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Virtual population analyses of Atlantic and Gulf king mackeral using tag-recapture data and alternative models of migration.

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Stock assessments of king mackerel in the U.S. have generally assumed that all king mackerel caught south of the Flagler-Volusia County line (southeast Florida) during November 1 through March 31 belong to the Gulf migratory group. Recent studies of tag-recapture data, otolith shape and otolith elemental composition all indicate that some of the fish south of this border are in fact from the Atlantic migratory group. These data are insufficient by themselves to determine the magnitude of intermixing south of the border, however the participants at the most recent SEDAR data workshop[1] concluded that the tagging data might be useful in this regard when combined with the two-area VPA discussed in Porch et al. (2001) and Porch (2003a,b). Such an integrated approach, which involves the simultaneous examination of catch, indices of abundance and tagging data, may allow the estimation of factors that would otherwise confound the analysis.

The two-area VPA software used here (VPA-2BOX, Porch 2003b) includes two types of box-transfer models: diffusion and overlap. The former assumes a fraction T_{jk} of the population in zone j transfers to zone k whereas the latter assumes a fraction $\tilde{T}_{sk}$ of stock s transfers to zone k. Essentially, the diffusion model ascribes membership to a stock based on the current location of an animal with the tacit assumption that immigrants adopt the movement and spawning behavior patterns of the endemic population. The overlap model, on the other hand, ascribes membership to a stock at birth, with the tacit assumption that the two stocks have overlapping ranges but otherwise seldom interact. Both models reduce to single-stock VPA's when the transfer fractions are set to zero, otherwise T and $\tilde{T}$ are not directly comparable inasmuch as the diffusion model allows fish born in one zone to accumulate in the other. For example, if the transfer fractions for both stocks were both 10%, the diffusion model (without mortality) would calculate that 10% of the fish born in zone 1 will be living in zone 2 after one year, 18% after two years and 24.4% after three years. The SEDAR working group concluded that the "preponderance of information suggested that the overlap model was perhaps more applicable than the diffusion model." Accordingly, this paper examines the implications of using the tag recapture data and various levels of overlap on the stock assessments of the Gulf and Atlantic migratory groups of king mackeral.

Methods

The application of the overlap model to King Mackerel is straightforward. The past approach of conducting two independent VPAs (one for each migratory group) is identical to conducting a two-stock VPA with zero mixing. The fact that the geographic boundary delineating the two stocks shifts with time poses no special problems for the two-stock VPA. The overlap model essentially assumes that the level of overlap across the moving boundary is temporally invariant (although the model does allow the level of overlap to vary with age). The model also assumes that the animals that transfer across the boundary have the same probability of being caught as the endemic population. This condition may be violated, for example, when mixing occurs within a limited area and the fishing pressure in that area is different from the overall average (in which case a three-area, two-stock model might be more appropriate).

We endeavored to emulate the most recent king mackerel base-case assessments as closely as possible. Apart from accounting for migration and tag recoveries, the same data and procedures were employed (see Ortiz et al., 2002, Anon. 2003, Ortiz 2004). The tag-recapture data used

[1]SEDAR data workshop

were limited to the internal anchor tags implanted through the Florida Marine Research Institute or U.S. National Marine Fisheries Service Cooperative Tagging Center (CTC). As per the recommendation from the SEDAR panel, other tag types were excluded on the basis of having too few recoveries or variable tag-shedding and reporting rates. The SEDAR panel also recommended that tag recoveries made less than 90 days after release be excluded inasmuch as they are unlikely to have mixed throughout the population.

Initially, the VPA runs were made with ages 0 to 11. However, even very small Gulf to Atlantic overlaps led to a very unstable situation where recruitment failures and negative stock sizes were predicted for the Atlantic population. This is probably an artifact related to the unstable behavior already observed for the single-stock VPA of the Atlantic migratory group when age 0 fish are included (see reference). Accordingly, subsequent analyses were done excluding age 0 fish. Of course doing so necessitated omitting the two indices of abundance corresponding to age 0 (SEAMAP in the Atlantic and the shrimp bycatch index in the Gulf). As it turns out, the trends obtained by omitting the age 0 fish are much the same as the original base case assessment with the exception of the most recent recruitments, which are less well-determined without the age 0 index data (Figure 1).

The overlap model was first applied to the catch and abundance index data alone. Previous analyses have demonstrated that the overlap coefficients are poorly estimated from the indices alone, therefore all ages were represented by a single parameter for each zone. A second set of analyses incorporated the tagging data in addition to the catch and abundance indices. The overlap model was then built in a stepwise fashion, sequentially adding parameters to account for incomplete reporting, tag-loss, incomplete mixing and overlap. There was some evidence that fish over 90 cm (generally over age 4) were less prone to seasonal movements (Figure 2), therefore two separate overlap fractions were estimated for each stock (one for ages 1 to 4 and one for ages 4 and older). The AICc criteria was used to guide the model selection process.

Results and discussion

The best fit to the indices of abundance was obtained under the assumption of zero overlap; the estimated overlap rates were not statistically different from zero. The solution was very sensitive to the level of overlap for the Gulf migratory group; even levels of only 10% led to a poor fit to the indices of abundance and very different abundance trends for the Atlantic (Figure 3). The solution was less sensitive to the fraction of the Atlantic stock residing in the Gulf, but similarly poor fits and disparate abundance trends were obtained with 50% Atlantic to Gulf overlap rates.

The tagging data strongly suggest either there is some degree of intermixing between the two migratory groups or else the boundary line is poorly placed. A large fraction of the fish tagged from the supposed Atlantic migratory group are recovered in the Gulf and vice versa (see Table 1). Not surprisingly, the VPA could not reconcile the tagging data with the indices of abundance without some degree of overlap. The VPA without overlap gave a very poor fit to the data (according to the AICc) and estimated trends that were very different from those indicated with the indices of abundance alone (Figure 4). Although all of the estimates for tagging parameters (reporting rates, tag shedding, premixing etc...) were statistically significant, by far the greatest improvement in the fit to the tagging data was obtained when the overlap fractions were estimated.

The overlap of Gulf fish into the Atlantic was estimated to be about 12% for ages 1-4 and 5%

for ages 5-11, qualitatively in line with expectations based on the length composition data in Figure 2. The overlap of Atlantic fish into the Gulf was estimated to be about 5% for ages 1-4 and 14% for ages 5-11 (the reverse of what was estimated for the Gulf). The estimated trends in the abundance of age 1 recruits and spawning age animals were quite similar to the estimates without the tagging data (Figure 4). The primary differences are seen in the population estimates for the most recent years, which are somewhat more optimistic. However, it should be kept in mind that these recent years are the most poorly estimated in the VPA. The last four recruitments (1998-2001) are especially poorly estimated, as is the most recent year for the spawner trend (since age 4 corresponds to the 1998 recruitment, which was off the scale).

In general, it seems that including the tagging data and estimating the degree of overlap have a relatively minor impact on the assessment results except perhaps in the most recent years, which are poorly determined. It seems it would be most productive to examine methods of constraining the solution for the most recent years, either by the introduction of new data focusing on age 1 animals or else through structural changes in the model. In particular, it would be useful to examine a three-area model where the so-called mixing zone is modeled as a separate area and intermixing confined to this zone (apparently a more realistic scenario than assuming the stocks intermix throughout their range as the two-area model must). This would probably be best accommodated through a forward projecting statistical model.

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Table 1. Number of tags released and recovered in the regions defined for the Atlantic and Gulf of Mexico migratory groups (> 90 days refers to tags recovered after being at large at least 90 days).

			Area recovered			
Area	Year	Number	ATL		GOM	
released	released	Released	> 90 days	All	> 90 days	All
Atlantic	1986	691	20	24		
	1987	1713	92	111	7	7
	1988	134	8	13	1	1
	1989	123	14	19	5	5
	1990	75	2	2	1	1
	1991	47	1	1		
	1992	42				
	1993	3				
	1994	7	1	1		
	1995	2				
	1996	4				
	1997	4	1	1		
	1998	7				
	1999	1				
	2000	3				
	2001	2				
GOM	1984	1				
	1985	252			18	20
	1986	39			21	32
	1987	721	1	1	43	62
	1988	1242	20	22	47	131
	1989	1407	34	52	55	69
	1990	883	33	38	28	38
	1991	1132	2	2	4	7
	1992	1893	8	9	8	12
	1993	1476	34	64	15	28
	1994	568	8	9	10	15
	1995	759	8	8	5	13
	1996	3				
	1997	1				
	1998	4				

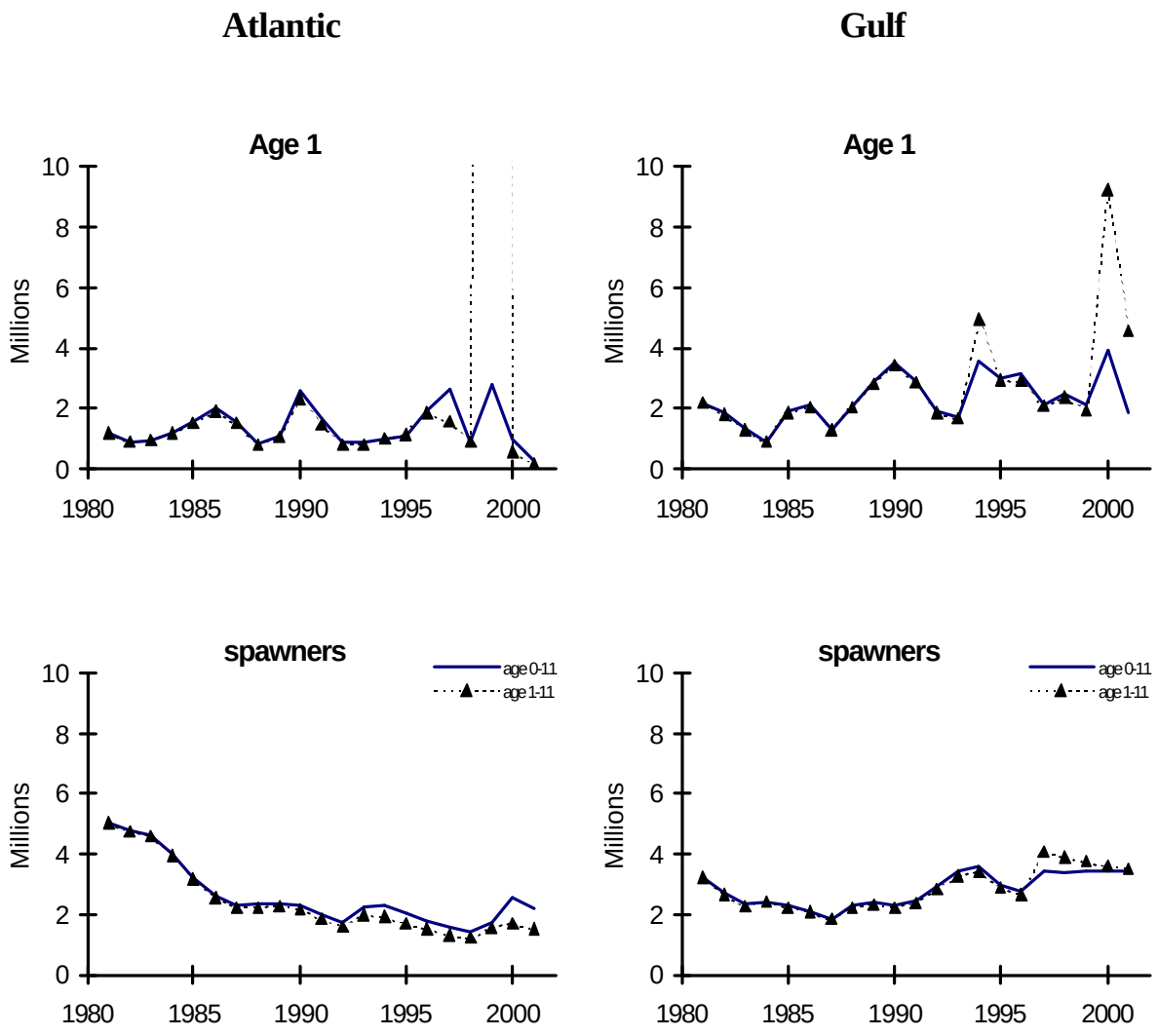

Figure 4. Number of recruits and number of spawners estimated by the VPA without the tagging data and assuming no overlap. The run labeled "age 0-11" uses data from age 0 to 11+ and the run labeled "age 1-11" uses only data pertaining to ages 1-11.

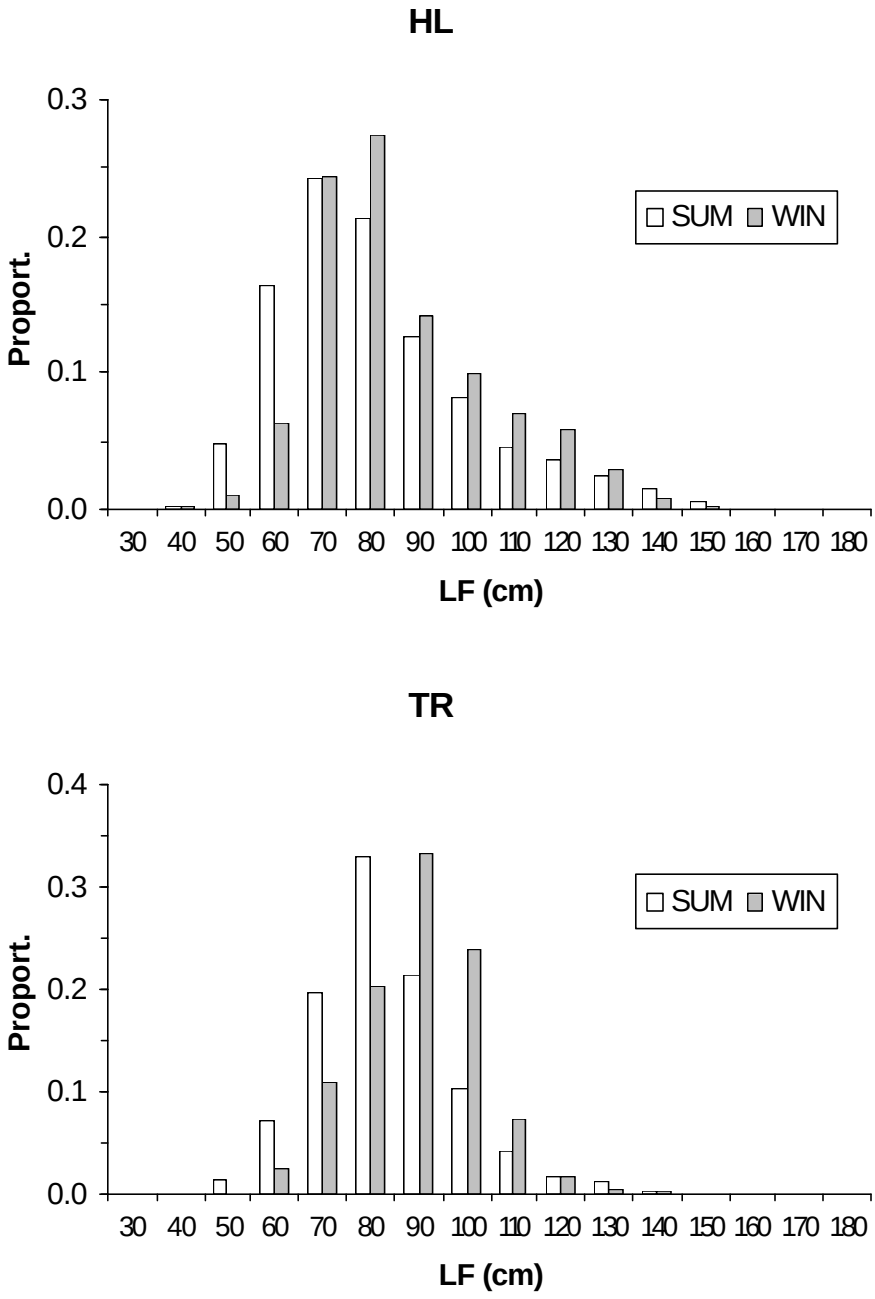

Figure 2. Length composition of catches in the northern Gulf of Mexico by handlines (HL) and (TR) in summer and winter. The greater proportion of fish over 90 cm in winter suggests that larger, older mackerel (more than 3 or 4 years old) are less prone to move from the Gulf to the Atlantic than younger fish.

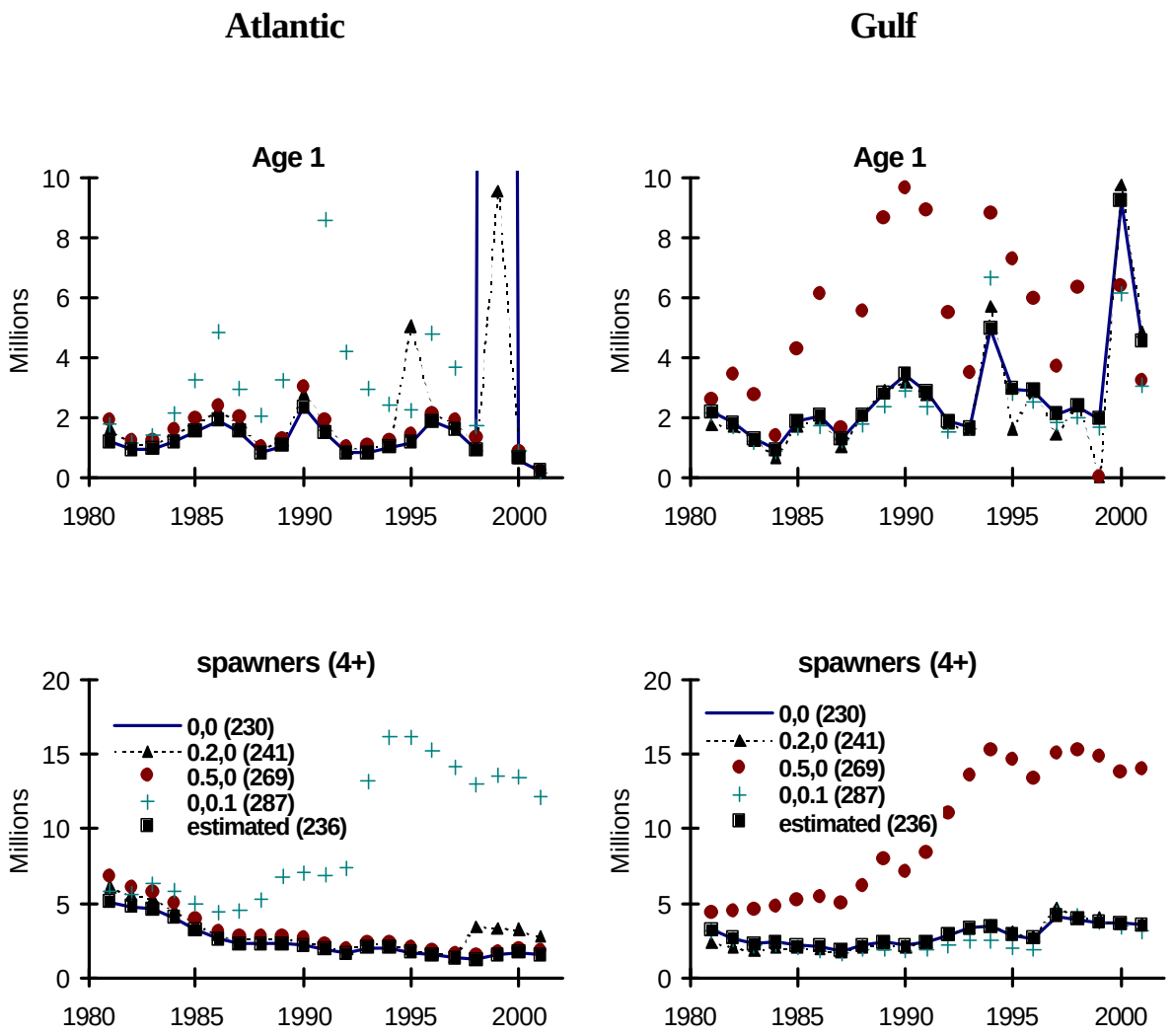

Figure 3. Number of recruits and number of spawners estimated by the VPA without the use of tagging data. The legend labels, e.g., “0.2, 0 (241)" refer to the assumed fraction of the Atlantic stock that resides in Gulf, here 20%, and the fraction of the Gulf stock that resides in the Atlantic, here 0%. The numbers in parentheses are the corresponding AICc values (lower is better). The label “estimated” refers to the fact that these overlap fractions were estimated (in this case they happen to be negligibly different from 0,0, but the AICc value is higher because the overlap parameters are estimated rather than fixed).

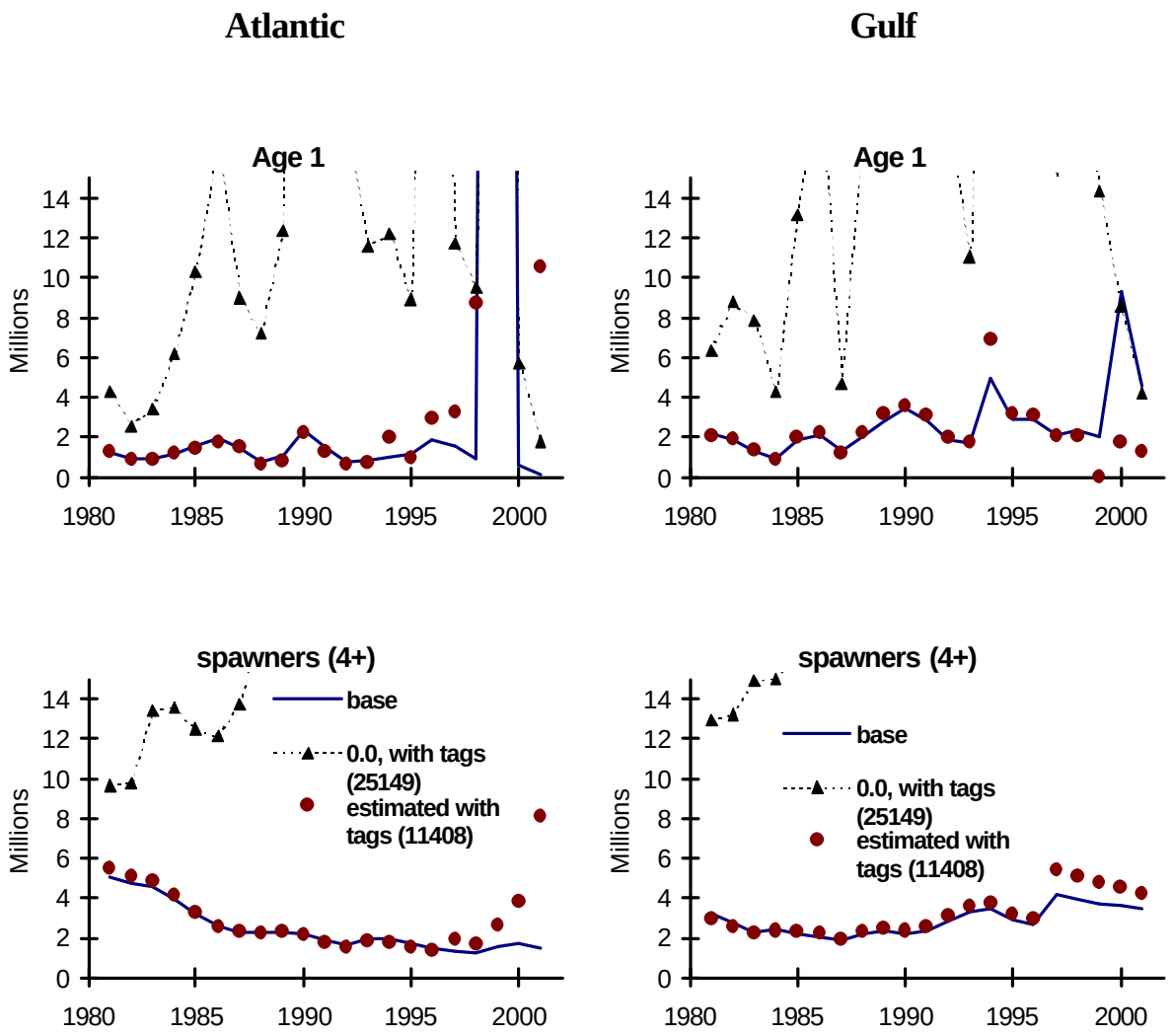

Figure 4. Number of recruits and number of spawners estimated by the VPA using the tagging data. The run labeled "base" refers to the VPA results obtained without tagging data and assuming no overlap. The run labeled "0,0, with tags" refers to the VPA results with tagging data and assuming no overlap. The label "est. with tags" refers to the VPA results with tagging data and estimated overlap rates. The numbers in parentheses are the corresponding AICc values (lower is better).