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Measures of fishing fleet diversity in the New England groundfish fishery

Eric M. Thunberg [a,*], Steven J. Correia [b]

[a] NOAA Fisheries Office of Science and Technology, Economic and Social Analysis Division, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA, United States

[b] Massachusetts Division of Marine Fisheries, Quest Center, 1213 Purchase St., New Bedford, MA 02740, United States

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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 1000 vessels from 1994 to 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. Measuring fleet diversity with indices commonly used in the biodiversity literature such as richness, effective diversity based on the Shannon index, and evenness appears appropriate for this context. In this paper these indices were applied to measure changes in diversity of the active New England groundfish fleet from 1996 to 2012. Fleet diversity as measured by the Shannon Index has declined by approximately 35% from 1996 to 2012, but has remained relatively stable since 2007. Forty vessel types were present in all 17 years, which accounted for about 85% of active groundfish vessels and over 90% of total groundfish landings in all years. Even though the fleet size and overall diversity have declined the “core” groundfish fleet remains stable.

1. 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 or Council) 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 U.S. 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 objectives 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

* Corresponding author.
E-mail addresses: eric.thunberg@noaa.gov (E.M. Thunberg), steven.correia@state.ma.us (S.J. Correia).

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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.

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. Throughout, the overriding management goal was to achieve a sustainable resource, consistent with U.S. national conservation objectives articulated in the Magnuson–Stevens Act. However, specific actions taken to achieve resource sustainability were prompted by either litigation, changes in statutory requirements, or new stock assessment information. Brodziak et al. [2] chronicle these events and the management response from a biological perspective beginning with the 1991 lawsuit filed by the Conservation Law Foundation (CLF) through 2008. The CLF lawsuit eventually led to Amendment 5 to the Groundfish Plan in 1994, which established a limited access effort control program coupled with limited vessel days at sea (DAS) that would be the primary management regime for the fishery until management transitioned to a catch share system known as sector allocation in 2010. Whereas meeting biological objectives were the primary drivers of management action, the management objectives guiding the choice of regulatory measures were not clearly articulated.

Even though management objectives may not be formally articulated or written down, they are often revealed through Council deliberations over management program design. Major actions developed by the Council may take several years and involve a large number of Council-related meetings (full Council, Oversight or Ad-Hoc Committees of the Council, Plan Development Teams, Industry Advisory Panels, or Scientific and Statistical Committee), all of which must be announced in the Federal Register (FR). In each FR announcement the type of meeting, date, location, and a meeting summary are provided, where the meeting summary describes the general topics that may be discussed. This does not necessarily mean that all topics included in the meeting summary have to be discussed, nor does it limit the possibility that issues or topics 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. This means that the FR meeting summaries are limited to management objectives that have typically been under development over multiple meetings, around which, some consensus has been reached. For this reason, the FR meeting summaries were used as an indicator of revealed management objectives. Since the interest in this study is on management objectives related to fleet size and/or fleet diversity and how these objectives may have changed over time, the focus was on FR meeting summaries that addressed these or related topics. 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. 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 Fig. 1.

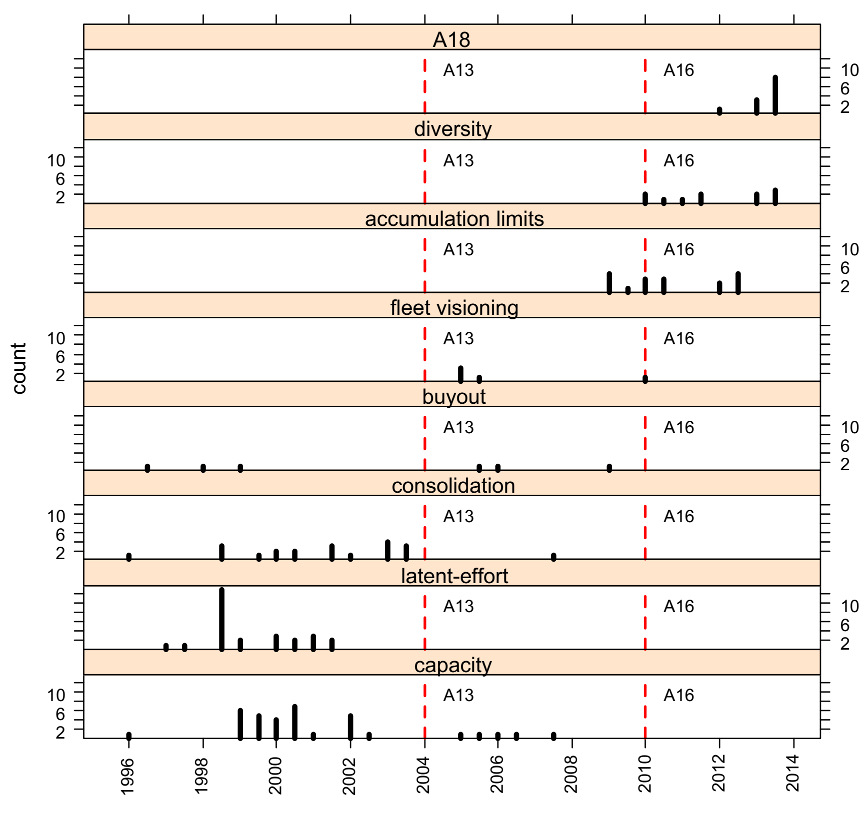

Fig. 1. Topics appearing in Federal Register meeting summaries 1996–2013.

From 1996 through 2004 FR 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 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]. In addition to a 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.

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.

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 objective, a systematic approach is lacking to quantify the diversity of the existing groundfish fleet and document how fleet diversity has changed over time. This paper quantifies fleet diversity based on common biodiversity indices and applies these indices to document fleet diversity change from 1996 to 2012. Throughout "vessel types" is used as a substitute for "species" for clarity in exposition. The following section describes the underlying rationale for the analytical approach as well as the formulation of the selected diversity indices. Section 3 outlines the data sources and definitions for each vessel type. Section 4 reports results and trends in fleet diversity. Section 5 discusses the results and Section 6 concludes.

2. 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 describing an ecosystem or biodiversity using a simple count and abundance of species. The most common measures of biodiversity include richness (herein, number of vessel types), the Simpson index, and the Shannon index. A general formula for biodiversity (in this case fleet diversity) based on Hill [5] is given by

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

where p_i is the proportional 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 order 0 is insensitive to proportional abundance and is equal to the number of vessel types or richness. In this case, that some vessel types are more numerous than others is irrelevant. Diversity orders between 0 and 1 give more weight to less common vessel types, while diversity orders greater than 1 give more weight to more common vessel types. For example, Simpson's index is of order 2 and is calculated as

$$SI = \sum_{i=1}^{N} p_i^2 \tag{2}$$

By squaring the proportional abundance of each vessel type, Simpson's index weights the proportions of common vessel types more heavily than less common vessel types. Only the Shannon index (diversity order 1) weights more and less common vessel types according to their relative frequencies. This mathematical property is consistent with present management practice as no management measures have been developed or proposed that would either favor more or less common vessel types. For this reason, the Shannon index [7] is used to measure fleet diversity where the index is calculated as

$$SH = -\sum_{i=1}^{N} p_i * \ln(p_i) \tag{3}$$

where N is the total number of vessel types. The Shannon index is an entropy index, which measures the uncertainty or likelihood that any two vessels drawn at random would be different vessel types [6]. However, the numeric value of the Shannon index does not provide an estimate of the effective number (hereafter referred to as effective diversity) of vessel types that are present. Effective diversity is interpreted as the number of vessel types of equal abundance that would be associated with the calculated diversity index [5]. Effective diversity has the advantage of converting indices of diversity to a common scale. Effective diversity for the Shannon index is given by

$$^{1}D = e^{SH} \tag{4}$$

The construction of the Shannon index means that the index for groups of vessel types are additive across all groups [8]. In this manner the contribution of sub-groups to the diversity index can be identified to examine trends in specific components of the fleet. These trends can be examined based on the absolute value of the partial index or each sub-group's share in the total index.

The Shannon index represents a composite of the number of vessel types and their relative abundance. The distribution of relative abundance is referred to as evenness, which is 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

Shannon effective diversity equals richness. As abundance among vessel types becomes increasingly unequal, evenness declines. This can occur even as total abundance and richness remain constant. Thus, evenness provides additional information on the distribution of relative abundance among vessel types.

In this study evenness was measured following [9], which is a special case of the similarity index of niche overlap used by Feinsinger et al. [10]. Feinsinger et al. [10] measure the area of intersection between two frequency distributions. Bulla's evenness measure is based on the concept of niche overlap except that the distributions to be evaluated are that of the observed and a uniform frequency distribution [8]. Bulla's evenness index is calculated as

$$O = 1 - 0.5\sum_{i}^{S}|p_i - q_i| = \sum_{i}^{S}\min(p_i, q_i) \quad (5)$$

where p_i is the proportional abundance of vessel type i, S is richness, and q_i is $1/S$. To assure that the index ranges between 1 and 0 [9] adjusts the index by

$$E = \frac{O - 1/S + (S-1)/N}{1 - 1/S + (S-1)/N} \quad (6)$$

where N is total abundance and O is defined as above. However, [11] questions the relevance of a zero value for an evenness index in practice, and points out that Bulla's adjustment is undefined in the extreme case where $S=1$. Beisel et al. [12] found E and O to be highly correlated in a comparative analysis of 14 indices of evenness for 189 populations. The authors also found O highly correlated with all but one of the indices that were tested. Furthermore, O satisfies all the required properties of an evenness index and the majority of desired features outlined in [13]. For these reasons, the evenness index O is used without Bulla's adjustment. Note that the cumulative distribution of the observed and uniform frequency distributions yields the Lorenz curve. In this manner, O is related to the Gini coefficient, which is often used in economics as an index of inequality [14]. However, the Gini coefficient is inversely related to O, as a Gini coefficient approaching 1 would signify increasing inequality, whereas an O value of 1 would signify equal abundance. Furthermore, O is a simple measure of percent overlap between two distributions, which has an intuitive interpretation.

3. Data

In this study vessel type or "species" was defined based on gear, vessel size, and port-group. These characteristics are consistent with fleet diversity as it was envisioned following the Fleet Visioning Project [4] as well as the goals and objectives for both Amendments 13 and 16 to the Groundfish FMP. Gear was characterized as one of the primary gears used to harvest groundfish including bottom longline, hook and line, gillnet, and otter trawl. Vessel size categories correspond to those that have been frequently used in economic impact analyses of fishery management actions. These sizes were less than 30 ft, 30 to less than 50 ft, 50 ft to less than 75 ft, and 75 ft or greater. In this study port-regions were based on aggregations of counties for two reasons. First, the regional aggregations chosen match those of the Northeast Region Input–Output model (see Table 1) [15]. Second, the larger aggregations allow for some movement among ports within a region without classifying that movement as a change in fleet diversity.

There are a number of "fleets" that may be of interest depending on permit type and fishing activity and a data base was developed that would accommodate several alternative fleet definitions. However, the primary management concern has been with the active limited access fleet harvesting groundfish, and in the interest of brevity, this fleet is the primary focus. Throughout, active was defined as having landed at least one pound of any species and groundfish species was defined as any of the 10 "large mesh" species regulated under the Northeast Multispecies FMP. Permit application data were used to determine valid limited access groundfish permits by fishing year from 1996 to 2012. Although the limited access program was implemented in 1994, Amendment 7 altered the limited access permit categories beginning with 1996. Additionally, a new hand-gear only limited access permit (category HA) was implemented in 2004. Although qualifying vessels for this new permit were a relatively small component of the fishery, their inclusion would change the diversity index from 2004 onward. This would reflect a change in permit status rather than the underlying fleet diversity. To construct a time series during which all limited access permits were consistently defined, fishing years 1994 and 1995 as well as HA permits were excluded from the analysis.

Vessel trip reports (VTR) for fishing years 1996–2012 were used to assign each vessel with a limited access permit to gear, size, and port regions based on a preponderance of groundfish landings. 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. Note that trips that had missing information on either gear or port region were excluded, and all trips taken by vessels for which length was missing were eliminated. Using these criteria, a unique vessel type (for example, large/trawl/lower mid-coast Maine or small/longline/Cape and Islands) was assigned to every vessel with a limited access groundfish permit. This process was repeated for every fishing year from 1996 to 2012.

4. Results

On average, 1707 limited access permits were issued from 1996 to 2001 (Table 2). The number of permits fell to 1434 in 2002 primarily 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 1063 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. As of 2012, a total of 254 were held in CPH. Accounting for these permits means that a total of 1317 limited access permits were issued during 2012.

Possession of a limited access permit does not necessarily mean that a vessel owner will choose to fish for groundfish, or for that matter, will fish at all. On average, 62% of limited access permit holders landed groundfish, while about 22% of vessels fished for something other than groundfish, 16% of all limited access permits issued from 1996 to 2003 were inactive (Table 2). Since 2003, the number of active groundfish vessels has declined to 344 vessels in 2012, which is about one-third of limited access permits issued. Compared to the active groundfish fleet in 1996 the size of the 2012 groundfish fleet has fallen by about 70%.

The four characteristics (4 gear types, 4 vessel sizes, and 23 regions) used to classify one vessel type from another potentially results in 368 unique vessel types. Of course, the actual number of vessel types (richness) in any given fishing year was much lower

Table 1
Northeast region port group definitions.

Region name	County
Downeast, ME	Washington
Upper Mid-Coast, ME	Hancock, Knox, Waldo
Lower Mid-Coast, ME	Androscoggin, Cumberland, Kennebec, Lincoln, Sagadahoc
Southern, ME	York
NH Seacoast	Hillsborough, Rockingham, Strafford
Gloucester, North Shore	Essex
Boston Area	Middlesex, Norfolk, Plymouth, Suffolk
Cape and Islands	Barnstable, Dukes, Nantucket
New Bedford, South Shore	Bristol
Rhode Island	Bristol, Kent, Newport, Providence, Washington
CT Sea Coast	Fairfield, Middlesex, New Haven, New London
NY Coastal	Bronx, Kings, Nassau, New York, Queens, Richmond, Rockland, Suffolk, Westchester
NJ North	Bergen, Essex, Hudson, Morris, Passaic, Sussex, Union, Warren
NJ South	Atlantic, Burlington, Camden, Cape May, Cumberland, Gloucester, Hunterdon, Mercer, Middlesex, Monmouth, Ocean, Salem, Somerset
DE Coastal	Kent, New Castle, Sussex
MD West	Anne Arundel, Baltimore, Baltimore City, Carroll, Cecil, Harford, Howard, Montgomery, Prince George
MD East	Calvert, Caroline, Charles, Dorchester, Kent, Queen Anne's, St. Mary's, Somerset, Talbot, Wicomico, Worcester
VA East	Accomack, Northampton
VA North	Essex, Fairfax, King and Queen, King George, King William, Lancaster, Manassas City, Manassas Park City, Middlesex, New Kent, Northumberland, Prince William, Richmond, Stafford, Westmoreland
VA South	Charles City, Chesapeake City, Chesterfield, Colonial Heights City, Gloucester, Hampton City, Henrico, Isle of Wight, James City, Mathews, Newport News City, Norfolk City, Poquoson City, Portsmouth City, Prince George, Richmond City, Suffolk City, Surry, Virginia Beach City, Williamsburg City, York
NC North	Bertie, Camden, Chowan, Currituck, Pasquotank, Perquimans, Tyrell Washington
NC Central	Beaufort, Carteret, Craven, Dare, Hyde, Pamlico, Pitt
NC South	Brunswick, New Hanover, Onslow, Pender

Table 2
Summary of limited access groundfish permits and activity (1998–2012).

Year	Limited access permits	Active primary gear groundfish fleet	Active non-groundfish fleet	Inactive permits
1996	1768	1114	384	270
1997	1802	1080	395	327
1998	1666	1058	363	245
1999	1677	1027	386	264
2000	1664	1022	385	257
2001	1668	1030	375	263
2002	1434	926	293	215
2003	1425	860	315	250
2004	1472	752	359	361
2005	1413	697	318	398
2006	1398	624	350	424
2007	1380	568	342	470
2008	1328	530	306	492
2009	1290	466	333	491
2010	1248	363	390	495
2011	1153	351	342	460
2012	1063	344	343	376

Table 3
Fleet diversity indicators for the active limited access groundfish fleet.

Year	Richness	Shannon index	Effective diversity	Overlap
1996	98	3.94	51	0.53
1997	95	3.90	49	0.52
1998	92	3.89	49	0.53
1999	91	3.86	48	0.52
2000	91	3.84	47	0.53
2001	94	3.85	47	0.52
2002	90	3.77	44	0.51
2003	82	3.74	42	0.53
2004	75	3.69	40	0.53
2005	74	3.70	40	0.54
2006	64	3.62	37	0.57
2007	60	3.54	34	0.57
2008	60	3.53	34	0.57
2009	63	3.49	33	0.54
2010	61	3.47	32	0.54
2011	57	3.51	33	0.57
2012	53	3.49	33	0.60

ranging from a high of 98 vessel types in 1996 to a low of 53 vessel types in 2012; a decline of 46% (Table 3). Effective diversity based on the Shannon index declined by 37% from 51 vessel types in 1996 to 33 vessel types in 2012. However, both richness and effective diversity have been fairly stable since 2007 as richness has ranged from 63 to 53 vessel types and effective diversity ranged between 32 and 34 vessel types. This means that even though the size of the active groundfish fleet continued to decline, fleet diversity did not appreciably change from 2007 to 2012. The distribution of vessel types has also become more even as the evenness index *O* has increased, which means that the proportional abundance among more common and less common vessel types has decreased.

The Shannon index is additive such that the relative role of subcomponents 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 54.7% in fishing year 2001 to a high of 64.4% of the index in 2012 (Table 4). Trawl gear dominates 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 19.4% of the diversity index from 1996 to 2001 but has been on an increasing trend, accounting for 27.9% of the index in 2012. On average, longline gear accounted for just over 16% of the diversity index from 1996 to 2001, but has since declined to approximately 2% in 2012. Similarly, hook (hand) gear averaged 7.6% of the Shannon index from 1996 to 2005, but has also declined in recent years to 5.5% in 2012.

Vessels ranging from 30 ft to less than 50 ft have accounted for at least 50% of the Shannon index in 14 of the 17 years from 1996 to 2012 ranging from a low of 49.1% in 2012 to a high of 53.5% in 2008 (Table 5). More recently, the relative contribution of vessels from 30 to 50 ft in the diversity index has consistently declined

Table 4
Shannon index percent share by gear.

Year	Gillnet	Hook	Longline	Trawl
1996	18.5	8.3	16.2	56.9
1997	18.1	9.5	15.4	57.0
1998	18.4	9.0	16.8	55.8
1999	19.4	6.9	16.2	57.5
2000	20.1	7.0	16.0	56.9
2001	21.5	6.7	17.1	54.7
2002	21.8	6.8	13.1	58.3
2003	22.6	5.7	11.9	59.9
2004	22.9	7.9	8.1	61.0
2005	23.1	8.6	7.4	60.9
2006	25.5	6.7	5.8	62.0
2007	25.8	6.1	5.1	63.0
2008	26.0	5.4	6.2	62.4
2009	29.9	5.1	6.5	58.5
2010	27.9	5.4	5.6	61.1
2011	28.0	5.8	5.4	60.8
2012	27.9	5.5	2.2	64.4

Table 5
Shannon index percent share by vessel size category.

Year	< 30′	30′ to < 50′	50′ < 75′	75′ +
1996	7.6	49.4	31.1	11.9
1997	7.3	51.0	30.1	11.5
1998	7.7	51.3	29.5	11.5
1999	6.6	50.7	29.7	12.9
2000	6.8	49.4	31.7	12.1
2001	7.0	52.0	29.5	11.5
2002	5.7	51.9	30.9	11.6
2003	6.2	50.5	31.5	11.7
2004	5.2	50.5	32.4	11.9
2005	4.2	50.6	32.0	13.3
2006	2.8	50.7	33.4	13.2
2007	2.8	51.7	32.7	12.8
2008	2.2	53.5	32.1	12.2
2009	3.1	52.9	30.7	13.2
2010	2.3	52.1	31.1	14.5
2011	2.7	51.1	30.5	15.6
2012	1.9	49.1	32.9	16.0

from 53.5% in 2008 to 49.1% in 2012. Vessels ranging between 50 and 75 ft averaged 31.3% of the Shannon index from 1996 to 2012. The relative contribution of these vessels to the diversity index averaged about 30% from 1996 to 2001 before gradually increasing from 29.5% in 2001 to a high of 33.4% in 2006. Since 2006, the contribution to the Shannon index by vessels in the 50–75 ft range has returned to its pre-2001 level, averaging about 31% from 2009 to 2012. Small vessels less than 30 ft accounted for 7.2% 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 at an annual average rate of 12%. After 2006 the small vessel contribution to the Shannon index stabilized, averaging 2.5% of the index from 2007 to 2011, but fell to 1.9% of the Shannon index in 2012. Vessels above 75 ft in overall length accounted for about 12% of the Shannon index from 1996 to 2003. Compared to all other size classes, larger vessel's contribution to the diversity index has been increasing. These larger vessels accounted for 11.9% of the Shannon index in 2004, but rose to 16.0% of the index in 2012.

Partitioning the Shannon diversity index by state reveals a steep drop after 2005 in the contribution of the index that is associated with vessel types in Maine regions (Table 6). From 1996 to 2005 the contribution to the Shannon index from Maine-based vessel types was stable, averaging approximately 17% of the index. After 2005, however, the contribution to the Shannon index dropped considerably from 16.0% in 2005 to 10% in 2010. The

Table 6
Shannon index percent share by primary landing state.

Year	ME	NH	MA	RI	CT	NY	NJ	Other
1996	17.1	6.0	49.6	8.8	3.0	9.8	4.3	1.3
1997	17.9	6.0	51.0	9.4	2.1	9.0	3.8	0.8
1998	17.0	5.9	51.4	9.1	2.7	9.1	3.6	1.2
1999	16.2	5.9	51.0	9.7	2.9	8.5	4.5	1.3
2000	16.6	6.7	50.8	9.5	2.9	8.4	4.4	0.7
2001	16.5	6.9	52.8	8.2	2.4	7.4	4.4	1.3
2002	16.8	6.6	54.2	7.9	2.0	7.5	3.8	1.1
2003	16.1	6.0	54.8	8.6	2.0	7.0	3.4	2.1
2004	16.1	7.1	54.0	9.0	1.8	6.5	3.7	1.9
2005	16.0	7.1	52.6	8.6	2.5	7.2	4.2	1.8
2006	14.7	7.3	52.9	9.9	1.9	7.5	4.7	1.1
2007	13.5	5.9	54.2	11.9	1.4	7.1	5.6	0.6
2008	10.9	6.2	54.9	11.7	1.5	7.7	5.5	1.6
2009	10.7	6.9	58.3	10.6	1.7	7.9	2.7	1.0
2010	10.0	7.2	57.3	11.5	0.8	8.2	3.5	1.4
2011	12.6	7.7	53.9	11.6	1.3	8.1	4.2	0.5
2012	12.4	7.1	51.8	14.4	1.0	7.1	5.3	1.0

Shannon index share for limited access vessel types that landed groundfish was higher in 2011 (12.6%) and 2012 (12.4%), but was still well below levels in years prior to 2005.

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 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 is attributable 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 that fleet has been defined in this study. These vessel types include i) trawl vessels greater than 75 ft, ii) gillnet vessels 30–50 ft, iii) trawl vessels from 50 to < 75 ft, iv) longline vessels 30–50 ft, and v) hook vessels 30–50 ft. 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.

5. Discussion

For the fleet of limited access permits landing groundfish, a total of 131 unique vessel types appeared in at least one year from 1996 to 2012. Of these, 40 vessel types (see Table 7) were present in every year while 20 vessel types appeared in only one year. An additional 9 vessel types appeared in only two years (Table 8). The former may be considered as a “core” component of the fleet as these vessels represented 75% of the Shannon index, 91% of landed pounds of groundfish, and 81% of the active fleet size from 1996 to 2001 (Table 9). Since 2001, the share of total fleet size, groundfish landings, and the Shannon index by this core fleet has increase and was 95.1%, 99.1%, and 92.2%, respectively, in 2012.

In addition to the vessel types that were always present there were a substantial 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 may be an artifact of the decision rules used to define vessel types and may not necessarily represent a real change in diversity. To further examine diversity change all vessel types that were present in at least any five consecutive years were identified. This

Table 7
Vessel types that were present in all years from 1996 to 2012.

Region	Gear	Size class
Upper Mid-Coast Maine	Trawl	30 to < 50, 50 to < 75
Lower Mid-Coast Maine	Gillnet	30 to < 50
	Trawl	30 to < 50, 50 to < 75
Southern Maine	Gillnet	30 to < 50
	Trawl	30 to < 50
NH Seacoast	Gillnet	30 to < 50
	Trawl	30 to < 50, 50 to < 75
Gloucester, North Shore	Gillnet	30 to < 50, 50 to < 75
	Hook	30 to < 50
	Trawl	30 to < 50, 50 to < 75, 75+
Boston Area	Gillnet	30 to < 50, 50 to < 75
	Hook	30 to < 50
	Trawl	30 to < 50, 50 to < 75, 75+
Cape and Islands	Gillnet	30 to < 50
	Hook	30 to < 50
	Longline	30 to < 50
	Trawl	30 to < 50, 50 to < 75
New Bedford, South Shore	Gillnet	30 to < 50
	Trawl	50 to < 75, 75+
Rhode Island	Gillnet	30 to < 50
	Trawl	30 to < 50, 50 to < 75, 75+
Connecticut Sea Coast	Trawl	50 to < 75
Seacoast, NY	Gillnet	30 to < 50
	Trawl	30 to < 50, 50 to < 75
Northern NJ	Trawl	30 to < 50, 50 to < 75

Table 8
Summary of years present and frequency.

Years present	Frequency
1	20
2	9
3	3
4	5
5	6
6	4
7	4
8	4
9	5
10	8
11	2
12	4
13	6
14	2
15	6
16	3
17	40

decision rule was adopted to discern between extirpation of any given vessel type, which would be considered a loss in diversity, from that attributable to the razor's edge definitions used to assign a vessel type to each vessel. In this study the actual number of consecutive years including beginning and ending year for any vessel type meeting the decision rule is reported. For purposes of discussion this interval is referred to as "qualifying" years. Additionally, the total number of years present, the last year present, and the minimum and maximum number of vessels present during the qualifying consecutive years are reported.

A total of 36 different vessel types were not present in all 17 years, but were present for at least five consecutive years. These vessel types included 12 (Table 10) where the last consecutive year was the same as the last year the vessel type was present, and 24 vessel types (Table 11) that met the five consecutive year criterion, but were also present in other years. Among the former vessel types several features emerge. First, 9 of the 12 vessel types listed in Table 10 were classified as either hook or longline vessels. Second, 5 of the 12 were less than 30-ft in length. Third, for 4 of

Table 9
Percent share of fleet size, landed groundfish and the Shannon index by vessel types present from 1996 to 2012.

Year	Fleet size share	Groundfish landings share	Shannon index share
1996	78.6	87.9	73.1
1997	81.1	89.6	76.0
1998	80.3	91.2	75.1
1999	81.2	92.4	76.0
2000	81.4	92.4	75.9
2001	81.0	93.5	75.2
2002	85.7	93.7	79.7
2003	86.4	93.9	80.8
2004	89.4	93.4	84.4
2005	89.7	93.9	84.4
2006	92.0	95.3	87.8
2007	93.7	96.4	90.0
2008	94.2	99.7	90.6
2009	92.3	99.2	88.0
2010	93.9	98.9	89.8
2011	93.4	99.0	89.7
2012	95.1	99.1	92.2

the 12 vessel types the last year present was 2005. Last, the number of vessels classified as either large (75′+) trawl vessels from Lower Mid-Coast, ME or small (< 30′) longline vessels from the Cape & Islands regions was, at one time, quite large. From 1996 to 2002 the number of large trawl vessels from Lower Mid-Coast, ME averaged 11 vessels and ranged between 17 and 8 vessels. However, the number of these Maine-based large trawl vessels declined in consecutive years from 12 vessels in 2002 to 2 vessels in 2007. There were more than 40 vessels classified as small longline vessels in the Cape & Islands region from 1996 to 2001. In 2002 the number of such vessels was nearly halved to 21, which marked the beginning of a consistent downward trend to fewer than 10 vessels by 2005 and down to only one vessel in both 2010 and 2011; the last year in the 17 year time series this Cape & Islands region vessel type was present.

The vessel types listed in Table 11 share the characteristic that they were present in one or more years outside of the minimum 5-year criterion used to examine the extirpation of vessel types. In all cases, the last year of continuous presence was 2009 or earlier, although the last year present ranged from 2003 to 2012. In most cases, these vessel types were present on only one or two occasions in years outside the beginning and ending qualifying years, while several vessels types (denoted with an ∗ in Table 11) were present for 3–5 consecutive years outside the qualifying years. For example, small gillnet vessels from Rhode Island were present from 1996 to 2002, then were absent over the next 4 years before being present again during 2007–2012. This suggests that the presence and absence of certain vessel types may be a transient condition. Nevertheless, the primary focus is on the period of qualifying consecutive years.

Among vessel types listed in Table 11 the number of consecutive years present ranged from 6 to 14 years, and with two exceptions all vessel types were present in 1996. The data indicate a pattern of sequential loss of continuous presence in the active groundfish fleet with the loss of 3 or 4 vessel types in each year from 2002 to 2007. From 2001 through 2006 14 of 16 vessel types were fixed gear (1 hook, 6 logline, and 7 gillnet) whereas from 2007 to 2009 the number of vessel types was evenly split between trawl and fixed gear. From 2002 to 2009 at least 1 small vessel type (< 30′) was lost in every year, while losses of medium sized vessel types were approximately evenly split (8 vessel types 30′ to < 50′ and 7 vessel types 50′ to < 75′). In terms of abundance, the maximum number of vessels ranged from 1 to 5 for 14 of 24 vessel types. There were only 4 vessel types where the maximum number of vessels was greater than 10.

Table 10
Summary of vessel types present for five or more consecutive years that were not present in any other years.

Region	Gear	Size category	Total years present	Last year present	Consecutive years present	Begin year	End year	Minimum number of vessels	Maximum number of vessels
CT Seacoast	Longline	30 to < 50	6	2001	6	1996	2001	1	4
Gloucester, North Shore	Longline	50 to < 75	8	2003	8	1996	2003	1	4
NY Seacoast	Hook	50 to < 75	8	2004	5	2000	2004	1	2
Boston Area	Longline	< 30	10	2005	10	1996	2005	1	5
Cape & Islands	Hook	< 30	10	2005	10	1996	2005	2	5
Gloucester, North Shore	Longline	< 30	10	2005	10	1996	2005	1	6
Lower Mid-Coast, ME	Longline	30 to < 50	10	2005	10	1996	2005	1	6
Upper Mid-Coast, ME	Gillnet	30 to < 50	11	2006	11	1996	2006	1	5
Lower Mid-Coast, ME	Trawl	75+	12	2007	12	1996	2007	2	17
NH Seacoast	Longline	< 30	15	2010	15	1996	2010	1	3
Cape & Islands	Longline	< 30	16	2011	16	1996	2011	1	47
New Bedford, South Shore	Trawl	30 to < 50	16	2011	16	1996	2011	1	3

Table 11
Summary of vessel types present for five or more consecutive years that were also present in other years.

Region	Gear	Size category	Years present	Last year present	Consecutive years present	Begin year	End year	Minimum number of vessels	Maximum number of vessels
Lower Mid-Coast, ME	Hook	50 to < 75	7	2003	6	1996	2001	1	4
Southern ME	Trawl	50 to < 75	9	2005	7	1996	2002	1	3
Southern ME	Longline	30 to < 50	9	2008	7	1996	2002	1	2
NJ South	Gillnet	30 to < 50	12	2012	7	1996	2002	1	7
Rhode Island[a]	Gillnet	< 30	13	2012	7	1996	2002	1	1
New Bedford, South Shore	Longline	< 30	9	2005	8	1996	2003	1	2
CT Seacoast	Gillnet	30 to < 50	10	2008	8	1996	2003	1	2
Rhode Island	Longline	30 to < 50	11	2010	8	1996	2003	2	7
CT Seacoast	Trawl	75+	12	2012	8	1996	2003	1	6
Cape & Islands	Gillnet	50 to < 75	10	2007	9	1996	2004	1	3
Gloucester, North Shore[a]	Longline	30 to < 50	13	2010	9	1996	2004	2	14
NY Seacoast[a]	Longline	< 30	14	2012	9	1996	2004	1	2
Rhode Island	Gillnet	50 to < 75	13	2012	9	1996	2004	2	3
NH Seacoast[a]	Gillnet	50 to < 75	15	2011	11	1996	2006	1	6
NY Seacoast [a]	Longline	30 to < 50	15	2011	11	1996	2006	1	19
NH Seacoast	Gillnet	< 30	13	2012	11	1996	2006	1	1
MD, West	Trawl	50 to < 75	13	2009	12	1996	2007	2	5
NY Seacoast	Trawl	75+	14	2011	12	1996	2007	1	12
Rhode Island	Longline	< 30	13	2011	12	1996	2007	1	2
Lower Mid-Coast, ME [a]	Gillnet	50 to < 75	15	2012	10	1998	2007	1	4
NJ South [a]	Trawl	75+	16	2012	13	1996	2008	1	7
Boston Area	Longline	30 to < 50	15	2011	14	1996	2009	2	14
CT Seacoast	Trawl	30 to < 50	15	2011	14	1996	2009	1	6
Gloucester, North Shore	Gillnet	< 30	12	2012	11	1999	2009	1	5

[a] Vessel types that appear in 3 or more consecutive years after the end year for the qualifying consecutive years present.

Notably, 3 of these 4 vessel types were classified as vessels 30′ to < 50′ using longline gear (one each from the Gloucester, North Shore, New York Seacoast, and Boston regions). In each of these cases the number of vessels present was higher from 1996 to 2001 than they were in other years.

6. Conclusions

In this study a quantitative approach was developed using indices commonly applied to measure biodiversity to examine trends in New England groundfish fleet diversity. The findings show that both richness and effective diversity have markedly declined since 2002. However, effective diversity has been stable since 2007, indicating that fleet diversity has not appreciably changed even as the fleet size has continued to decline. Although 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 interpreting the loss and appearance of vessel types as a real change in fleet diversity. The estimated effective diversity based on the Shannon index was substantially less than the total number of vessel types (richness), which is an artifact of the mathematical property of the index, and the methods used to designate vessel types.

The Shannon index is based on proportions. Mathematically, 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 Simpson's index would be larger since Simpson's index weights common vessel types more heavily than rare vessel types. To illustrate, a total of 98 different vessel types actively fished during fishing year 1996. Of these vessel types, the one vessel type with the highest frequency (74) accounted for 6.6% of total vessels. By contrast, 22 vessel types consisted of only one vessel. Each of these “rare” vessel types accounted 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 22 vessel types with only one vessel was 3.5%; 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 increases Shannon effective diversity by 2% increase. 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. A comparatively more even distribution among remaining vessel types results, hence, increasing effective diversity. By contrast, the loss of one of the least common vessel types reduces effective diversity by 0.4%, because the increase in relative influence of the most common vessel type is more than offset by the change in richness.

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 in the biodiversity indices is of considerable debate in the biodiversity literature as the loss of rare species may have important implications for ecosystem function. The implication of losing rare vessel types fishing fleet functionality 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 classification criteria employed for designating vessel type may 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 as a unique “species”.

Since 1996, the size and composition of the fleet of limited access vessels landing groundfish have substantially changed. The fleet size has shrunk from over 1000 participating vessels to 337 in 2012 with corresponding declines in richness and effective diversity. Yet, effective diversity has been stable since 2007 and 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. The more notable changes in the groundfish fleet's composition include increases in the relative contribution of gillnet and trawl gear and larger vessels. There has been a decrease in hook and longline gear as well as reductions in both the relative contribution of small vessels and Maine-based vessels.

Based on the decision rules adopted herein, 131 unique vessel types were identified based on vessel size, gear, and region. As previously noted, 40 of these vessel types were present in every year leaving 91 vessel types present in 16 or fewer years from 1996 to 2012. A substantial number of these “transient” vessel types were present on few occasions while others were present in the majority of years. The former may be an artifact of the decision rules, which may have created 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 changes in rare or unusual vessel types resulting from definition error. That said, the Shannon diversity measure will retain the ability to detect changes in richness and may be better at detecting changes in relative abundance of the more common vessel types.

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