by participants were generated using a two-step process. Changes identified by participants were first grouped into broad categories, for example ‘Aquaculture Activity’ or ‘Erosion / Sediment’. Each change was coded as a +1, -1, or 0 depending on if the participant referred to an increase/positive change, decrease/negative change, or no change. Next, broad categories were further grouped into top level categories and the total net score (based on the sum of the +1/-1/0 codes) was calculated.

Appendix 2: Interview Guide.
Note this guide was used in studies of both the Damariscotta and Medomak River estuaries. For more information about this guide and related research, please contact heather.leslie@maine.edu.

General Characteristics

1. What is your age?
2. What is your gender? Male/Female/Nonbinary
3. Where were you born? (Town and state)
4. Where do you live now?
5. (If other than where they were born) How many years have you lived in [the current location?]

Place-based Experience

6. Please tell me how you spend your time on the [Damariscotta/Medomak] river.
7. During what times of year do you spend time on the [Damariscotta/Medomak] river?
8. How many years have you been harvesting/recreating/using the river?
9. Where do you primarily harvest shellfish/sea farm/boat/etc.?
    a. How frequently? (Ask to reference maps)

[For harvesters only]

10. Which species do you harvest? (If softshell clams: how would you describe high, medium, and low abundance?).
11. What is the habitat like where you find that species?
12. What other types of shellfish do you find in the intertidal mudflats?
    a. What is the habitat like where you find that species?
13. Are there predators that affect that shellfish species (positively or negatively)
14. What environmental or river use factors affect shellfish species (positively or negatively)?
15. What environmental or river use factors affect predator species (positively or negatively)?
16. Where do you access the river from? (Ask to reference maps)
    a. Has that changed over time? If so, in what way?
17. What are the most common activities that you observe on the river?
    a. Where do they take place?
    b. When do they take place?
    c. Have they changed? If so, in what way?
    d. Have you observed any commercial fishing on the river?
        i. If so, what types?
        ii. If so, where does it take place?
        iii. If so, during which times of the year?
    e. Have you observed any recreational boating on the river?
        i. If so, what types?
        ii. If so, where does it take place?
        iii. If so, during which times of the year?
18. During or after completing the mapping exercise did you notice any patterns in the stickers? Can you describe them?
    a. If you feel that kayaking/sailing, etc are widespread, have you noticed any areas where it is particularly common, like a hotspot of activity?
    b. Where did they take place?

c. What do you think caused those patterns?
d. For razor clams, quahogs, and wild oysters are the densities uniformly distributed across the estuary?
    i. If not, in what ways do they vary?

19. What has changed on the river since the start of your career/use to present? [Prompt to discuss economic, social, and environmental changes
    i. Did you use the significant change sticker? If so, where/why?
    b. How has the river changed? Is the change uniform across the river?
    c. Where have those changes taken place?
    d. When did you start to notice them? Did they occur quickly or over time?
    e. In your opinion, how would you rank the most significant changes (up to 3)?
    f. In your opinion, what do you think caused those changes? (Ask specifically about the 1-3 changes listed)
    g. Have those changes impacted how you use the river? In what ways?
    h. Have those changes impacted how others use the river? In what ways?
20. Is there anything else you would like to add? Or any questions for us? Suggestions of what we might consider.

Debriefing

21. Did you have any problems completing the mapping exercise?
22. Question about uses of the river (split by initial allocation of stickers)
    a. River Use participants:
        i. You were a Use Expert, so you received stickers for aquaculture, recreational fishing, sailing, kayaking, tourism & sightseeing, and areas of significant change. We also asked other participants about shellfish populations and marine worms. Between these two groups, did we miss any important activities or species in the river?
    b. Shellfish Harvester participants:
        i. You were a Shellfish Expert, so you received stickers for high, medium, and low abundances of softshell clams, as well as the locations of razor clams, quahogs/hard clams, wild oysters, marine worms, and areas of significant change. We also asked other participants about aquaculture, recreational fishing, sailing, kayaking, and tourism & sightseeing. Between these two groups, did we miss any important activities or species in the river?
23. Do you know anyone else who might be interested in taking this study?