From Fishing Capacity to Diversity: Changing Fishery Management Priorities in the New England Groundfish Fishery

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Abstract

After 16 years under a limited access program with effort controls, the New England groundfish fishery transitioned to a catch share management system in 2010. For much of its earlier management history issues related to fishing capacity were paramount as effort controls were increasingly restrictive to meet biological objectives. As the size of the active fleet declined from over 1,000 vessels from 1994-2001 to less than 400 vessels in 2012 the management concern shifted to fleet diversity. Fleet diversity has been cast in terms of vessels based on characteristics such as size, gear, and region rather than their share in landings or economic value. This lends itself to indices used to measure biodiversity such as richness, and the numbers equivalent of the Simpson's Index and Shannon Index. The paper describes the management context surrounding the transition from concerns over capacity to fleet diversity and provides estimates of fleet diversity from 1996 to 2012. The results indicate that fleet diversity as measured by the Shannon Index has declined by approximately 35% from 1996 to 2012 yet there were 40 vessel types or "species" that were present in all 17 years. These vessel types accounted for about 85% of active groundfish vessels and over 90% of total groundfish landings in all years. Thus, even though the size of the fleet and overall diversity has declined the "core" groundfish fleet remains.

Keywords: fishery management, fleet diversity, biodiversity index

INTRODUCTION

The New England groundfish fishery is prosecuted in Northwest Atlantic waters of the United States EEZ by fishermen using both fixed (gillnet and hook gears including bottom longline, tub trawls, and rod and reel) and trawl gears. The groundfish resource is distributed throughout waters of the Gulf of Maine and Georges Bank and to a lesser extent Southern New England and the Mid-Atlantic bight. The overwhelming majority of landings occur in the New England states, which is why the fishery is commonly referred to as the New England groundfish fishery. Management measures for the fishery are developed by the New England Fishery Management Council (NEFMC) under the Northeast Multispecies Fishery Management Plan (hereafter referred to as the Groundfish FMP) and implemented by the National Marine Fisheries Service (NMFS). The principal species managed under the Groundfish FMP include cod, haddock, Acadian redfish, pollock, and white hake, as well as several flatfish species including yellowtail flounder, winter flounder, American plaice, and witch flounder. Some of these species (cod, haddock, yellowtail flounder, and winter flounder) are further subdivided into stock areas and the Georges Bank cod, haddock, and yellowtail flounder stocks are shared between the US and Canada.

The first Groundfish FMP was implemented in 1986 after having abandoned quota-based management of cod, haddock, and yellowtail flounder from 1978 to 1982 and an Interim Groundfish FMP in effect from 1982 to 1985 which was intended to provide the Council with the time to formulate a longer term approach to management of the fishery. The first FMP established a major policy that would guide management of the groundfish fishery over time [1]. This policy was based on the recognition that the fishery had always operated in an adaptive manner taking advantage of natural fluctuations in species abundance, and that management actions should be avoided that would secure benefits for a single stock. Included in the major policy were biological considerations based on minimum abundance levels defined as a level of abundance below which there is an unacceptably high risk of recruitment failure. Economic criteria were not to be considered in setting minimum abundance levels. The major policy did not include any specific social or economic benchmarks or thresholds. Rather, the policy emphasized allowing fishery operations to evolve with minimal regulatory intervention as well as freedom of choice for fishermen. The Council also sought to avoid abrupt economic dislocations in implementing the major policy. Notably, in doing so

> "…in no event shall continued access by individual fleet sectors, net economic impacts on individual fishermen, or impacts on quality of life be considered in framing management measures developed consistent with this policy." [1]

This statement of management approach did not necessarily mean that the Council was indifferent about matters of fleet diversity, but that management approaches would not seek to adopt measures that would create preferential treatment to explicitly affect any particular composition of the groundfish fleet. Of course, it is also true that in 1987 neither fleet size nor fleet diversity were thought to be contemporary management problems.

Since its inception, the Groundfish FMP has been amended 17 times and has been modified through an abbreviated process of framework adjustments on 49 occasions. With a few exceptions, the primary focus of these management actions was to meet biological imperatives driven by either litigation, changes in statutory requirements, or new stock assessment information. Brodziak et al. [2] chronicle these events and management response from a biological perspective beginning with the lawsuit filed by the Conservation Law Foundation (CLF) in 1991 through the third Groundfish Assessment Review Meeting in 2008. The CLF lawsuit eventually led to Amendment 5 to the Groundfish Plan in 1994, which established a limited access effort control program that would be the primary management regime for the fishery until it transitioned to the current catch share system known as sector allocation.

The extent to which fleet size or its composition was viewed as a management problem has changed over time. Any Council or Council-related meeting must be announced in the Federal Register (FR) in which information on the meeting type (Council, Oversight or Ad-Hoc Committees of the Council, Plan Development Teams, Industry Advisory Panels, or Scientific and Statistical Committee), date, location, and meeting summary is provided. The meeting summary describes the general topics that may be discussed at each meeting. This does not necessarily mean that all topics included in the meeting summary have to be discussed, nor does it limit the possibility that topics that are not listed in the FR may come up. However, substantive action or votes cannot be taken on topics that have not been included in the FR meeting announcement. For this reason, the FR meeting summaries were used as an indicator of relative importance and prior development of considerations related to either fleet size and/or fleet diversity. Procedurally, the meeting summary from each of 98 FR meeting announcements from calendar years 1996 through 2013 was reviewed for any topic or key word related to either fleet size or diversity and assigned a value of 1 if that topic was mentioned. These keywords were then grouped into sub-topics. For fleet size the sub-topics included capacity, buybacks, latent effort, and consolidation, whereas the fleet diversity sub-topics included fleet visioning, diversity, and accumulation limits. The frequency counts for each sub-topic were summed over six-month intervals beginning in January, 1996 and ending in December, 2013 as depicted in Figure 1.

From 1996 through 2004 Federal Register meeting summaries only included topics related to fleet size. During these years the effort control program became increasingly restrictive leading to extensive deliberations over the size of the fleet, the potential for activation of latent permits and effort, and the economic viability of the fleet. Responses to these concerns included vessel and latent permit buybacks, redefining days at sea (DAS) allocations in terms of "effective" days based on demonstrated use, a permit transfer program as well as DAS leasing. Buybacks were implemented in three stages, a pilot vessel buyback was conducted in 1995 followed by an expanded vessel buyback in 1996 and a latent permit buyback which was implemented in 2001 [3]. Although these buybacks were actually implemented by the NMFS through Congressional appropriations the Council supported the buybacks and was engaged in their design[1]. In addition to the permit buyback, deliberations over latent effort eventually led to the recalibration of DAS allocations as "effective" days first in 2002 as part of a Settle Agreement to a lawsuit filed by the CLF in 2000 and then continued with modifications with implementation of Amendment 13 in 2004. Concerns over the economic viability of fishing operations took the form of management measures to promote consolidation, which would serve the dual purpose of improving individual financial stability by increasing the number of DAS that an individual fishing business could acquire and reducing fishing capacity. Management actions to promote consolidation that had been under development from July 1998 to December 2003 included DAS transfer and leasing of DAS where the former would allow the permanent acquisition of DAS by merging two limited access permits onto one vessel while the latter was a temporary transfer of DAS from one vessel to another. Both of these programs were included in Amendment 13.

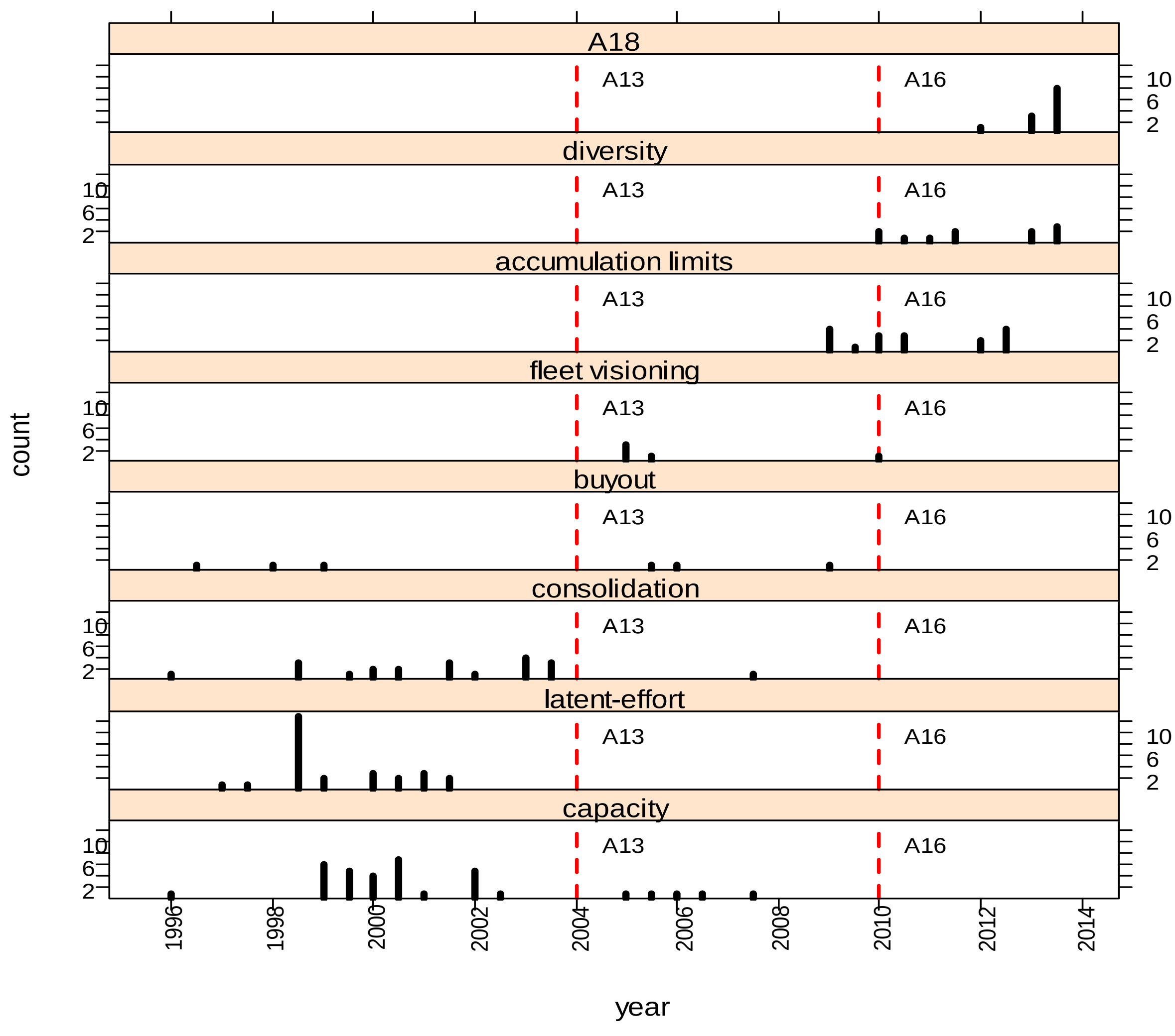

Fig. 1: Topics appearing in Federal Register meeting summaries 1996 to 2014

[1] Appropriations for the pilot vessel buyback came from the Emergency Supplemental Appropriations Act, 1994 and appropriations for the expanded vessel buyback came from the Fisheries Disaster Assistance Act, 1996. Appropriation for the latent permit buyback was from the Military Construction Appropriations Act, 2001.

Fleet diversity was not mentioned in any FR meeting announcement for a Council-related meeting until 2005, yet maintaining a diverse fleet was included as a management objective for Amendment 13. This objective was counterbalanced by the management goal to create a management system so that fleet capacity will be commensurate with resource conditions. Nevertheless, even though the Amendment did not include any specific measures to promote fleet diversity, the fact that it was included as a management objective is an indication that fleet diversity was an emerging management issue prior to 2004.

Fleet diversity was first mentioned in a Council-related FR meeting announcement during 2005 in which progress reports on a fleet visioning project initiated by the Northwest Atlantic Marine Alliance (NAMA) were scheduled for a series of meetings. The fleet visioning project was completed in December 2005 [4], but issues related to fleet diversity were not taken up again in earnest until 2010 and 2011 as concerns over allocations resulting from qualification criteria for Potential Sector Contribution (PSC) shares adopted for Amendment 16 spilled over into issues of fleet diversity and accumulation limits. These issues led to initiation of Amendment 18 in 2012 which is intended to develop management measures to deal with fleet diversity and establish limits to accumulating either permits or PSC in the groundfish fishery.

Although fleet diversity has been identified as a management problem, a systematic approach is lacking to measure the diversity of the existing groundfish fleet and how fleet diversity has changed over time. This paper develops measures of fleet diversity based on common biodiversity indices and applies these indices to measure fleet diversity change from 1996-2012. The following section describes the underlying rationale for the analytical approach as well as the formulation of the selected diversity indices. The third section describes data sources and the forth section reports fleet diversity change over time. The last section includes discussion and conclusions.

METHODS

To date, deliberations over fleet diversity in the New England groundfish fishery have focused on the structure of the fishing fleet in terms of the presence or absence of specific types of vessels and numbers of each, rather than on their share of groundfish landings or fishing revenue. This is analogous to the population size and composition of species in an ecosystem or its biodiversity. The most common measures of biodiversity include richness (the number of vessel types), Simpson's index, and the Shannon index. A general formula for biodiversity based on Hill [5] is given by

$$ {}^{q}D \equiv \left(\sum_{i=1}^{N} p_i^q \right)^{1/(1-q)} \qquad \text{(Eq. 1)} $$

where p_i is the share of vessel type i of the entire fleet and q is referred to as the diversity order. The order of diversity is related to its sensitivity to common and rare vessel types [6]. Diversity of order 0 is insensitive to proportional abundance and is equal to the number of vessel types or richness. In this case, the fact that there are more of some vessel types than others is completely irrelevant. Diversity orders between 0 and 1 would give more weight to rare vessel types while diversity orders greater than 1 give more weight to common vessel types. For example, the Simpson's index is of order 2 and is calculated as

$$ SI = \sum_{i=1}^{N} p_i^2 \qquad \text{(Eq. 2)} $$

By squaring the proportional abundance of each vessel type, the Simpson's index weights the proportions of "abundant" vessel types more heavily than less abundant vessel types. Only the Shannon index (diversity of order 1) weights more and less abundant vessel types according to their relative frequencies [6]. For this reason fleet diversity is measured by the Shannon index [7] calculated as

$$SH = -\sum_{i=1}^{N} p_i * ln_e p_i \; where \; p_i = \frac{q_i}{V} \qquad \text{(Eq. 3)}$$

where i denotes vessel type, N is the total number of vessel types, p_i is the number of vessels of type i (q_i) divided by total vessels (V).

Both the Simpson's and Shannon index are entropy indices, which provide a measure of the uncertainty or likelihood that any two vessel types drawn at random would be different vessel types and not a measure of true diversity [6]. For this reason, the Shannon index is converted into its "numbers equivalent" [5] given by

$$^{1}D = e^{SH} \qquad \text{(Eq. 4)}$$

The numbers equivalent is interpreted as the number of vessel types of equal abundance that would be associated with the calculated diversity index. True diversity for the Simpson's index is equal to its inverse.

The construction of the Shannon index means that the index for groups of vessel types are additive across all groups [8]. This is also true of the Simpsons index. In this manner the contribution of sub-groups to the diversity index can be identified to examine trends in specific components of the fleet.

The Shannon index is a composite of the number of vessel types and their relative abundance or evenness. Evenness refers to the degree to which the abundance or number of vessels of each type is the same [9]. In cases where abundance is the same for all vessel types the numbers equivalent of both the Shannon and Simpson's index is equal to one another and is equal to richness. As abundance among vessel types becomes increasingly unequal, evenness declines. The Gini coefficient provides a measure of the relative difference between the actual distribution of abundance and equal abundance among all vessel types. The Gini coefficient is related to the Lorenz curve which is the cumulative distribution of the share of abundance of each vessel type. The Gini coefficient measures the difference between the Lorenz curve and the cumulative distribution of equal shares and may be calculated as

$$G = \frac{\sum_{i}^{N}(2i - N - 1) * v_i}{N^2 \mu} \qquad \text{(Eq. 5)}$$

where i denotes the rank (ordered from lowest to highest number of vessels), v_i is the number of vessels corresponding to rank i, N is the total number of vessel types, and μ is the average number of vessels among all vessel types. The Gini coefficient ranges from perfect evenness (0) to complete dominance by one vessel type (1).

DATA

Vessel type or "species" was based on gear, vessel size, and port-group. These characteristics are consistent with fleet diversity as it was envisioned following the Fleet Visioning Project (NAMA, 2005) as well as the goals and objectives for both Amendments 13 and 16 to the Groundfish FMP. Gear categories were based on the primary gears used to harvest groundfish including bottom longline, hook and line, gillnet, and otter trawl while vessel size categories that have been frequently used in economic impact analyses of fishery management actions. These sizes were less than 30 feet, 30 to less than 50 feet, 50 feet to less than 75 feet, and 75 feet or greater. The port-regions in the present study were based on aggregations of counties for two reasons. First, the regional aggregations chosen match those of the Northeast Region Input-Output model [10]. Second, the larger aggregations allow for some movement among ports within a region without classifying that movement as a change in fleet diversity.

Although the “fleet” of interest may be defined in several different ways, the primary management concern has been with the active limited access fleet harvesting groundfish so this is the fleet of interest for this paper. The limited access program was implemented in 1994. However, permit categories were changed beginning with 1996 and a new hand-gear limited access permit category was implemented in 2004. To construct a time series during which all limited access permits were consistent permit years 1994 and 1995 were excluded. Hand gear-only permits were also excluded since they reflect a change in permit status and not a change in the underlying fleet diversity.

Vessel trip reports (VTR) for fishing years 1996 to 2012 were used to assign each vessel with a limited access permit to gear, size, and port regions based on a preponderance of groundfish landings. The VTR data were used instead of dealer reports for two reasons. First, the number of dealer records with missing or known gear designation increased substantially following the conversion to dealer electronic reporting beginning in 2004. Second, dealer data in Connecticut and Delaware do not identify unique vessels. This means that reliance on dealer data for operators that land most of the time in either of these two states would compromise the ability to classify these vessels based on gear or port-region. Procedurally, every trip was assigned a port region based on state and county of landings as reported in the VTR. For vessels that landed groundfish, the assigned region was determined by the majority of landings reported for all species on trips that landed groundfish. Similarly, gear categories were based on whichever gear accounted for the majority of total pounds of all species landed on groundfish trips. Permit application data were used to determine vessel length. In this manner every active limited access groundfish vessel was assigned to a unique vessel type as being, for example, large/trawl/lower mid coast Maine or small/longline/Cape and Islands. This process was repeated for every fishing year from 1996 to 2012.

RESULTS

On average, 1,674 limited access permits were issued from 1998 to 2001 (Table 1). The number of permits fell to 1,439 in 2002 due to the removal of 245 permits through the latent permit buyback that was completed during 2001. Since 2002 the number of limited access permits has declined to 1,063 valid permits during 2012. Note that valid permits exclude permits that may be held in abeyance due to a permit sanction or placement of the permit in the Confirmation of Permit History Program (CPH). In the Northeast Region all permits are assigned to a unique vessel. The CPH program allows permit holders to retain their limited access permit without assigning the permit to a vessel. Since 2002, a total of 226 permits have been placed in CPH. Accounting for these permits means that there were a total of 1,317 limited access permits that were issued during 2012.

The number of limited access groundfish vessels that landed groundfish on at least one trip was at least 1,000 vessels in every year from 1996 to 2001, but has since declined to 337 vessels in 2012 (Table 1). Compared to 1996 the number of active vessels in 2012 has declined by nearly 70%. The four characteristics (5 gear types, 4 vessel sizes, and 23 regions) used to distinguish one vessel type from another results in a potential of 920 unique vessel types. Of course, the actual number of vessel types in any given fishing year was much lower ranging from a high of 95 vessel types in 1996 declining to a low of 51 vessel types in 2012; a decline of 46% (Table 1). Shannon effective diversity declined by 37% from 51 vessel types in 1996 to 32 vessel types in 2012.

The Gini coefficient was stable from 1996 to 2005 ranging from 0.59 in 2004 to 0.63 in 2002 (Table 1). Thus, the relative distribution of abundance among vessel types or evenness was relatively constant through 2005. Since then, the Gini coefficient has been on a general downward trend at an average rate of 1.6%. Since 2009, the Gini coefficient has declined in each year, which means that the relative abundance among vessel types has been becoming more even particularly during the most recent 3-4 years.

The size of the active groundfish fleet, number of vessel types, and effective diversity all declined at similar average annual rates of 1-2% from 1996 to 2001. Since 2001, the active fleet declined by an average annual rate of almost 11% through 2009 before declining at a more modest rate of 2-3% per year from 2010 to 2012. Compared to fleet size both the number of vessel types and effective diversity declined less rapidly through 2007 averaging 7.2% and 4.9% respectively. However, since 2008, the number of vessels types and effective diversity have leveled off somewhat. The total number of vessel types was 56 types in 3 of 6 years from 2008 to 2012 and effective diversity ranged from 31 to 33 vessel types in every year since 2008.

Table 1: Groundfish Fleet Size, Richness, and Effective Diversity 1996 to 2012.

Year	Limited Access Permits	Groundfish Active	Number of Vessel Types	Shannon Index	Shannon Effective Diversity	Gini Coefficient
1996	1772	1098	95	3.92	51	0.60
1997	1806	1072	92	3.89	49	0.60
1998	1669	1049	91	3.88	48	0.60
1999	1685	1013	89	3.86	47	0.60
2000	1669	1015	89	3.83	46	0.61
2001	1673	1019	92	3.84	46	0.62
2002	1439	918	89	3.77	43	0.63
2003	1427	855	81	3.75	42	0.62
2004	1473	750	74	3.69	40	0.59
2005	1413	693	75	3.70	40	0.60
2006	1398	621	63	3.62	37	0.56
2007	1380	564	58	3.53	34	0.55
2008	1328	523	56	3.49	33	0.56
2009	1290	462	62	3.49	33	0.60
2010	1248	356	56	3.44	31	0.58
2011	1153	344	56	3.51	33	0.55
2012	1063	337	51	3.46	32	0.53

For the fleet of limited access permits that landed groundfish there were a total of 132 unique vessel types that appeared in at least one year from 1996-2012. Of these, there were 40 vessel types that appeared in every year while there were 24 vessel types that appeared in only one year and an additional 8 vessel types that appeared in only two years. The former may constitute a “core” component of the fleet as these vessels represented 75% of the Shannon index, 90% of landed pounds of groundfish, and 81% of the active fleet size from 1996 to 2001 (Table 2). More recently these core vessel types have accounted for more than 98% of landed groundfish, 94% of active limited access permits, and has accounted for about 91% of the Shannon index.

In addition to the vessels that were always present or vessel types that were rarely so, there were a number of vessel types that appeared in multiple years some of which appeared in multiple consecutive years while others appeared sporadically. These sporadic vessel types as well as the rare vessel types may be the result of the decision rules used to define vessel types and not necessarily to a real change in diversity. Note that while the contraction of the fleet as a whole is unambiguous, it is the uncertainty created by the razor's edge classification for each vessel that complicates interpretation of the loss and appearance of vessel types as a real change in fleet diversity. For this reason the following examines whether there have been any notable systematic trends in diversity by gear, vessel size, or state.

Table 2: Share of Total Fleet Size, Groundfish Landings, and Shannon Index for Vessel Types Present in all Years 1996 To 2012.

Year	Fleet Size Share	Groundfish Landings Share	Shannon Index Share
1996	79%	88%	73.8%
1997	81%	89%	76.0%
1998	80%	91%	75.3%
1999	81%	91%	76.0%
2000	81%	92%	75.9%
2001	82%	93%	76.0%
2002	86%	92%	80.2%
2003	86%	93%	80.6%
2004	89%	93%	84.5%
2005	90%	92%	84.5%
2006	92%	94%	87.5%
2007	94%	95%	90.3%
2008	95%	100%	91.5%
2009	95%	99%	88.3%
2010	92%	99%	91.6%
2011	94%	99%	90.4%
2012	96%	99%	93.4%

The Shannon index is additive such that the relative role of sub-components of specific vessel types of interest can be examined. Trawl gear has represented more than half of the Shannon diversity index, ranging from a low of 56.2% in fishing year 1998 to a high of 65.6% of the index in 2012 (Table 3). Trawl gear plays a dominant role in the diversity index because there are a comparatively large number of trawl gear vessel types with high relative abundance for some of these vessel types. Gillnet gear averaged 19% of the diversity index from 1996 to 2001, but has been on an increasing trend accounting for 27.5% of the index in 2012. On average, longline gear accounted for about nearly 16% of the diversity index from 1996 to 2001, but has since declined to just over 2% in 2012. Similarly, hook (hand) gear averaged 7.8% of the Shannon index from 1996 to 2005, but declined in recent years to 2.3% in 2012.

Vessels ranging from 30 feet to less than 50 feet have accounted for at least 50% of the Shannon index in 13 of the 17 years from 1996 to 2012 ranging from a low of 49% in 1996 to a high of 53% in 2008 (Table 4). Since 2008, the relative role of vessels from 30 to 50 feet in the diversity index has been declining to 49% in 2012. Vessels ranging between 50 and 75 feet averaged 31% of the Shannon index from 1996 to 2012. The relative contribution of these vessels to the diversity index averaged about 30% from 1996-2001 before gradually increasing from 29.6% in 2001 to a high of 33.2% in 2006. Since 2006, the contribution to the Shannon index by vessels in the 50 to 75 foot range has returned to its pre-2001 level averaging about 31% from 2009 to 2012.

Table 3: Shannon Index Share by Vessel Gear Type

Year	Gillnet	Hook	Longline	Trawl
1996	18.4%	8.4%	15.5%	57.7%
1997	18.0%	9.2%	15.2%	57.5%
1998	18.6%	8.9%	16.3%	56.2%
1999	19.5%	7.2%	15.7%	57.6%
2000	20.0%	6.9%	16.2%	57.0%
2001	21.6%	6.7%	16.1%	55.6%
2002	21.4%	7.0%	12.7%	58.8%
2003	22.4%	6.3%	11.4%	59.9%
2004	22.9%	8.3%	7.6%	61.1%
2005	22.7%	9.1%	7.1%	61.1%
2006	25.0%	6.6%	6.0%	62.4%
2007	25.3%	6.3%	4.7%	63.8%
2008	25.5%	5.5%	5.9%	63.1%
2009	29.5%	4.2%	7.0%	59.3%
2010	27.4%	6.1%	4.8%	61.7%
2011	27.9%	5.6%	5.5%	61.0%
2012	27.5%	4.6%	2.3%	65.6%

Table 4: Shannon Index Share by Vessel Size Class in Feet.

Year	< 30	30 to < 50	50 to < 75	>= 75
1996	7.6%	48.8%	31.1%	12.4%
1997	7.2%	50.8%	30.1%	12.0%
1998	7.1%	51.3%	29.7%	11.9%
1999	6.5%	50.2%	30.2%	13.1%
2000	6.8%	49.4%	31.2%	12.6%
2001	6.7%	51.8%	29.6%	11.9%
2002	5.7%	51.7%	31.0%	11.6%
2003	6.0%	50.7%	31.1%	12.2%
2004	5.2%	50.0%	32.2%	12.6%
2005	4.2%	49.9%	31.9%	14.0%
2006	2.8%	50.1%	33.2%	13.9%
2007	2.5%	51.0%	32.8%	13.7%
2008	1.9%	53.2%	31.8%	13.0%
2009	3.1%	52.6%	30.4%	13.9%
2010	2.4%	51.4%	31.4%	14.8%
2011	2.8%	51.1%	30.1%	16.1%
2012	2.0%	49.4%	32.3%	16.3%

Small vessels less than 30 feet accounted for 7% of the Shannon diversity index from 1996 to 2001. Since 2001, the contribution of small vessels declined to 2.8% of the Shannon index in 2006. After 2006 the small vessel contribution to the Shannon index stabilized averaging 2.5% of the Index from 2007-2012. Vessels above 75 feet in overall length accounted for about 12% of the Shannon index from 1996 to 2003. Compared to all other size classes, the contribution of larger vessels to the diversity index has been increasing. These larger vessels accounted for 12.6% of the Shannon index in 2004, but has risen to 16.3% of the index in 2012; an average annual increase of 3.7%.

Partitioning the Shannon diversity index by state reveals a steep drop after 2005 in the proportion of the index that is associated with vessel types in Maine port groups (Table 5). From 1996 to 2005 the proportion of the Shannon index from Maine-based vessel types was stable averaging approximately 17% of the index. However, after 2005 the contribution to the Shannon index dropped considerably from 16.1% in 2005 to 10.3% in 2010. The Shannon index share for Maine limited access vessel types was higher in 2011 (12.8%) and 2012 (12.7%), but was still well below levels in years prior to 2005.

Table 5: Shannon Index Share by Vessel Type for Primary State of Groundfish Landings

Year	ME	NH	MA	RI	CT	NY	NJ	Other
1996	17.1%	6.1%	49.7%	8.8%	3.0%	9.9%	4.2%	1.2%
1997	17.9%	6.0%	51.2%	9.6%	2.0%	9.0%	3.7%	0.6%
1998	17.0%	6.0%	51.8%	8.9%	2.6%	9.1%	3.6%	0.9%
1999	16.1%	5.9%	51.4%	9.8%	2.7%	8.6%	4.4%	1.0%
2000	16.8%	6.8%	51.2%	9.4%	2.7%	8.5%	4.1%	0.6%
2001	16.7%	7.0%	53.2%	8.4%	2.5%	7.2%	4.0%	1.0%
2002	16.9%	6.7%	54.7%	7.9%	2.0%	7.4%	3.6%	0.7%
2003	16.2%	6.2%	55.0%	8.7%	2.0%	6.9%	3.3%	1.7%
2004	16.2%	7.1%	54.0%	9.0%	1.8%	6.3%	3.7%	1.9%
2005	16.1%	7.3%	52.8%	8.6%	2.5%	6.9%	4.1%	1.6%
2006	14.9%	7.4%	53.1%	9.9%	1.9%	7.2%	4.5%	1.1%
2007	13.7%	5.9%	54.3%	11.6%	1.4%	7.1%	5.4%	0.6%
2008	11.1%	6.0%	55.8%	11.5%	1.2%	7.9%	5.6%	1.0%
2009	10.8%	7.0%	58.7%	10.5%	1.7%	8.0%	2.3%	1.1%
2010	10.3%	7.3%	58.3%	11.5%	0.8%	7.7%	3.1%	1.0%
2011	12.8%	7.6%	54.4%	11.7%	1.3%	7.6%	3.9%	0.5%
2012	12.7%	7.2%	52.5%	13.8%	0.5%	7.3%	4.9%	1.0%

The majority of the reduction in Maine-based vessel types took place during 2006, 2007, and 2008 as the contribution to the total fleet diversity index declined by an average of 10.5% per year. This sharp decline was due to two interrelated factors. First, the overall decline in the total number of vessels classified as being in a Maine region declined at a faster rate than the fleet as a whole. As noted earlier, the total fleet size of limited access vessels that landed groundfish declined by 69% from 1996 to 2012, but the Maine component of that fleet declined by almost 80%. Second, the higher rate of decline in the Maine fleet was due to the disappearance of several vessel types in 2006, 2007, and 2008 that had historically accounted for about 18% of the Shannon diversity index for Maine and 14% of the total Maine fleet, at least as it has been defined in this study. These vessel types include 1) trawl vessels greater than 75 feet, 2) gillnet vessels 30 to 50 feet, 3) trawl vessels from 50 to < 75 feet, 4) longline vessels 30 to 50 feet, and 5) hook vessels 30 to 50 feet. Note that this does not necessarily mean that these vessel types do not land any groundfish in a Maine port group. It only means that these vessel types landed the majority of groundfish elsewhere.

DISCUSSION

The estimated effective diversity based on the Shannon index was substantially less than the total number of vessel types (richness). This occurs for two reasons one of which has to do with the mathematical property of the index, while the other has to do with the methods used to designate vessel types.

The Shannon index is based on proportions. Mathematically, this means that the effect on the index of the most common vessel type will be larger than that of the least common vessel type. Note that under these conditions the effect on the Simpson's index would be even larger since the Simpson's index would weight common vessel types more heavily than rare vessel types. To illustrate, there were a total of 95 different vessel types that were active during fishing year 1996. Of these vessel types, the one vessel type with the highest frequency (73) accounted for 6.6% of total vessels. By contrast, there were 20 vessel types each having only one vessel of each type. Each of these "rare" vessel types account for 0.09% of the total fleet. The most common vessel type was 4.6% of the Shannon index, whereas the least common vessel type accounted for 0.2% of the Shannon index. In fact, the combined effect on the 1996 Shannon index for all 20 vessel types with only one vessel was 3.3%; still less than the influence of the single most common vessel type.

Even though the most common vessel type had a comparatively larger influence on the Shannon index than the least common vessel type in a given fishing year, loss of either the most common or least common vessel type has an opposite effect on effective diversity. Continuing to use the 1996 fishing year as an example and assuming abundance of all other vessel types remains constant, losing the most common vessel type actually results in a 1.8% increase in Shannon effective diversity. Effective diversity increases even though richness has declined, because the proportional abundance of all remaining vessel types including those of the least common vessel types has increased. This results in a comparatively more even distribution among remaining vessel types, hence, an increase in effective diversity. By contrast, the loss of one of the least common vessel types results in a 0.4% reduction in effective diversity, because even though the relative influence of the most common vessel type increases this is offset by the change in richness resulting in a decline in Shannon effective diversity.

These examples highlight the importance of more and less common vessel types in measuring fleet diversity both within a fishing year and over time. The treatment of rare "species" as compared to abundant species is of some consternation in the biodiversity literature as the loss of rare species may have important implications for ecosystem function. The implication of losing vessel type with low numbers on fleet diversity is less obvious. Fishing vessels are fungible assets that may enter and exit a fishery depending on economic conditions or may change gears, fishing location, or base of operation. Furthermore, the manner in which vessel type designations had to be made forces a razor's edge determination that is likely to be more rigid than how the groundfish fleet actually operates. Many vessels fish with more than one gear, and land groundfish in multiple ports. Forcing each vessel into a single category is likely to result in classifications that may be suitable for the most common types of vessels, but may increase the likelihood that unusual or infrequent vessel types will be identified.

CONCLUSIONS

Since 1996 the size and composition of the fleet of limited access vessels landing groundfish has undergone substantial change. The fleet size has shrunk from over 1,000 participating vessels to 337 in 2012 while measures of richness and effective diversity have also declined. Yet there remains what may be considered a core groundfish fleet that has historically accounted for at least 75% of groundfish landings, active vessels, and the Shannon diversity index. Overall, the more notable changes in the composition of the groundfish fleet in terms of fleet diversity include an increase in the relative contribution of gillnet and trawl gear, a decrease in hook and longline gear, an increase in the relative contribution of larger vessels, a reduction in the relative contribution of small vessels, and a reduction of the contribution of Maine-based vessels.

Based on the decision rules adopted herein there were a total of 132 unique vessel types indentified based on vessel size, gear, and region. As previously noted, 40 of these vessel types were present in every year leaving 92 vessel types that were present in 16 or fewer years from 1996-2012. A substantial number of these "transient" vessel types were present on only a few occasions while others were present in the majority of years. The former may be an artifact of the razor's edge decision rules which may have resulted in some artificial vessel types that may or may not represent a loss in fleet diversity. For this reason, the Shannon effective diversity measure may be a more reliable indicator of fleet diversity than richness since it will be less sensitive to rare or unusual vessel types resulting from measurement error. That said, the Shannon diversity measure will retain the ability to detect changes in richness and may be better suited to detect changes in relative abundance of the more common vessel types.

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