APPENDIX XIX

ANALYTICAL METHODS USED TO IDENTIFY SOME OF THE HABITAT CLOSED AREA ALTERNATIVES (5a-d)

1.0 Description of Working Group EFH Model Used To Develop Habitat Closed Area Alternative 5 (options a-d)

1.1 Theoretical Background and Methods

MacCall (1990) developed mathematical treatment of spatial population dynamics for marine fish populations. While doing so, he utilized and extended the population theory of density-dependent habitat selection which says that the marginal value of an animal's habitat is dictated not only by the physical and chemical characteristics of its environment, but also dictated by the competition for resources (food, refugia, etc.) with other individuals in the population. The realized habitat suitability of the individual is therefore affected by competition, predation, territoriality, and oceanographic/substrate conditions. MacCall (1990) postulates that individuals occupy habitats with the highest suitability to their survival and growth. It requires an assumption of an ideal free distribution where animals move, recruit to, or survive in response to marginal differences in their habitat and at higher population levels, occupy areas that would be less suitable at lower population size.

Extending the concept of density-dependent habitat suitability, originally developed by Fretwell and Lucas (1970), MacCall (1990) proposed a "Basin Model", relating habitat suitability to the intrinsic rate of population growth (r) and to population size as a function of the local carrying capacity (K) of the habitat (Figure 1). When at the carrying capacity (K) or high population size (Figure 1), the abundance distribution is affected by the fitness of the underlying habitat, but the population occurs at some level thorough its range. In an ideal free state, individuals are re-distributed such that the marginal habitat suitability due to competition is equal for all and all individuals contribute equally to the intrinsic rate of population growth (r). At lower population size, marginal habitats (outside the domain of B in Figure 1) become unoccupied. Thus at mean or low population size, the abundance distribution is proportional to the habitat value of an area to a population and to its intrinsic rate of growth (i.e. habitat is more valuable and productive to the species at location A than at locations B or other locations throughout the range). Thus, over a long time series, the mean abundance at any location is suitable as a proxy for the value of the habitat to a population.

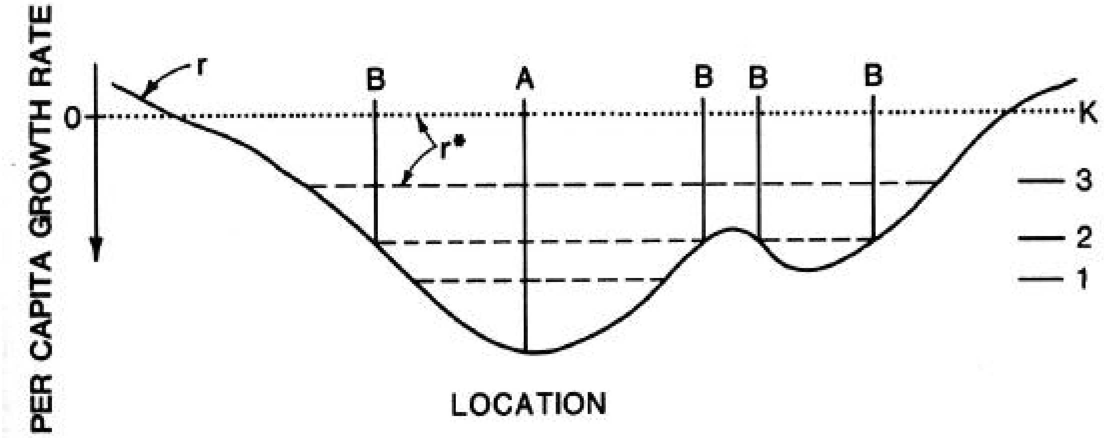

Figure 1. **Diagram of the "Basin Model", proposed by MacCall (1990), relating habitat suitability to the intrinsic rate of population growth (r) and to stock size as a proportion of carrying capacity (K).**

Garrison (2001) examined the spatial patterns of 27 finfish sampled by the bottom trawl survey on the NE US continental shelf (Azarovitz 1981). Although there were temporal changes in abundance and distributions, there was a strong fidelity to relatively stable faunal regions. Spatial ranges for many species however contracted at low population size (Atkinson *et al.* 1997, Wigley *et al.* 1996), often concentrating in areas having higher CPUE at high abundance (e.g. haddock in Garrison 2001).

The EFH designations in the Essential Fish Habitat amendments used median abundance data from 1963 to 1997 and were normalized with respect to differences in catchability between species (see explanation below). For each species, the abundance data was categorized by life stage (eggs, larvae, juvenile, adult) and binned by ten-minute square throughout the extensive range of the bottom trawl survey. This treatment made the data ideally suited for identifying candidate habitat closures by applying MacCall's (1990) Basin Model to the standardized abundance data in a GIS format (ArcView 8.1 for display and analysis; Minami 2000).

In preparation for the 1998 EFH amendment, the survey abundance data were post-stratified by ten-minute square and their geometric means were ranked for all ten-minute squares by species and life stage (eggs, larvae, juvenile, and adult). All ten-minute squares were assumed to be of equal size with a homogenous distribution of catches within a ten-minute square. Ranked from highest to lowest, a ten-minute square was designated as a '25th percentile' if the cumulative sum was less than 25% of the total summed catch, i.e. 25 percent of the total swept-area abundance for a species and life stage. By design, the squares with the highest catches therefore were often represented by much less than 25 percent of the area where a species occurred[1]. Ten-minute squares with the next 25 percent of the cumulative abundance were designated as the 50th percentile category, followed by 75th and 90th percentile categories. Finally, the EFH designations included a 100th percentile category that included all ten-minute squares where there was one or more observations during the 37 year time series, but did not contribute to more than 10 percent of the total swept area abundance.

This analysis produced maps of EFH designations by species (37) and life stage (4), producing 148 maps or data layers, with varying distributions that relate to the preferred habitats for each species. Some examples for four groundfish species [cod (Gadus morhua), monkfish (Lophius americanus), white hake (Urophycis tenuis), and yellowtail flounder (Limanda ferruginea)] are shown in Figure 2. These data, categorized by species, life stage, and EFH designation were assigned weights to account for the relative EFH value between ten-minute squares and for the association with sensitive, complex habitat for a given species and life stage.

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[1] A species with a uniform distribution would have 25 percent of the ten-minute squares designated as the 25th percentile, for example.

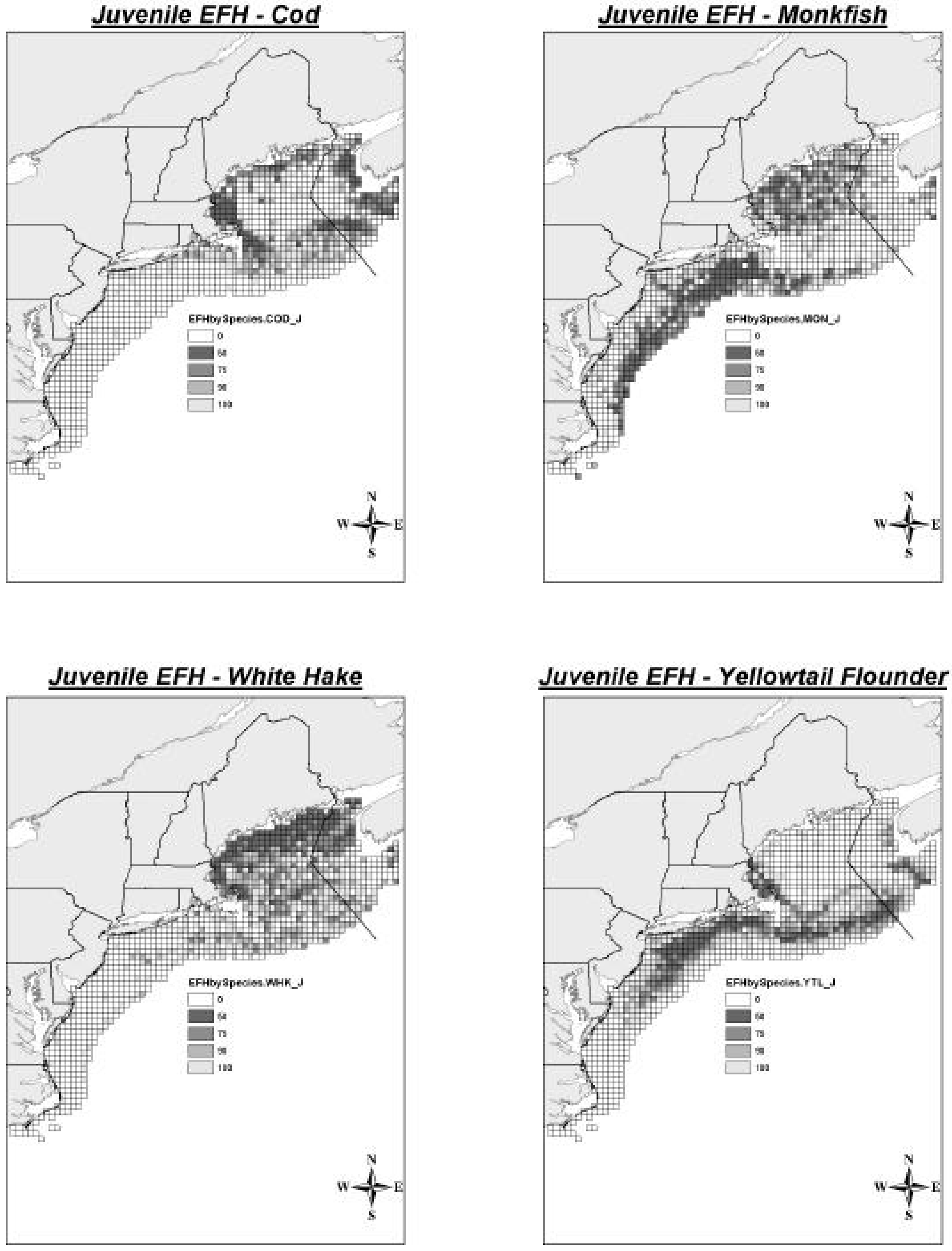

Figure 2. **Ten-minute square distributions of mean survey abundance (1963-1998) using juvenile cod, monkfish, white hake, and yellowtail flounder as examples.**

1.2 Enumerating EFH classifications as a proxy for habitat value

Utilizing the above percentile ranks as a starting point, ten-minute squares received an initial value based on Equation 1, where p = 50, 75, 90, and 100. This results a corresponding values of 25, 5, 1.9, and 1, respectively, reflecting a relative species/life-stage EFH index based on the abundance distributions. For this analysis, the 25th and 50th percentiles were combined into one category with an index value of 25. A subsequent sensitivity analysis was conducted, giving the 25th percentile an EFH index value of 125, but it did not materially change the eventual identification of the habitat closure areas. EFH index values using the 25th percentile were not used in the final analysis, because these rankings were unavailable for some species in the model.

Equation 1

$$5^{(100-p)/25}$$

EFH values by life stage were given unequal weight in the GIS framework to account for the stage's relationship with the bottom habitat that may be altered by fishing. Except for herring (Clupea harengus), eggs and larvae were given a zero weight and not included in the aggregate EFH value because these life stages for oceanic species are mostly pelagic and would be unaffected by bottom conditions. The EFH values for the juvenile life stage were given a weight of 4:1 relative to the adult life stage because:

- Juvenile life stage is generally more vulnerable to changes in bottom habitat
- Juvenile stage is the best metric of resource potential
- Juvenile stage generally favors an invertebrate diet, whereas adult stage tends to be piscivorous
- Adult distributions can vary due to fishing and management effects

The EFH values described above were furthermore given unequal weight in the GIS framework to account for the species association to habitat thought to be vulnerable to fishing effects and for the species management status. A working group of habitat experts and plan development team members determined which of the criteria were met by a species. This weighting factor ranged from zero to four, depending on how many of the following criteria were satisfied by the species included in the GIS framework.

- Association with bottom habitat that might be affected by fishing activities
    - i.e. does the species rely on bottom habitat for food, refuge, or another important ecological function?
- Vulnerability of bottom habitat to fishing activities
    - i.e. is there a potential conservation benefit for the habitat that is associated with the species?
- Stock status
    - i.e. is the species or stocks for that species depleted and considered overfished?
- Relative value to the fisheries
    - i.e. would there be a potential direct economic or social benefit to conserving EFH for the species?

These weights for each species in the analytic framework are shown in Table 1 under the "EFH factor weight" heading. Species with a weight of zero were not considered further in the analysis and did not contribute to the ten-minute square EFH value. These species with zero EFH value for the purposes of this analysis were either pelagic, ubiquitous over varied habitats, or both.

Table 1. **EFH and productivity data weights by species.**

Family	Species	Scientific name	EFH factor weight	EFH factor weight wo relative value	Fishery productivity weight
Clupeidae	Herring (eggs)	Clupea harengus	3	3	0
Gadidae	Cod	Gadus morhua	4	3	1
	Haddock	Melanogrammus aeglefinus	4	3	1
	Pollock	Pollachius virens	1	1	0
	Red hake	Urophycis chuss	2	2	0
	White Hake	Urophycis tenuis	3	2	0
Lophiidae	Monkfish (Goosefish)	Lophius americanus	4	3	1
Malacanthidae	Tilefish	Lopholatilus chamaeleonticeps	4	3	0
Mrrlucciidae	Whiting (Silver hake)	Merluccius bilinearis	2	1	2
Paralichthyidae	Summer flounder	Paralichthys dentatus	3	2	2
Pleuronectidae	American plaice	Hippoglossoides platessoides	4	3	3
	Halibut*	Hippoglossus hippoglossus	4	3	1
	Winter flounder	Pseudopleuronectes americanus	2	2	3
	Witch flounder	Glyptocephalus cynoglossus	3	3	3
	Yellowtail flounder	Limanda ferruginea	3	3	3
Pomatomidae	Bluefish	Pomatomus saltatrix	0	0	0
Rajidae	Skate, barndoor	Dipterus laevis	2	2	0
	Skate, clearnose	Raja eglanteria	0	0	0
	Skate, little	Leucoraja erinacea	0	0	0
	Skate, rosette	Leucoraja garmani virginica	1	1	0
	Skate, smooth	Malacoraja senta	1	1	0
	Skate, thorny	Amblyraja radiata	1	1	0
	Skate, winter	Leucoraja ocellata	0	0	0
Scombridae	Atlantic mackerel	Scomber scombrus	0	0	0
Scophthalmidae	Windowpane flounder	Scophthalmus aquosus	2	2	0
Scorpaenidae	Acadian redfish	Sebastes faciatus	4	3	1
Serranidae	Black sea bass	Centropristis striata	4	3	1
Sparidae	Scup	Stenotomus chrysops	2	2	2
Squalidae	Dogfish	Squalus acanthus	2	2	1
Stromateidae	Butterfish	Peprilus triacanthus	0	0	0
Zoarcidae	Ocean pout	Zoarces americanus	2	2	0
Loliginidae	Longfin squid	Loligo pealeii	0	0	2
Arcticidae	Ocean quahog	Arctica islandica	2	1	2
Geryonidae	Red crab	Chaceon quinquedens	0	0	0
Pectinidae	Scallops*	Placopecten magellanicus	2	1	0
Ommastrephida	Shortfin squid	Illex illecebrosus	0	0	0
Mactridae	Surf Clam	Spisula solidissima	2	1	3

Managers expressed concern that the EFH values for certain species were inappropriate because it included a weight for “Relative value to the fisheries”. Although possible, no species received a weight of one solely due to this consideration and a sensitivity analysis was conducted with the weights listed in the next column of Table 1. These results did not make an appreciable difference in the distribution of aggregate EFH values for all species and life-stages.

The aggregate EFH value was calculated according to Equation 2 as the sum of the above weights multiplied by the EFH classification values for each species (37) and life-stage (juvenile and adult). These aggregate EFH values were plotted in ArcMap to allow visual inspection of the patterns to identify areas where closures might be most effective for protecting the habitat of a variety of species meeting the above criteria. Because these values were weighted, the distribution favors the highest abundance of juveniles for overfished species that are associated with vulnerable bottom habitats.

Equation 2

$$EFH_{TMS} = \sum_{p=50,75,90,100} g_p \left[\sum_{s=1}^{37} w_s \left(j * EFH_{j,s} + a * EFH_{a,s} \right) \right]$$

where: $EFH_{j,s}$; $EFH_{a,s}$ = Essential fish habitat values by ten-minute square, species, and life stage; averaged survey abundance over the 37-year time series for juveniles or adults

g_p = EFH value determined from Equation 1

w_s = EFH species weights given in Table 1

j, a = Life stage weight: 4 for juvenile data, 1 for adult data

EFH_{TMS} values were plotted using ArcMap to examine the distribution of the high valued ten-minute square and possibly identify areas that would efficiently conserve EFH for a variety of species. This distribution favors the juveniles of overfished species that are associated with vulnerable bottom habitats. Generally, the pattern shows the highest values along the inshore portions of the Gulf of Maine, along the South Channel region east of MA, in Southern New England south of RI, along the Hudson Canyon east of NJ, and along the outer shelf margin of the Mid-Atlantic region.

1.3 Productivity tradeoffs to account for practicality

The productivity by ten-minute square was calculated to estimate the relative cost of closing areas to protect habitat. Although individuals of some species will contribute to an export of recruits or adults from closed areas, closures potentially limit access to adult, harvestable portions of the resource. Areas with high productivity, or abundance of adult species, will tend to cost more to close than other areas given equal migratory, fishing cost, and other effects. The aggregate adult abundance data, classified into percentiles as for the EFH data above, were deemed an acceptable proxy for a more direct measure of geographic productivity. Except for sea scallops, a more direct measure of productivity was unavailable. Adult biomass, on the other hand, could be a better measure of the yield that might be harvestable from various areas, but the survey biomass data are biased by overfishing and historic exploitation patterns.

Even though the distribution of adult abundance might estimate the potential productivity of an area and its potential cost, various factors unique to each species influence whether the cost due to closure would be high or low. Similar to the criteria for EFH value, three criteria were developed to weight the influence of a species adult abundance on the overall distribution of 'productivity'. This weighting factor ranged from zero to three, depending on how many of the following criteria were satisfied by the species included in the GIS framework. Some species (e.g. whiting and longfin squid) had higher weights for productivity than for the EFH value (see "Fishery Productivity Weight" in Table 1).

- Whether the species can be caught by gear that would not be excluded by a habitat closure
    - i.e.. passive, fixed gears could substitute for a mobile, bottom tending gear that would be excluded
- Mobility of adults
    - i.e. would the individuals later become available to the fishery
- Relative value to the fisheries
    - i.e. prohibiting access to more valuable species would have a higher cost

Direct estimates of the distribution of sea scallop productivity were available by rotational management area, under consideration by managers. The long-term maximum yield had been estimated for rotation management based on estimated local recruitment, growth and realized size selection from area rotation and gear management (Hart 2003). These area estimates were distributed over the ten-minute squares within them according to Equation 3.

Equation 3. Ten-minute square sea scallop productivity.

$$P_{TMS} = \left(\frac{LTPY_{RMA} * \frac{i_{40-72,TMS}}{i_{40-72,RMA}}}{A_{TMS}} \right)$$

where: $LTPY_{RMA}$ = long-term potential yield for a rotation management area

i_{40-72} = post-stratified index of abundance for 40 – 72 mm scallops
A_{TMS} = Area of ten-minute square (UTM projection)

Various combinations of productivity tradeoffs against aggregate EFH value were considered. The total productivity estimates, summed across species, were standardized by dividing their mean values into the mean aggregate EFH value (994.6 with four criteria weights; 799.8 with three criteria weights; see Table 2) for the 1104 ten-minute squares in the GIS framework, resulting in a set of productivity weight factors (Table 2). When subtracted from the aggregate EFH value from Equation 1, the net conservation value mean for all ten-minute squares was zero. Positive values meant that the closure of a ten-minute square would favor more EFH protection than it might cost by limiting access to adult finfish and shellfish. Negative values generally meant that a closure would protect fewer species' EFH and/or have a potentially high cost.

Equation 4

$$Q = \sum EFH_{TMS} - w_s P_s - w_g \sum_{s} EFH_{a,s}$$

Where: EFH_{TMS} = aggregate EFH species-weighted value for ten-minute square
P_s = long-term potential yield for sea scallops, when fished at Fmax
$EFH_{a,s}$ = aggregate, species-weighted EFH value for adult life stage
w_s = normalizing weight for sea scallop productivity
w_g = normalizing weight for standardized adult EFH distributions for groundfish and monkfish

Table 2. **Mean aggregate EFH and productivity values and productivity tradeoff weights used in** Equation 4.

Net conservation value (Q)	EFH value (4 factors; $\sum EFH_{TMS}$)	EFH value (3 factors; $\sum EFH_{TMS}$)	Groundfish productivity (w_1)	Groundfish productivity incl. scallops (w_s)	Sea scallop productivity (w_3; mt/nm^2)	Monkfish productivity (w_4)
Mean value in all ten-minute squares	994.6	799.8	120.2	128.5	3.325	6.137
Groundfish & Scallop (1:1)	1	0	4.137	0	149.6	0
Groundfish & Scallop (2:1)	1	0	5.516	0	99.71	0
Groundfish, scallop, & monkfish (1:1:1)	1	0	2.758	0	99.71	54.02
Groundfish & Scallop (1:1)	0	1	3.327	0	120.3	0
Groundfish incl. Scallop	0	1	6.624	0	0	0