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Gulf of Maine cod in 1861: historical analysis of fishery logbooks, with ecosystem implications

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Abstract

Since 2000, virtually every major assessment of ocean policy has called for implementing an ecosystem approach to managing marine resources, yet crafting such an approach has proved difficult. Ecosystems today exhibit little of the abundance and complexity found in the past, and populations of over-fished species have declined dramatically world-wide, yet historical evidence has been difficult to assimilate into complex ecosystem models. Here, we look to the testimony of Gulf of Maine fishermen for insights on the abundance of Atlantic cod (*Gadus morhua*) and the environment that once supported such large numbers of them. Using logbook data from Frenchman's Bay, Maine, and other New England communities at the time of the Civil War, we estimate cod landings in the Gulf of Maine in 1861, establish a population structure for cod at that time, and map the geographical distribution of fishing effort of a fleet that minimized risk and cut expenses by fishing inshore where cod and bait species were plentiful. Log entries list the pelagic and bottom-dwelling invertebrate species these fishermen used for bait, when and how they acquired it, and what species they looked for in the water to signify the presence of cod. Ranked descriptions of both cod and bait abundance were found to be statistically significant indicators of cod catch. Frenchman's Bay fishermen 140 years ago provided a minimum set of ecosystem requirements for abundant cod, conditions that may inform management plans aimed at restoring both the species and the Gulf of Maine marine ecosystem.

Keywords Bait species, cod population indicators, ecosystem-based management, fishing effort distribution, Gulf of Maine cod (*Gadus morhua*, Gadidae), historical marine ecology

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Introduction

Since 2002 reports by the UN Millennium Ecosystem Assessment (2005–2008), the US Oceans Commission (US Commission on Oceans Policy 2004–2008), the Pew Oceans Commission (2003–2008), and the European Council (2008) have recommended that ocean policy include an ecosystem approach to the management of ocean resources. Conceptually, this focuses on the ecosystem's ability to provide a full suite of services to support human well-being (UN Millennium Ecosystem Assessment (2005–2008), McLeod *et al.* 2005–2008). To do that, it must be healthy and resilient (Worm *et al.* 2006).

However, ecosystems can take many different configurations. Human activity can shift their condition and state, and this has been observed in many situations (Jackson *et al.* 2001, Scheffer *et al.* 2001; Lotze and Milewski 2004; Frank *et al.* 2005; Pandolfi *et al.* 2005; National Academy of Sciences 2006, McClenachan and Cooper 2008). Understanding the spectrum of configurations subject to human influence is important in evaluating the services an ecosystem may provide. Historical analysis of fisheries and marine ecosystems is critical in acquiring that understanding (Pauly 1995; Jackson *et al.* 2001; Pandolfi *et al.* 2003; Lotze *et al.* 2006; Sáenz-Arroyo *et al.* 2006; Lotze and Worm 2009).

Historical analysis has another, more proximate, role in ocean policy. Many marine species around the world have been subject to decades of overfishing (Myers and Worm 2003; Pauly and McLean 2003; Rosenberg *et al.* 2005; National Academy of Sciences 2006, MacKenzie and Myers 2007; Poulsen *et al.* 2007; Ferretti *et al.* 2008). Recent changes in fisheries policy in the USA and other countries have emphasized rebuilding over-fished fisheries with some success (Rosenberg *et al.* 2006), though additional progress is needed. In this context, questions arise regarding the ultimate target for rebuilding depleted stocks. When conventional fisheries science is applied to the legal standards for fishery management used in most of the world, it yields targets for rebuilding fish biomass to the level needed to support maximum sustainable yield (MSY), or related quantities (Lutgen and Andrew 2008). However, the calculation of the stock abundance needed to support MSY necessarily utilizes recently observed data, and estimates potential system productivity based only on recent productivity (Hilborn and Walters 1992; Pauly *et al.* 2002). Such calculations suspend attention to historic productivity. Worse yet, estimates of the potential stock necessary for rebuilding may continue to decline if the stock is further depleted (Rosenberg *et al.* 2005) in the 'shifting baseline syndrome' discussed by Pauly (1995). Historical analysis provides a critical alternative for the consideration of policy-makers by broadening the spectrum of known productivity and pushing back the baseline for rebuilding stocks. It also reveals snapshots of population abundance, size structure, and distribution in the more distant past to identify changes through time, and to help distinguish human from natural agency (Sáenz-Arroyo *et al.* 2006; Knowlton and Jackson 2008).

Sáenz-Arroyo *et al.* (2006) have argued that 'a pre-requisite for trying to manage marine ecosystems should be to put together early testimonies on how the seascape once looked'. That is, a historical approach is a necessary precursor for ecosystem-based management. Using this approach, we set out to learn about the Gulf of Maine ecosystem in the 1860s from the logbooks of vessels that fished there for cod (*Gadus morhua*, Gadidae). Fishing logbooks have been recognized as reliable sources of quantitative data (Rosenberg *et al.* 2005; Bolster 2006), and as specialized documents recording qualitative observations about the surrounding ocean (Bolster 2006, 2008; Leavenworth 2006; Alexander in press). Here, we analyse quantitative and qualitative entries in 19th century logbooks to establish a historical baseline for Gulf of Maine cod landings and population structure, relate this to other ecosystem components simultaneously observed and recorded, and compare the results to their modern counterparts.

Historical background and sources

Cod have been fished in the Gulf of Maine since prehistoric times (Bourque 1995; Lotze and Milewski 2004). Bones more than 5000-year old collected in Penobscot Bay suggest that cod was an important source of protein for local aboriginal peoples (Spiess and Lewis 2001), and vertebrae measurements have shown that these fish were significantly larger than cod caught today (Jackson *et al.* 2001). Although inshore grounds off Newfoundland and Nova Scotia were fished for cod since the early 1500s, no evidence has been found of 16th century Europeans fishing in the Gulf of Maine (Harrington 1994).

Reports from the earliest explorers, such as John Smith (1616), excited interest in the region's commercial fishing potential. First fishing stations, then settlements had sprung up before 1630, the year the Puritans founded Massachusetts Bay. However, already by the 1650s grounds near Boston showed signs of over-fishing (Leavenworth 2008). Ensuing conflicts at least in part over-fishing rights embroiled the English Pilgrims, Puritans, and Royalists, and later the English, French, Native Americans and American colonists for more than 100 years (Andrews 1964; Clark 1970). Despite numerous wars that destroyed fishing vessels and drove fleets into port, salt cod was the fourth leading export from the American colonies on the eve of the Revolution (McCusker and Menard 1985). Import and export duties funded the new Federal Government, and a successful economic stimulus package directed at cod fishing, in the form of federal bounties, was first passed in 1792 (Sabine 1852, 159).

That more than 1500 cod fishing logs from mid-19th century New England ports remain in archives today is a collateral benefit of early bureaucratic regulations. Starting in 1852, Congress required captains of cod fishing vessels to submit their logbooks to local Customs Inspectors at the end of the season to receive the bounty payment (Sabine 1852). Few logs exist from before 1852 or after 1866, when the cod bounty expired and logbooks were no longer collected (O'Leary 1996).

Overall approach and methods

Our study shows a suite of related results based on information from these logbooks. The results were derived using historical analysis, enhanced with simple statistical tools and Geographic Information Systems (GIS), rather than the sophisticated mathematical models developed to assess modern fisheries, which are often difficult to adapt to historical datasets (although see McClenachan and Cooper 2008; Poulsen *et al.* 2007, Rosenberg *et al.* 2005). Historical methods, described here, allowed us to identify, explain and extract pertinent information, and to standardize historical units of measurement with modern units for comparison – that is, to turn the historical information into data. Spatial and statistical analyses vary for each result, and these methods will be considered case by case.

Logs provide the numbers of cod landed daily by each crewman, wind and weather, location information, days fished or days at sea, and occasional narrative descriptions. Fishing agreements, the corresponding contracts between the vessel's agent and its crew, provide the seasonal weight of the catch measured in quintals (50.8 kg cured fish), the vessel's tonnage, and the names of the fishermen. Licenses divided the fleet by size. *Vessels* were ≥20 tonnes. *Boats* ran from 5 to 20 tonnes. These distinctions were important since range was roughly dependent on size. Each legal document sanctioned traditional custom and usage among merchants, captains and crew (Sabine 1852). Most vessels divided a single season into short trips called fares, and some agreements contain catch weight per fare. We aggregated catch data spatially and temporally. Biomass totals and average fish weight were calculated per season and, for some vessels, per fare.

Although the historical sample is far from complete, it indicates that, between 1852 and 1866, only 3% of all vessels fishing in the Gulf of Maine were from the Massachusetts Customs Districts of Salem-Beverly and Newburyport (Table 1 and Fig. 1). These towns sent out large distant water vessels that fished on the Scotian Shelf (Rosenberg *et al.* 2005) and the Labrador coast respectively. In contrast, logs from the Maine Customs Districts of Bath, Penobscot-Castine, Frenchman's Bay, and Machias demonstrated concentrated fishing effort in the Gulf of Maine (Table 1 and Fig. 2a).

The Frenchman's Bay Customs District (Fig. 2b) presented the largest and most complete set of logs and agreements for the Gulf of Maine cod fishery, and included a nearly complete run of logs for 1861, verified by comparison with license records of the US Customs Service. It became our primary focus for determining distribution of catch and

Table 1 Summary log statistics of Maine (ME) and Massachusetts (MA) the Gulf of Maine (GoM) fishing fleet, 1852–1866.

State	Customs District	Year range	*n*	GoM no.	GoM (%)	With fishing agreements (%)	With agreements (%)
ME	*Machias*	1856–64	113	103	91.15	53	51.45
	Frenchman's Bay	1861–65	524	482	91.98	482	100.00
	Penobscot-Castine	1860–66	46	37	80.43	20	54.05
	Bath	1852–57	45	40	88.89	16	40.00
MA	*Newburyport*	1857–59	233	35	15.02	6	17.14
	Salem-Beverly	1857–62	703	16	2.27	12	75.00
Total		1852–66	1664	713	42.84	589	82.61

Fishing agreements give the number of fish caught per man per day, and fishing location. Agreements give vessel size, total weight of catch at the end of the season, and fishermen's names.

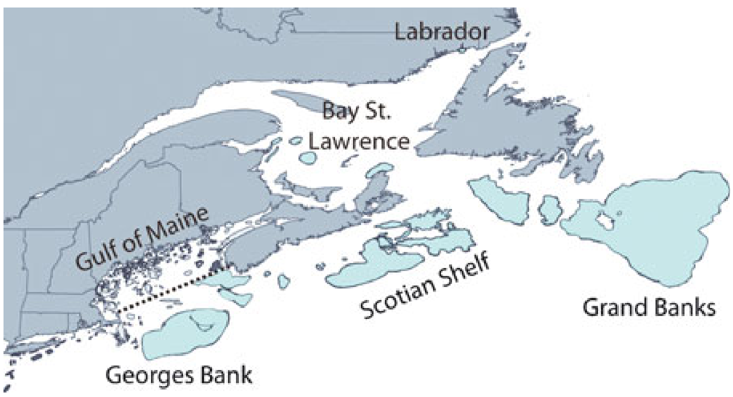

Figure 1 Cod fishing grounds in the Northwest Atlantic. Distant water banks (pale blue) are the Grand Banks, the Bay St. Lawrence, the Scotian Shelf, and, to a much lesser extent in the 1860s, Georges Bank. Gulf of Maine grounds are much smaller that the distant water banks. They lie northwest of a line running from Provincetown, Cape Cod, to the Nova Scotia Shore. Pale blue banks and grounds were charted by Goode (1887–8). Light grey banks were charted by Rich (1929).

effort. Quantitative information from Frenchman's Bay logs was transcribed into three databases scaled to fishing season, fare and day, respectively, so that landings could be aggregated by different time periods as well as geographical area. Descriptive observations were also transcribed in the daily database. Seasonal landings and fishing locations were recorded for vessels from the other Customs Districts. In each sample set the number of logs differs and is provided on the appropriate statistical chart.

We converted cured cod measured in quintals to live weight in metric units to standardize with today's figures. However, the question of conversion factors in historical marine ecology deserves more attention than it has yet received. A number of conversion factors, ranging from 2.2 to 6.1, exist in historical literature for converting cured cod to live weight. They apply to different size fish, in different years, seasons, localities, climates, when different qualities of salt were used, and different markets intended. So far we have found none for the Gulf of Maine in the 1850s and 60s, and it is unclear how to employ the others (Leavenworth in progress). In the 1950s, Canadian DFO scientists empirically derived a conversion factor of 4.9 from cured to live weight for Newfoundland cod (Beatty and Fougere 1957; Pope 1995, Rosenberg *et al.* 2005). Therefore, we used both the empirically derived 4.9 and an average of historical conversion factors – 3.9 – to give a range for the landings estimate; 4.9 was used for population structure calculations because sizes thus calculated correspond well with contemporary descriptions (Harper's New Monthly Magazine 1861; Innis 1978, 4–5).

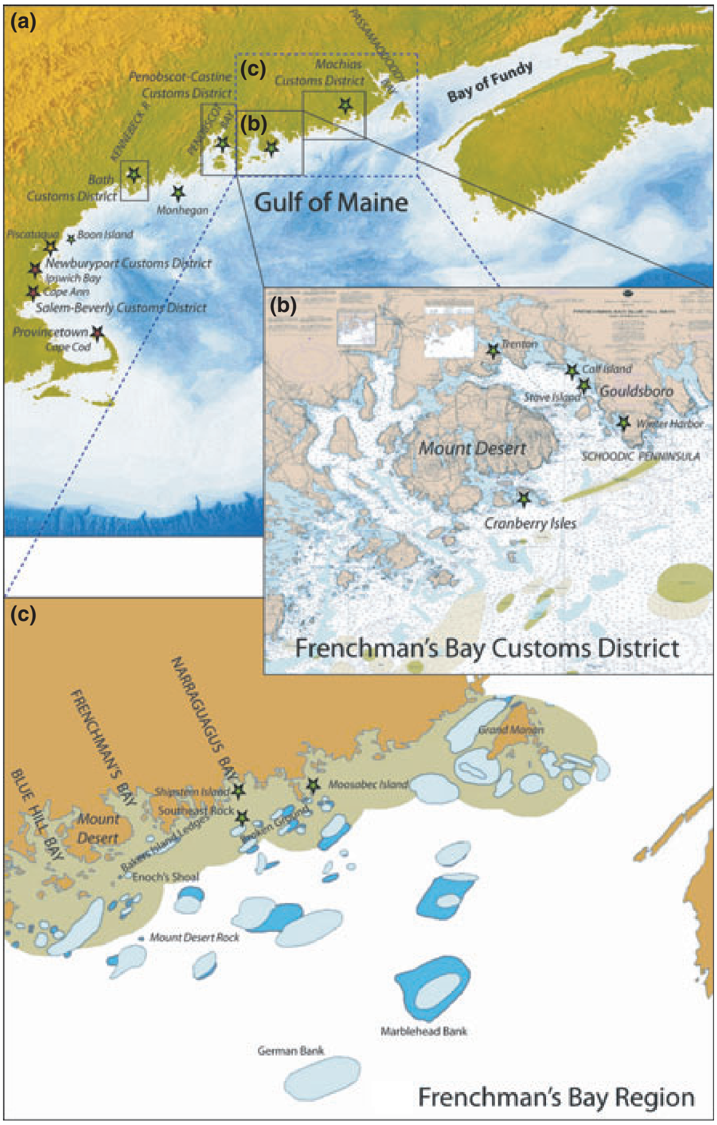

Figure 2 The Gulf of Maine. Cities and towns are marked with large stars; islands and fishing grounds are marked with small stars. Map 2a, the Gulf of Maine from Cape Cod to the Bay of Fundy, shows Customs Districts with logs, and other locations on land. Fishing in the Newburyport and Salem-Beverly Customs Districts was concentrated in the ports of Newburyport and Beverly, but Maine Customs Districts served wider areas, the extents of which are drawn in solid-edged boxes. The large, broken-line box maps the Frenchman's Bay Region, the geographical region fished by vessels licensed in the Frenchman's Bay Customs District. Map 2b, close-up of the Frenchman's Bay Customs District, showing near-by fishing grounds drawn in GIS on a Coast Guard navigational chart. Map 2c, close-up of the Frenchman's Bay Region. Dark and light blue marine areas are fishing grounds mapped by Goode (1887–8) and Rich (1929) respectively; the green strip along the coast marks the area 32 km from shore.

Distant water banks are almost always named in logs. In contrast, Gulf of Maine fishing locations were most often identified by range and bearing on landmarks and less frequently by ground name. We plotted fishing locations in the Frenchman's Bay logs first using traditional methods on navigational charts, and then in GIS. Fishing patterns built up from many such log entries allowed us to distinguish with some accuracy where vessels fished (Fig. 2c). When we correlated fishermen's names to Federal Census records and seasonal catch to mercantile prices, the resulting sociological and economic information explained some observed differences in fishing patterns. Thus, fishing patterns, social behaviour and technological capability combined to identify which vessels likely fished in the Gulf of Maine and which fished on distant water banks even when no specific location information was given.

Methods and results

Frenchman's Bay Landings in 1861

The quantity of cod caught by Frenchman's Bay vessels in the Gulf of Maine was obtained using simple arithmetic. In 1861, the year with the best data, 220 wooden sailing vessels averaging

48.7 tonnes, comprising only 15% of Maine's cod fishing fleet, landed 3 281 897 cod weighing 48 729.2 quintals, or, using the conversion factor of 4.9 – 12 134 m. Using the 3.9 conversion factor extrapolated from historical literature, landings come to 9658 m. This does not include subsistence fishing from boats <5 tonnes, for which no Customs records exist (Sabine 1852). At this time all cod were caught with handlines or tub trawls, similar to long-lines (Goode 1887–8, V). Almost all of these cod were caught between Penobscot Bay and Grand Manan, the waters commonly fished by the Frenchman's Bay fleet (Fig. 2c). By contrast, commercial landings in the entire Gulf of Maine in 2007 were 3989 m, recreational catch excluded (Mayo *et al.* 2008).

Gulf of Maine Landings in 1861

Although the logs do not represent total fishing effort in the Gulf of Maine, we devised a method to extrapolate overall catch based on fishing patterns exhibited within the logs, the geographical distribution of fishing effort, and the tonnage of vessels licensed for cod fishing from Provincetown, at the tip of Cape Cod, to Passamaquoddy, in the Bay of Fundy (Fig. 2a). Our estimate for total cod landings in the Gulf of Maine in 1861 is based upon 1664 logbooks from six different customs districts in Maine and Massachusetts (Table 1).

Prevailing winds and the sailing ability of traditional craft divided the Gulf of Maine into distinct but permeable regions traditionally fished by towns and villages along shore. Fishermen chose banks that they could sail to and from easily, for which, in prevailing winds, approach and return would not normally require sailing close-hauled, and they generally went to the east and northeast along the coast from their homeports. Massachusetts vessels concentrated on distant waters, from the Scotian Shelf to the Grand Banks (Table 1 and Fig. 1; also see Rosenberg *et al.* 2005). Boats and small schooners from the Newburyport Customs District fished inshore grounds still productive today in the Gulf of Maine between Ipswich Bay and Boon Island. The inshore fleet from Salem and Beverly, most of which

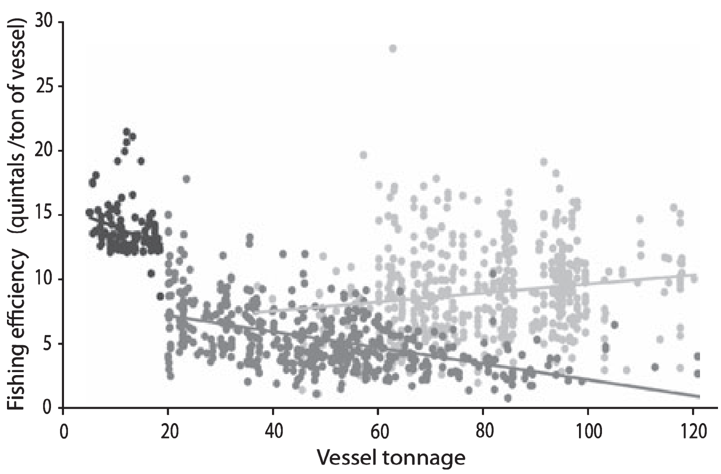

Figure 3 Fishing efficiency [quintals (50.8 kg cured fish) × (tonne of vessel)$^{-1}$] in the Gulf of Maine compared with fishing efficiency on distant water banks using One-way ANOVA and discriminant analysis. Cohorts are vessels in the distant water fleet (R^2 = 0.027), vessels fishing in the Gulf of Maine (R^2 = 0.253), and boats (R^2 = 0.070). Sample size = 1140 craft.

Oneway ANOVA	DF	Sum of squares	Mean square	F Ratio	Prob>F
Efficiency	2	7556.535	3778.27	432.0084	<.0001*
Tonnage	2	535071.26	267536	917.4820	<.0001*

Discriminant analysis test	Prior probabilities		
Tonnage, GoM under 20 tons	P = 0.0939	Number misclassified	124
		Percent misclassified	10.88%
Tonnage, GoM over 20 tons	P = 0.4228	–2 log likelihood	303.3
Tonnage, distant water banks	P = 0.4833		

were <20 tonnes, primarily fished between the arms of Cape Ann and Cape Cod, rarely rounding the capes into Ipswich Bay or onto Crab Ledges (Fig. 2a).

Almost all vessels and boats from Maine's Customs Districts of Frenchman's Bay and Machias fished in the same region, although a few large Machias schooners ventured into the Canadian Bay of Fundy (Table 1 and Fig. 2c). Some Penobscot-Castine schooners sailed to the offshore Marblehead and German Banks, but most threaded the islands from Mt. Desert Rock to Monhegan. Bath's Gulf of Maine fleet kept between the Kennebec and Penobscot Bay, occasionally venturing southwest to Boon Island (Table 1 and Fig. 2a).

Fishing effort varied among Maine captains because of social and economic factors that led to different priorities in decision-making, not to differences in gear. For this reason, Catch per Unit Effort cannot be calculated for the Gulf of Maine fishery, and it is impossible to estimate the total cod population using fisheries models dependent upon standardized effort. Here we define fishing efficiency as fish landed/tonne of vessel – that is, fishing effort without standardization. Figure 3 shows fishing efficiency according to vessel size and geographical region for the 1140 Gulf of Maine and distant water craft with logs and agreements extant. Sailing craft are divided into 5-to-20 tonnes boat, and over-20 tonnes vessel categories; geographical distribution is divided into the Gulf of Maine and the distant water banks.

Three cohorts emerge. Boats comprise the first. Safety dictated that no boat fish offshore, and all of these boats fished in the Gulf of Maine. Boats comprised the most efficient group (Fig. 3). Because the cod bounty was based on vessel size and not fish caught, boats received small subsidies and depended on catch for income.

Vessels over-20 tonnes fishing in the Gulf of Maine (Gulf of Maine vessels), and vessels over-20 tonnes fishing on the distant banks (distant water vessels) make up cohorts two and three. Gulf of Maine vessels were the least efficient. Overall vessel efficiency was only 38% of boat efficiency, and it declined as tonnage increased (Fig. 3). Census records show that Maine fishermen who manned larger inshore schooners worked in a mixed farming and fishing economy. Work was apportioned between sea and shore, and the income targeted from fishing determined the fishing effort expended. Because bigger vessels contributed larger bounty payments, incentive existed to operate the largest schooner possible, while expending the least effort, to achieve a target income (for similar economic histories, see Ray and Freeman 1978; Blanchard 1978; Apollonio 2002).

In contrast, the distant water fleet increased in efficiency with increased size (Fig. 3). Distant water fleets aimed to maximize profit, and they fished hard. Merchant owners rewarded more successful skippers with bigger vessels, where the captain's cut of larger bounty payments acted as incentive pay.

Tonnage and efficiency are each significantly different with respect to the Gulf of Maine and the distant water fleets (*$P < 0.0001$, Fig. 1). Discriminant analysis returns a confidence level of 89.12% for distinguishing between vessels fishing in the Gulf of Maine and on distant water banks based solely on tonnage and efficiency, without corroborating locations from the logs. Frenchman's Bay boats and vessels comprise the largest portions of those cohorts in the Gulf of Maine fleet, and the rest fit nicely within the two parameters.

Until after the Civil War, US Treasury Department Commerce and Navigation Reports aggregated fleet statistics, but did not distinguish between Gulf of Maine and distant water fleets. The US Department of the Treasury's *Annual Report on the Foreign Commerce and Navigation of the United States* compiled yearly tonnage totals by state for boats and vessels in the cod fishery (O'Leary 1996, 346–347). For vessels, the tonnage proportion for each customs district was given in 5-year intervals (O'Leary 1996, 350–351). Since logs show that fishing efficiency and vessel tonnage correlate well with the geographical region targeted for fishing, and Frenchman's Bay vessels and boats are representative of the Gulf of Maine fleet, then total Gulf of Maine landings in 1861 may be reasonably estimated in terms of Frenchman's Bay landings and the total tonnage of the Gulf of Maine fleet that year.

Logs show that the proportion of vessels fishing in the Gulf of Maine roughly increases with the latitude of the customs district (Table 1 and Fig. 2a). It is lowest in Massachusetts and highest for the northeastern-most Maine ports. We arrayed the customs districts from north to south, included the percentage fishing in the Gulf of Maine for customs districts *with* logs, and estimated the percentage for customs districts *without* logs based on geographical location. Based on our knowledge of total fleet tonnage, tonnage distribution and

Table 2 Estimates of the tonnage of Maine vessels over 20 tonnes fishing in the Gulf of Maine (GoM).

Customs Districts	Tonnage (%)	Total tonnage	Fished (%) in GoM (logs)	Likely to have fished in GoM (%)	Total estimated GoM tonnage
Passamaquoddy	4	2953.24	UK	85	2510.25
Machias	3	1785.68	86.48		1544.33
Frenchman's Bay	16	11126.16	88.36		9830.85
Penobscot Bay	29	20123.24	63.07		12692.46
Bangor	2	1510.96	UK	65	982.12
Belfast	12.30	8447.64	UK	65	5490.97
Waldoboro	9.10	6249.88	UK	65	4062.42
Wiscasset	9.90	6799.32	UK	65	4419.56
Bath	3.90	2678.52	71.82		1923.66
Portland-Falmouth	7.80	5357.04	UK	10	535.70
Biddeford	0.60	412.08	UK	10	41.21
Kennebunk	1.50	1030.2	UK	10	103.02
York	0.40	274.72	UK	10	27.47
Total					44164.03

From the total state tonnage and the proportional tonnage for each Customs District (O'Leary 1996), total vessel tonnage for each Customs District is calculated. Using the proportion of vessels known to have fished in the GoM (from logs), and assuming that the proportion decreases with decreasing latitude, we estimate the proportion of vessels likely to have fished in the GoM, and the total vessel tonnage for all Maine Customs Districts.

fishing efficiency, we used this conservative set of assumptions in our calculations:

1. All vessels <20 tonnes fished inshore. Their contribution was significant – 20493.6 m of cod were landed by Maine boats and 9019.0 m by Massachusetts boats in 1861.
2. The proportion of Maine vessels fishing in the Gulf of Maine increases with increasing latitude (Table 2).
3. No Massachusetts vessels over-20 tonnes fished in the Gulf of Maine. (In fact, Massachusetts vessels over-20 tonnes contributed only 7.15% of all Gulf of Maine vessels, and averaged just 29.1 tonnes.) (Table 1).
4. No New Hampshire or Canadian vessels fished in the Gulf of Maine.
5. No Massachusetts vessels <20 tonnes fished south of Cape Cod.

Assumptions 3 and 4 are obvious underestimates. Logs exist for a few large Massachusetts vessels that fished the Gulf of Maine, and some offshore bankers finished out their 120-day bounty requirement by making a short autumn fare along shore. They didn't fish hard – some did not even record catch – however, total landings may have been considerable. New Hampshire and Canadian vessels fished in the Gulf of Maine, but as yet we have no tonnage or landings data for these fleets. As a parenthetical note, however, 63 miles of trawl-lines with 96 000 hooks were set off Portsmouth Harbour, New Hampshire, in 1870, landing more than 453 m of cod (Goode 1887–8, VII-680).

Assumption 5 is an obvious overestimate. Boats from the southern shore of Cape Cod fished in the Great South Channel and on Nantucket Shoals, but it's impossible to distinguish them from boats fishing in the Gulf of Maine. We believe this overestimate is offset by the underestimates in Assumptions 3 and 4, and the unknown catch near shore of boats <5 tonnes. Although this catch went entirely unrecorded, it could have been considerable. For instance, in 1803 small boat day fishermen from Block Island unsuccessfully petitioned Congress to extend the bounty to boats <5 tonnes, because 'the number of fishermen upon the island was nearly two hundred; [and] that they caught from ten to fifteen thousand quintals of fish [from 2000 to 3700 m] annually…' (Sabine 1852, 160–161). By the 1860s boats <5 tonnes were supplying fresh fish to urban industrial centres like Portland and Boston (Storer 1839, 451; Goode 1887–8, VII, 194) in addition to subsistence fishing further downeast. For these reasons we believe our landings estimate to be conservative (McFarland 1911, 168–169).

Using these statistics to approximate vessel and boat tonnage fishing in the Gulf of Maine in 1861, including vessel tonnage for all Maine customs

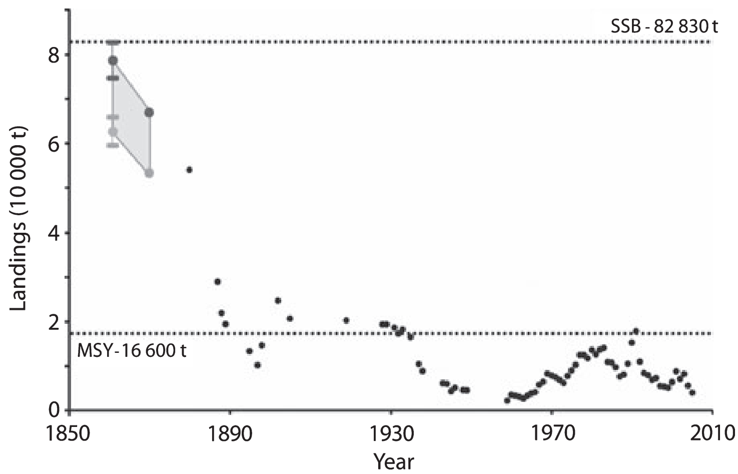

Figure 4 Landings estimate for Gulf of Maine cod in 1861, compared with landings records by the US Fish Commission, the Bureau of Fisheries and NMFS reports from 1870 to 2007 (Goode 1887–8; Northeast Fisheries Science Center 2008), MSY and SSB (Mayo *et al.* 2008). The 1861 landings estimate is given, with SD, using both 4.9 (large dark grey dot) and 3.9 (large light grey dot) values for converting cured to live fish. The 1870 catch, originally given in quintals, is converted to tonnes using the same multipliers. Parallelogram shows the range in which historical landings likely fall. Starting in 1880, catch weight given in live pounds is here converted to tonnes and shown as small black dots.

districts (Table 2), Frenchman's Bay cod catch in 1861 was scaled in proportion to Gulf of Maine fishing tonnage to estimate total landings that year. After testing a range of distributional assumptions and propagating uncertainty throughout, we estimate that 78 600 m of cod were caught in the Gulf of Maine in 1861 (std 4015), given a multiplier of 4.9; using the 3.9 conversion factor, estimated cod landings in 1861 were 62 600 m. In 1880, the US Fish Commission changed units in their reports from quintals dried to pounds fresh (Goode 1887-8, sec. II). With 53 880 m of cod landed that year in the Gulf of Maine, landings estimates using both multipliers appear plausible. Figure 4 compares our result with landings compiled by the US Fish Commission, the Bureau of Fisheries and NMFS from 1870 to 2005, the MSY (16 600 m) and Spawning Stock Biomass (SSB_{MSY}, 82 830 m) for cod in the Gulf of Maine today (Mayo *et al.* 2008; Northeast Fisheries Science Center 2008). Today's SSB_{MSY} falls just outside the upper confidence limit for our range of estimated cod *landings* in 1861, when landings are calculated with the 4.9 multiplier.

Population structure

The average weight of the cod landed by the Frenchman's Bay fleet in 1861 was 3.7 kg (std 2.1), exactly the same as the average weight for Gulf of Maine cod in 2007 (Mayo *et al.* 2008)! This suggests no difference in cod size between 1861 and 2005. Surprising in light of the population decline in modern times and the enormous cod described in historical literature, it can be explained by different population distribution curves surrounding the same mean. During the 1860s, the average weight of seasonal catch varied substantially from vessel to vessel. Since weight correlates well with age for fish, we used average weight of catch to investigate the population structure of cod landed during the 1860s, and compared it with the population structure today.

We compiled a table of numbers and average weight of cod landed for 482 Frenchman's Bay vessels between 1861 and 1865. Then we converted NMFS stock assessment year class data from 2003 to 2007 to numbers of cod landed at average weight (Mayo *et al.* 2008). Using NMFS weight to age conversion ratios, data were binned in 2-kg intervals and plotted. Figure 5a & b suggests that landings distributions in the 1860s and most recently are in fact similar. The greatest difference is in landings of small cod weighing <2 kg, most of which were likely juveniles (Mayo *et al.* 2008). They made up almost 15% of catch in the 1860s, but <1% today, likely because of regulated mesh size in gill nets and otter trawls. While large cod over 6 kg were 1.4 times more common in the 1860s than they are today, the reverse is true for very

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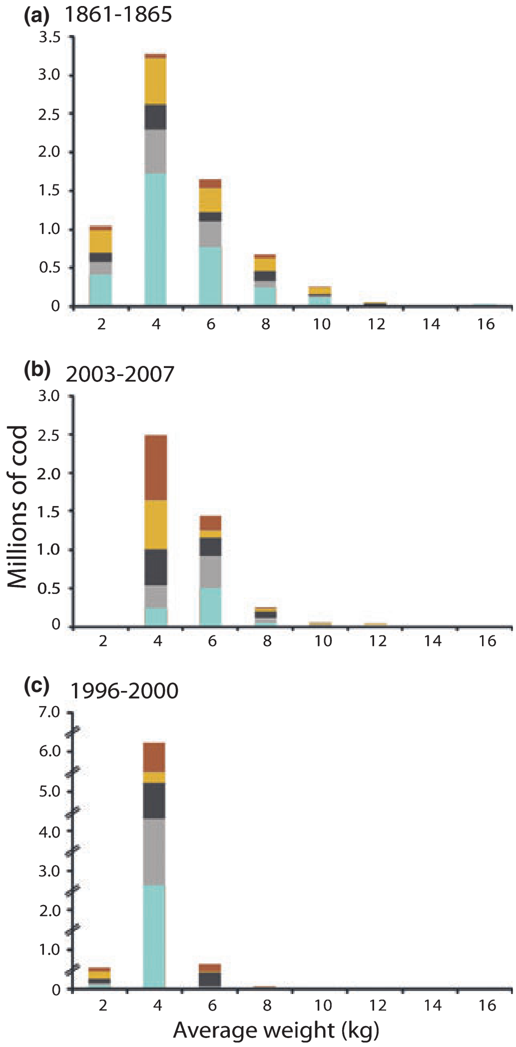


Figure 5 Seasonal cod landings distributed by numbers binned at average weight for: (a) the Frenchman's Bay region, 1861–1865 (sample size = 482 logs); (b) recent landings in the Gulf of Maine, 2003–2007; (c) Gulf of Maine landings, 1996–2000. In each graph, the earliest year is on the bottom, and succeeding years progress from bottom to top. Note that the scale of the *Y*-axis in graph (c) is twice that of the other two graphs. This population is almost entirely made up of cod weighing from 2 to 4 kg.

large cod over 14 kg, which are 1.8 times more common today.

Again, the similarity in population structure is surprising in light of the great difference in population size, but examining data from the recent past shows that this was not always the case. Figure 5c shows the cod population structure from 1996 to 2000. Then, 83.3% of all cod landed were between 2 and 4 kg. Large cod over 6 kg were at 38%, and very large cod over 14 kg at just 20% of their current quantity. During the population crisis in the late 1990s, many more cod were landed that weighed much less.

Cod over 16 kg cannot be identified using yearly or seasonal data, but logs give us a glimpse of them in the 1860s. To receive the bounty, Federal law stipulated that vessels had to fish for 120 days or more (Sabine 1852). Since quintals were totalled at the end of the season, any variation in cod size during that time disappears in the averaging. However, 112 Frenchman's Bay fishing agreements listed the weight of cod landed by fare. These records allow us to sharpen the temporal scale from seasons of 3 months or more to fares lasting weeks or days.

For fare data, cod averaging over 6 kg were 1.6 times more common than cod averaging <2 kg, and more detail was added at larger weights (Fig. 6). Comprising 0.35% of total landings by fare, 5548 cod averaging over 16 kg were landed. This corresponds with observations on size made by Henry B. Bigelow and William C. Schroeder in 1927: '…a 75-pound fish is a rarity, but 50 to 60 pounders [22.7–27.2 kg] are not unusual. The so-called 'large' fish that are caught nearshore run *c.* 35 pounds [15.9kg]…but shore fish large and small together, average only between 6 and 12 pounds [2.7 and 5.4 kg] in weight' (Bigelow and Schroeder 1927, 411).

To look for fluctuations in size during the season, we calculated the average *daily* weight of cod from the fare data for the entire Frenchman's Bay Region (Figs 2c & 7a). Larger cod averaging 6.8 kg or more appeared in late March and early April, and again in November. Smaller fish averaging <4.5 kg each kept the grounds during late summer and early fall.

Finally, we calculated average daily weight for smaller geographical areas within the Frenchman's Bay Region to search of spatial variability. These areas, or zones, are comprised of adjacent grounds often worked as a group during a single fare, and the logs exhibited 11 different zone combinations. For simplicity's sake, we will not map them here. Some fish were quite small, such as the 0.86 kg cod landed by Samuel J. Rice and his nephew Wilbert, age 11 years, from the boat SWAN, 5.76 tonnes, near Cranberry Isles in September 1862 (Rice 1862; US Federal Census 1860; Fig. 2b). Others go off the chart. These include the 887 very large cod, averaging 28 kg, landed by the schooner MERMAID, 52 tonnes, of Gouldsboro in 19 days during

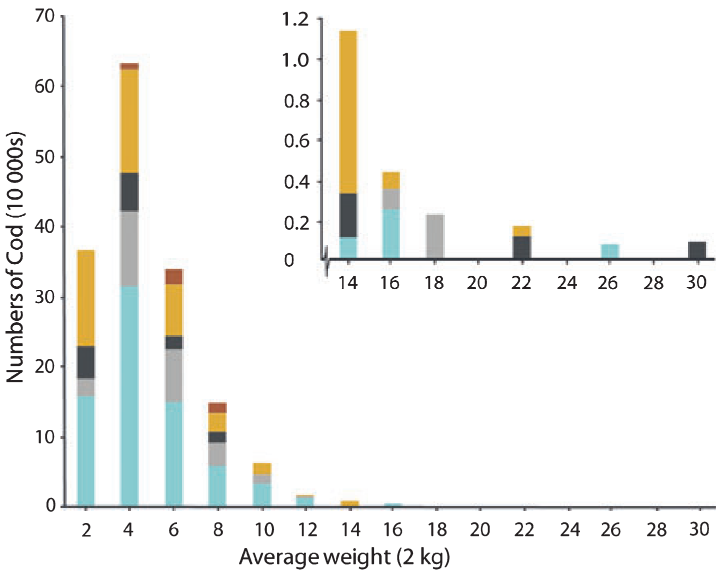


Figure 6 Cod landings per fare distributed by numbers binned at average weight for the Frenchman's Bay region, 1861–1865 (sample size = 112 logs). In each graph, the earliest year is on the bottom, and succeeding years progress from bottom to top. Very large cod are shown inset, but they only make up *c.* 16% of the population.

November, 1863 (Grover 1863). Although the SWAN was too small to venture far from shore, the MERMAID, if seaworthy, could easily have gone to the Bay of St. Lawrence or the Scotian Shelf. Narrative analysis of fishing patterns in the MERMAID's log, given here in detail, showed where they actually fished.

Captain Edmund Grover sailed on 5 November with his father George, age 78 yeras, his brother Ebenezer, his 17-year-old son, Freeman, neighbour John McGrath (an illiterate farmer from Ireland) and McGrath's 15-year-old stepson, Tom Bickford (US Federal Census 1860). Grover took the MERMAID out of Winter Harbour and began fishing the same day. His log does not mention where they anchored, but since they 'went to fishing' so quickly, they could scarcely have gone more than 32 km from shore. Entries over the 3 weeks read 'blowing heavy…storming…blowing…foggy…' The weather was blustery and cold. On 9 days the crew did not fish, not counting Sundays when it was customary to abstain from fishing. They probably spent these days in a sheltered anchorage, further constricting the vessel's range this fare. Two days of strong, unfavourable breezes from the northwest may have prompted them to head for home on 23 November.

Grover captained the MERMAID from 1861 to 1865, with his family as the majority of its crew after 1861 (Grover 1861, 1862, 1863, 1864, 1865). That first year the schooner fished off the Schoodic Peninsula between Frenchman's Bay and Mt. Desert Rock, 33.8 km from Mt. Desert Island. Once they went into Frenchman's Bay for bait, to dig clams (likely *Mya arenaria*, Myidae) or buy herring-like fish from the weir at Stave Island (Grover 1861). Subsequent logs are less specific about location, but show similar fishing patterns. Consistent fishing patterns, the bad weather, and the age of the crew suggest that the MERMAID never ventured far from home in 1863 and that these very large cod were landed east of Mount Desert Rock on the Broken Ground, a series of submarine ridges running parallel to the coast that stretched from the Schoodic Peninsula to Moosabec Island (Rich 1929, 66; Fig. 2b & c).

Historically, Gulf of Maine fishermen described distinctive local 'races' of cod, cohorts that could be identified by size, coloration, spawning time and migration patterns as they appeared along the coast at different times of the year (Goode 1887–8, I-203; Ames 2004). Here these observations are supported quantitatively. Figure 7a shows seasonal variability in size that suggests an overall migratory pattern for the Frenchman's Bay region in which larger spring and fall cod are replaced by smaller fish during summer months. Figure 7b shows even wider variation in size at small spatial and temporal scales. Cohorts that varied substantially in size occupied different parts of the region at the same time. Within a single-season schools of cod appeared, possessed individual fishing areas for a time, and were displaced by successive groups. This suggests a population structure for cod more complex than any recently observed.

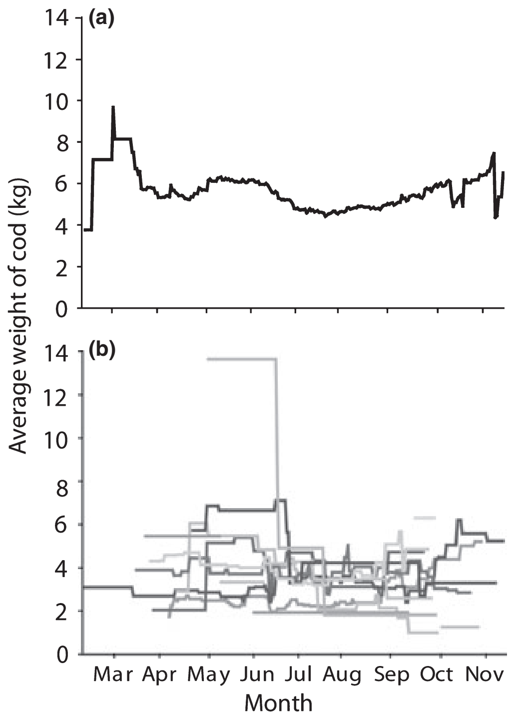


Figure 7 Average weight of cod landed per month at different spatial scales: (a) over the Frenchman's Bay region (sample size = 112 logs); (b) over smaller fishing zones (sample size = 45 logs). While seasonal variability in fish size is evident at the regional scale, the smaller scale reveals and even more complex mix of different sized cohorts simultaneously occupying the region, and moving on and off individual groups of fishing grounds throughout the season.

Geographical distribution of Frenchman's Bay catch and effort

Although separated by a year and a month, the MERMAID and the SWAN likely caught their fish on grounds <64 km apart. The MERMAID was 10 times larger than the SWAN, but Edmund Grover chose to fish only a day's sail from his home at Winter Harbour. Unlike modern fishing fleets (Therkildsen 2007) and the Massachusetts fleets of the 1850s and 60s (Rosenberg *et al.* 2005; Leavenworth 2006; Alexander in press), the effort distribution of Frenchman's Bay cod fishing vessels was not linked to vessel size. Almost 92% of Frenchman's Bay captains fished in the Gulf of Maine and 91.62% of the catch in the Frenchman's Bay Customs District was taken near shore, within 32 km of a protected anchorage (Figs 2c & 8), a range roughly equivalent to that of small, motorized lobster-boats today.

US Fish Commissioner Goode (1887–8) first charted the fishing grounds in the Gulf of Maine, based upon copious questionnaires he had customs agents distribute to skippers, and interviews of experienced fishermen who worked closely with the Commission. Four decades later Bureau of Fisheries Scientist Walter Rich (1929) updated these charts and descriptions in a new publication that followed Goode closely, but also added inshore grounds based upon interviews conducted with fishermen in the 1920s.

Using GIS, we mapped all the fishing grounds charted by Goode and Rich, and calculated centre

Figure 8 Frenchman's Bay landings near shore and offshore in the Gulf of Maine, 1861–1865.

points, or centriods. The average distance from shore to centroid of all 225 grounds mapped by Rich and Goode is 36.84 km. The 88 grounds within the Frenchman's Bay Region averaged 24.22 km from shore, well within the range of boats, and our logs show activity on 42 of them (Fig. 2c). Fishing on Enoch's Shoal, 22 October, Captain Eldridge (1864) noted laconically in log of the LADY JAYNE: 'The fish we think have struck in shore'. Mapped by Goode and Rich, Enoch's Shoal 'lies ENE 3 miles from Great Duck Island', 10.71 km from Mount Desert. Important fishing grounds today, such as Jeffrey's Bank at 72.52 km, Fippennies at 105.09 km and Cashes Ledge at 124.01 km, are much farther offshore and among the most distant Gulf of Maine fishing grounds charted by Goode and Rich. None of the three appear in Frenchman's Bay logs, although the BURNHAM HARDY, 45.76 tonnes out of Beverly, Massachusetts, visited Cashes Ledge in 1862 (Trask 1862).

With one exception, all grounds more than 32 km from shore found in Frenchman's Bay logs were charted by Goode and Rich. In addition to the charted grounds, however, Frenchman's Bay logs describe 56 hitherto uncharted fishing locations with landmarks, ranges and bearings. These micro grounds were clustered inshore, near or within the broad bays perforating the coast (Fig. 9a), and were exploited by large vessels and small boats at the same time.

Occasionally, logs reveal social factors affecting crew composition and choice of fishing location in the Gulf of Maine in the 1860s. Of the eight distinct fishing locations Captain John K. Whitaker noted in his log aboard the CONTENT, sailing out of Trenton in 1861, only two were mentioned by Rich (1929). Whitaker's crew consisted of his three sons, aged 18, 15 and 13, and Moses McFarland with his two sons, aged 14 and 13 (US Federal Census 1860). At 69.29 tonnes, the CONTENT was also large enough to take offshore, but Whitaker never went beyond Baker's Island Ledges at the mouth of Frenchman's Bay. During her second fare, the CONTENT worked waters between Trenton and Calf Island in upper

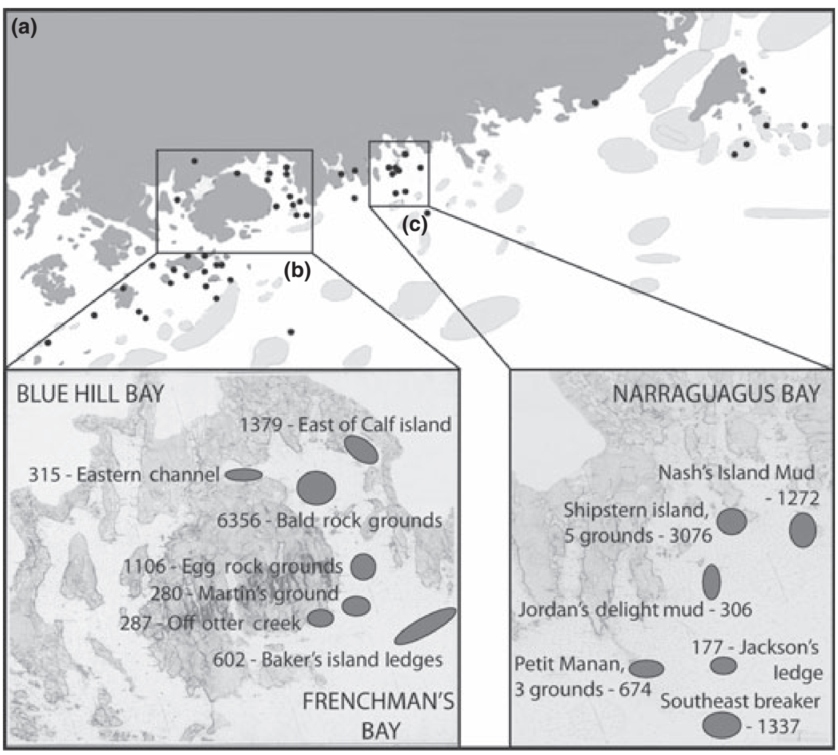


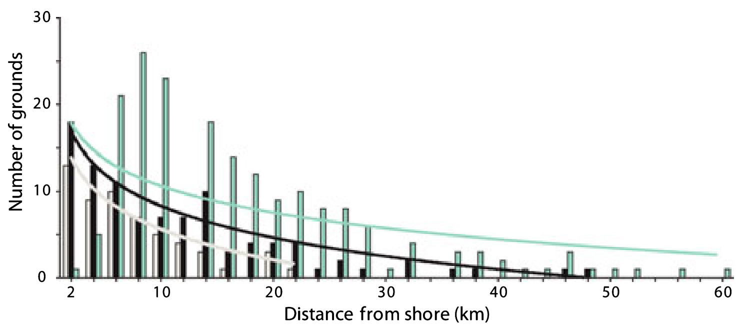
Figure 9 Inshore grounds in the Frenchman's Bay region. (a) Centroids of micro grounds identified from logs (1860s) and mapped in GIS, shown as black circles. Light grey fishing grounds were mapped by Rich (1929). Average distance from shore for micro grounds = 10.2 km; Average distance from shore for Rich's grounds = 36.8 km. (b) Cod landed by the CONTENT out of Trenton on micro grounds in Frenchman's Bay, 1861. (c) Cod landed by the WASP out of Gouldsboro on micro grounds in Narraguagus Bay and near Petit Manan, 1862.

Bay, within 21 km of home; there Whitaker, McFarland and the five boys took 5355 small cod in 66 days (Fig. 9b). Whitaker, his neighbour and their sons fished close to home on well-known inshore grounds that were safe for a young, inexperienced crew (Whitaker 1861). Cod were plentiful.

Captain Edward E. Swett's log of the boat WASP in 1862 distinguished 23 separate fishing locations. At 6.7 tonnes, the WASP, of Gouldsboro, was one of the smallest vessels licensed in the Frenchman's Bay Customs District. Swett was not local, but the WASP's crew included Abner Randall from Harrington, a sea captain undoubtedly well versed in local fishing knowledge, and Stephen Frye, the son of another Harrington sea captain (US Federal Census 1860). In July, Swett, Frye and Randall fished on eight different grounds as far out as Moulton Ledge and Southeast Rock, past Petit Manan, landing 2118 cod. However, 19 fishing days were spent on micro grounds around Shipstern Island, Nash's Island and Jordan's Delight in Narraguagus Bay, grounds no more than 8 km apart and no more than 11 km from shore (Fig. 9c). Here they caught 1991 cod, 94% of July's landings (Swett 1862). Swett hired experienced fishermen with an intimate knowledge of local inshore grounds. His log contains more ground locations than usual, probably for future reference. Again, cod were plentiful.

The most prolific fishing ground in the logs, Mt. Desert Rock Grounds, was also the most distant micro ground. Although in 1929 Rich described Clay Bank, a fishing ground lying 11.2 km to the SSW of Mt. Desert Rock, this is not where Frenchman's Bay vessels fished. Rather, they fished within 6.4 km of the Rock on all sides (Fig. 2c). Although 34.2 km from shore, it is only 25.3 km from safe harbour on Long Island. In good weather, small boats sailing out of Frenchboro Long Island or the Cranberry Isles could make Mt. Desert Rock safely in a long day trip, and it was worthwhile. In 1861 89 125 cod were landed there.

Micro grounds described in the logs averaged 10.2 km from shore (Fig. 9a). Except for Mt. Desert Rock Grounds, none individually contributed much to overall landings (Fig. 9b & c), but in aggregate they suggest that cod were once spread more or less diffusely in shallow water, and concentrated on the submarine plateaus farther out that correspond to well-known fishing grounds today. Not just the micro grounds, but all 98 grounds fished by Frenchman's Bay vessels in the 1860s were significantly closer to shore than the grounds Rich charted 64 years later ($P < 0.0001$; Fig. 10), possibly signifying a change in the geographical



Wilcoxon Rank Sum Significance Test

	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0	S	Z	P
Micro grounds	56	3749.0	67.0	–7.6	3749.0	–762026	<.0001*
Rich grounds	225	35872.0	159.4	7.6			
All FMB grounds	98	11275.5	115.1	–5.96	11275.5	–5.9618	<.0001*
Rich grounds	225	401050.5	182.4	5.96			

Figure 10 The number of grounds fished by Frenchman's Bay vessels divided into three categories and distributed by distance from shore. *Micro grounds* discovered in the Frenchman's Bay logs from the 1860s, light grey. All grounds fished by Frenchman's Bay vessels in the 1860s (*FMB grounds*), include both the micro grounds and those charted later in 1929 by Rich, black. All Gulf of Maine grounds charted by Rich (1929); (*Rich grounds*), in light blue. Trend line shade matches variable category shade.

distribution of catch and effort related to the introduction of otter trawls.

Modern metrics often separate Georges Bank and the Gulf of Maine cod in stock assessments. To find out the distance from shore where cod are now targeted, we looked at observer data from 944 tows made by vessels over 5 tonnes fishing in 2005 from Gulf of Maine ports, targeting cod with otter trawls [Observer Database System (OBDBS) 2007]. The majority of observed tows began in the northwest corner and central portion of Georges Bank (363), the southernmost central Gulf of Maine bordering Georges Bank (388), and the southern coastal shelf between Cape Ann and Cape Cod (124; Fig. 1). The mean near distance to shore for tows originating on Georges Bank was 185.8 km, in the central Gulf of Maine, 105.6 km, and on the southern coastal shelf, 17.5 km. Only 39 tows started on the coastal shelf north of Cape Ann, at a mean distance of 19.8 km from shore. None was north of Boon Island, at the mouth of Saco Bay (Fig. 2a). There was no activity at all in the formerly prolific Frenchman's Bay region. Overall, the mean distance from shore at which vessels over 5 tonnes fished for cod in 2005 was 118.9 km, with a SD of 71.0 km. As with historical data, modern figures do not account for the activity of small craft <5 tonnes.

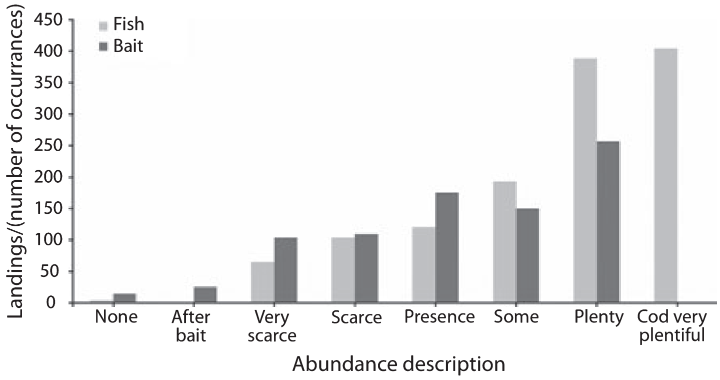
What cod ate in the 1800s

Information on what cod ate came from descriptions in the Frenchman's Bay logs of bait species observed at sea and often caught to bait cod hooks. As a precursor to ecological studies of this marine ecosystem (Backus and Bourne 1986; Conkling 1995; Steneck and Carleton 2001; Lotze and Milewski 2004; Steneck *et al.* 2004), fishermen identified and observed a functional group of marine animals, cod and their prey, and recorded these observations. We analysed bait descriptions for predator–prey information.

Distant water fleets fishing for cod on the Scotian Shelf or the Grand Banks purchased barrels of salted clams and herring-like fish for bait at the beginning of a voyage, and augmented the supply with bait caught at sea: herring (likely *Clupea harengus*, Clupeidae), menhaden (*Brevoortia tyrannus*, Clupeidae), squid (likely *Illex illecbrosus*, Ommastrephidae, or *Loligo pealeii*, Loliginidae) or seabirds (Leavenworth 2006; McKenzie 2008). By comparison, inshore Frenchman's Bay fishermen started with fresh bait, usually clams or herring, and replenished it whenever possible. They liked to use fresh bait because cod took it better than salt clams or pickled herring, and fishermen could often obtain it at no monetary cost. Stomach contents that would stick on a hook, particularly clams and squid, were reused. Gillnets were set for herring and menhaden, and a vessel would occasionally weigh anchor at night to drift for bait if none could be had nearby. Fishermen bought baitfish from local weirs that crosshatched the coast, and dug clams in mudflats at low tide. Across from Bar Harbour in Frenchman's Bay, Stave Island, with its weirs and extensive clam flats, attracted many vessels going in for bait.

Fishermen watched for herring or menhaden in the water because baitfish attracted feeding schools of cod. They related the presence or absence of bait with local cod abundance. Frenchman's Bay logs record 3028 descriptions of cod abundance in the following categories: no fish, fish very scarce, fish scarce, fish, some fish, fish plenty and fish very plenty. They also record 2878 descriptions of bait abundance: after bait, no bait, bait very scarce, bait scarce, bait, some bait and bait plenty. Fishermen ranked abundance in exactly these words, using the same modifiers in six of seven paired terms. Figure 11 correlates the average number of cod landed per term occurrence for both bait and cod. One would expect to see a strong correlation between cod rank and landings ($P < 0.0001$), but bait rank is also strongly correlated with cod landings ($P < 0.0001$). In describing bait species, Frenchman's Bay fishermen not only provided an ecosystem indicator for cod abundance, but showed that 'herron' – herring, 'pogies' – menhaden and 'clambs' – clams were the ingredients they considered necessary to the support of such abundance, and that forage could be gathered within 20 miles of shore. This is corroborated by 61 Gouldsboro fishermen, some of whom penned logs used here as sources, who in 1857 petitioned the Maine State Legislature to ban menhaden seining, since 'it will be to the material injury of the codfishery interest in this State…' (Adams *et al.* 1858, Legislative petition, Maine State Archives).

Interestingly, lobsters (*Homarus americanus*, Nephropidae) were not mentioned as food for cod in Frenchman's Bay logs or in US Fish Commission reports. According to 19th century marine scientists, adult cod ate various molluscs, crabs and echinoderms from the bottom, and small-to-medium pelagics such as herring, menhaden, shrimp (*Pandalus borealis*, Pandalidae) and squid (US Fish Com-



Wilcoxon rank sum significance test	
Cod description	Bait description
S = 550.7533, Z = 6, *P* = <.0001	S = 146.9474, Z = 6, *P* = <.0001

Figure 11 Correlation between numbers of cod landed and abundance descriptions of both cod and bait species from Frenchman's Bay logs, 1861–1865. Each set of descriptions is a statistically significant indicator of landings. Abundance Categories.

mission Report 1886, 36). Table 3 lists species found in cod stomachs on four different occasions in Northwest Atlantic regions from 1845 to 1895 (Baird 1873; Kendall 1898). Neither the Rev. Mr Linsley in 1845 nor Mr Simon F. Cheney in 1871 reported the number of occurrences of species or the number of cod examined, but they provided lists of species found. Cheney mentioned that thirteen sea crabs of various species were found in one 167 cm cod caught near Grand Manan (Baird 1873). Early Fish Commission scientists sometimes recorded the number of cod examined, but not the number of each prey species found. What can be said is that out of more than 168 different cod taken between Long Island Sound and the Bay St. Lawrence, only one 10 cm lobster was found near Prince Edwards Island, Canada, and fish packers, also on Prince Edward Island (PEI), reported lobster eggs in one cod stomach. 'Numerous' animals, 'several' of which were found in cod stomachs on 'several' occasions, were crabs, shellfish, herring-like fish, echinoderms and prawns.

Table 3 (a) Animals present in the stomach contents of more than 168 cod, numbered by group, and aggregated for four different location in the Northwest Atlantic, from four sources, 1845, 1871 (Baird 1873), 1892–3 and 1894–5 (Kendall 1898); (b) Crustaceans from all geographical regions are broken into smaller categories, and occurrences of these categories are counted.

(a)	Long Island Sound	Gulf of Maine and Georges Bank	Bay St. Lawrence	Scotian Shelf	Total
Annelids		3	6	2	11
Crustaceans		14	11	2	27
Echinoderms	1	4	1		6
Fishes		14	3	1	18
Hydroids		1	0		1
Molluscs	26	9	3	1	39
Total	27	45	24	6	102

(b) Crustaceans	Crabs (four species)	Lobsters	Shrimp	Isopods (likely Idoteidae or Epimeriidae)	Sea fleas
Occurrences	17	2	1	1	1

Discussion: cod as a lens on the Gulf of Maine ecosystem

The cod fishery 140 years ago was so profoundly different from its counterparts today that it is difficult to make useful comparisons. We now know that between two and three times the amount of cod landed in the entire Gulf of Maine in 2007 (3989) m were landed within 32 km of shore between Penobscot Bay and Grand Manan in 1861 (from 8849 to 11117 m). Our 1861 landings estimate for Gulf of Maine cod (from 62 600 to 78 600 m) comes much closer to the contemporary SSB_{MSY} (82 830 m) than to the projected MSY (16 600 m) (Mayo *et al.* 2008; Northeast Fisheries Science Center 2008). In fact, when Mayo *et al.* (2008) calculated these reference points using a different, nonparametric approach, MSY (at 10 014 m) and SSB_{MSY} (at 58 248 m, slightly more than the biomass of cod landed in 1880) were even lower, reflecting uncertainties inherent in modelling with different approaches and assumptions.

Our historical landings estimates open questions about the recovery goals for Gulf of Maine cod. Yet it is naive to suggest that these goals should be higher based on historical reference points alone. Higher goals fuel the ongoing debate on the nature and state of the Gulf of Maine marine ecosystem as a whole, whether it can support such an abundance of cod, and what the trade-offs might be. If historical and modern configurations are extreme versions of the same ecosystem, then greater cod productivity and abundance might be possible. However, if a regime shift has occurred, then the modern ecosystem may be so fundamentally different that it can only support a remnant of the historical population (Rosenberg *et al.* 2005). In addition, if total biomass is conserved in the Gulf of Maine, an increase in cod may cause a decrease in other valuable commercial species like lobster (Yuying 2005). But if biomass is variable, a historical Gulf of Maine capable of supporting cod in such large numbers was likely more productive. Although overall productivity may have declined, this scenario admits the possibility of increasing productivity in the future, and breaks the strictures of a zero-sum game.

Clearly things have changed, yet comparing quantities alone tells us little about how and when change occurred, whether the Gulf of Maine can support such an abundance of cod today, and, if so, how it can be restored. Historical analysis employs a holistic approach to understanding information. Here we examine these results holistically to speculate about a way forward.

Cod catch in 2007 was between 5% and 6% of what it was 140 years ago, yet the population structure was similar to that of Frenchman's Bay cod landed in the 1860s. In 2000 catch was still between 5% and 6% of the Frenchman's Bay catch, and at 2.96 kg, mean weight from 1996 to 2000 was not significantly different from the Frenchman's Bay mean, but the distribution curve was severely truncated. Almost all landings in 2000 fell between 2 and 4 kg. Only 1.3% of this population were large cod, compared with 9.9% most recently, and 14.35% in the 1860s.

Tagging surveys have revealed current migratory patterns of cod in different regions of the Atlantic (Robichaud and Rose 2004). There is some mixing between the Gulf of Maine and Georges Bank cohorts that are managed as separate stocks (O'Brien *et al.* 2005, 95; Northeast Fisheries Science Center 2008). Most cod travel in loose schools based on fish size and migrate on and offshore during the year (Ames 2004). However, Gulf of Maine stocks exhibit little of the complexity they showed in the 1860s (Goode 1887–8, I-200–223).

Peak spawning now occurs in the Gulf of Maine in the early spring, from March to May (O'Brien 1999) and extends into the summer months, but during the 1600s, winter spawning stocks were deemed valuable enough that Puritans in Massachusetts protected them through regulation (Leavenworth 2008). The identification of once prolific, but now entirely barren, spawning grounds in the Gulf of Maine (Ames 2004), makes clear the extent to which individual spawning groups have been lost.

Heavier, older cod are better spawners than smaller fish, all else being equal, because they produce more and better quality eggs (O'Brien 1999). Although cod over 6 kg are still <10% of total commercial landings, numbers of them in 2007 have more than quadrupled since 2000. A comparison of the curves in Fig. 5 shows that the population structure from 2003 to 2007 has already rebounded enough to resemble the much larger, more productive, and healthier cod population in the 1860s rather than the population in crisis in the 1990s.

We believe this is good news. Despite the great disparity in landings, cod may have come out of the tight bottleneck of the late 1990s. The stock may have shifted into a healthier configuration that promotes more successful spawning and faster population growth. Indeed, Mayo *et al.* (2008) note that the 2003 and the 2005 year classes appear to be strong. Recruitment has improved in 2003, 2005 and 2006, and increased mesh size ensures that more of these fish will live long enough to reproduce. Fisheries scientists might look for increasing complexity in patterns of movement, especially of larger cod, as another indicator that the population is rebounding.

While the cod fishery on the Scotian Shelf had not recovered 30 years after it had crashed in 1859 (Rosenberg *et al.* 2005; Leavenworth 2006), comparing past and present in the Gulf of Maine indicates that 10 years of regulations are finally showing a structural improvement in the cod stock. Not only does it validate difficult management decisions, but, by providing a longer perspective, it should encourage policy makers and stakeholders to fix on long-term goals and stay the course (Safina *et al.* 2005).

Now we examine the historical results for environmental conditions that promote rebuilding cod stocks. The New England Fishery Management Council recognizes inshore areas as 'essential fish habitat' for cod eggs, larvae, juveniles and adults, but inshore trawl surveys in recent years have found virtually no cod in the Frenchman's Bay Region (NMFS Office of Habitat and Conservation 2008a; NOAA Fisheries Service, Habitat and Conservation 2008b). Today, only three spawning grounds remain active in the Gulf of Maine and none lies north of Portland (Ames 2004). No large-vessel commercial cod fishery exists in the Frenchman's Bay Region except for vestigial effort around Grand Manan (Murawski *et al.* 2005; Maine Department of Marine Resources 2008). Inshore areas are inhospitable to cod of all age groups, yet our results show that more than 90% of the cod landed by Frenchman's Bay vessels in 1861 came from the inshore fishery.

This coastal habitat is essential for cod at all life stages, but especially for spawning, larvae and juvenile survival that increase recruitment. Breeding grounds and nursery areas need as much protection as fishing grounds, but inshore areas are not afforded protection through year-round fishery closures. In land-based conservation, emphasis is currently placed on establishing protected corridors through which animals can pass from one essential habitat to another in relative safety during seasonal migrations (Beier and Noss 1998; Meynecke *et al.* 2008; Vos *et al.* 2008). In ocean conservation, systems of reserves linking essential fish habitat may offer similar protection, but this has rarely been considered for a commercially valuable fish stock. One notable exception is the network of marine protected areas in the Channel Islands of California (Airamé *et al.* 2003).

The Gulf of Maine offers a number of advantages to such an experiment in coastal protected area management. The Western Gulf of Maine Closed Area, the Cashes Ledge Closure, and the Stellwagen Bank National Marine Sanctuary are near important coastal spawning grounds, although some coastlines are heavily populated and developed. Nevertheless, establishing coastal and estuarine protected areas would create connectivity to the current protected areas, potentially beneficial to cod at all life stages, as well as increase the habitat complexity of key prey species like herring and alewives (*Alosa pseudoharengus*, Clupeidae). If a stock that once again is achieving mature complexity has access to such habitat, fallow spawning grounds may be re-colonized and recruitment materially increased. In a modelling study of survivorship of juvenile Atlantic cod in relation to habitat quality of Stellwagen Bank National Marine Sanctuary, Lindholm *et al.* (2001) determined that movement and post-settlement density where critical in determining survivorship for marine protected areas of different sizes. In addition, the study showed that negative impacts to habitat further affected juvenile survivorship (Lindholm *et al.* 2001). Today conservationists are moving to make the Penobscot River and part of the Bay a conservation area. If this is successful, fisheries scientists should monitor the effect on Gulf of Maine cod.

In the past, cod were clearly associated with a wide number of prey species – but lobster was not among them. Not only were herring and menhaden important bait species in the cod fishery, but before the extensive use of gill-nets and the introduction of otter trawls, clams were dug by the tonne throughout the Gulf of Maine to use as bait. These results suggest that an increase in the cod population would not necessarily affect the abundance of lobsters. Both species coexisted for millennia before over-fishing perturbed the Gulf of Maine ecosystem.

More important is the lack of alternative prey. In coastal Maine, Steneck *et al.* (2004) explain the current predatory invertebrate dominance (lobsters and crabs) as a shift in alternative stable states induced by fishing pressure first on fish and later on green sea urchins (*Strongylocentrotus droebachiensis*, Strongylocentrotidae). Before 1940, Steneck *et al.*

believed that the coastal community was dominated by predatory fishes, such as cod, haddock, hake (Phycidae or Merlucciidae), pollock (*Pollachius virens*, Gadidae) and flounder (Pleuronectidae), controlling green sea urchin populations. With the removal of predatory fishes, green sea urchin populations surged and suppressed kelp (Laminariaceae) species from 1970–1990 (Steneck *et al.* 2004). Harvesting of green sea urchin began in 1987 lowering their population numbers such that after 1995, macroalgal dominance occurred followed by invertebrate dominance (Steneck *et al.* 2004). Here, too, coastal-protected areas that increase populations of anadromous and small-to-medium pelagic fishes, and restore benthic habitat for annelids, echinoderms, molluscs and crabs, are also good for cod.

Using historical fishing logs from Frenchman's Bay, Maine, we have not only generated a landings estimate for Gulf of Maine cod in 1861 that is an order of magnitude greater than landings today, but taken a snapshot of the ecosystem that supported these fish, and shown that the ranked descriptions of contemporary fishermen correlated statistically with numbers of cod landed. While it does not answer questions about regime shifts or biomass conservation, this snapshot provides a set of minimum conditions for abundant cod in the Gulf of Maine: large populations of small pelagics, a healthy benthic community with a profusion of shellfish, and inshore feeding and spawning grounds supporting multiple stocks, including herring, menhaden and cod.

Taken together, the population indicators, geographical distribution of fishing effort and functional food group indicate, albeit imperfectly, how the Gulf of Maine ecosystem once looked. It indicates that cod stocks are improving, however slowly, and suggests research questions and management actions that might prove fruitful.

Historical evidence strongly suggests that single-species regulation is not enough to restore cod populations to any semblance of former health. Ecosystem-based management plans must include all essential habitat and all components of the functional food group. To avoid the pitfalls of the 'shifting baseline syndrome', to recognize the potential productivity of depleted marine ecosystems, and to better understand the spectrum of ecosystem configurations that have existed in the past, marine scientists and fisheries managers should consider a holistic application of historical evidence whenever it is available and reliable. To do otherwise is to short-change the ecosystem's potential.

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