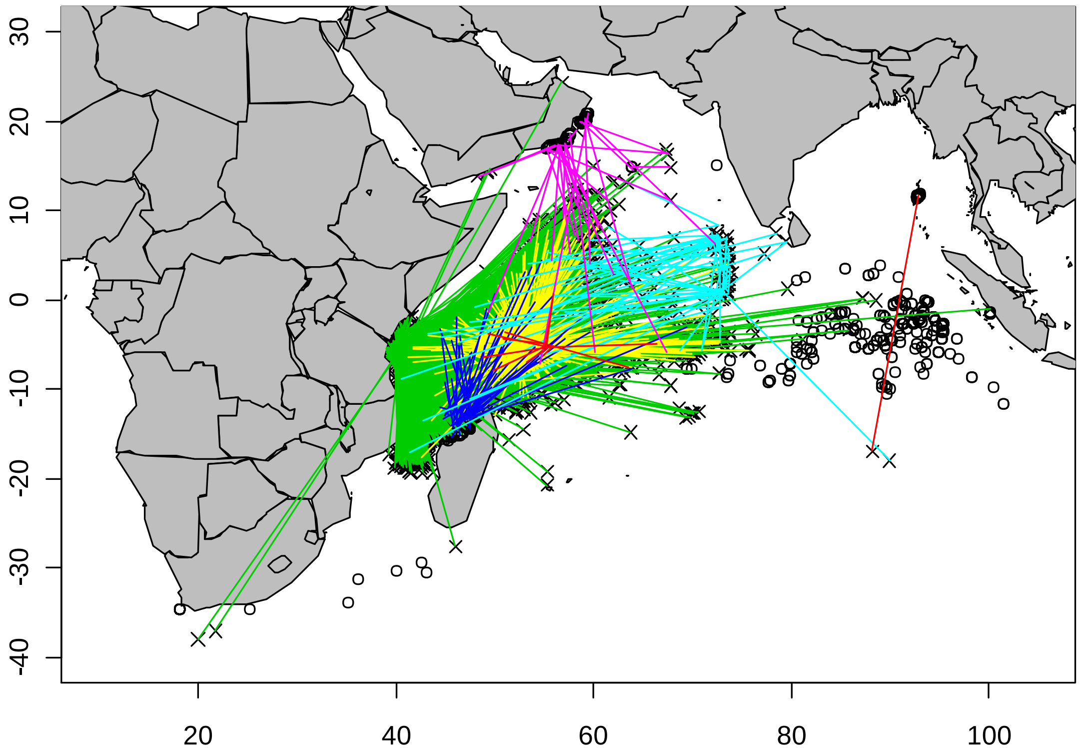

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Application of the Brownie-Petersen method to yellowfin tag-recapture and catch data from the Indian Ocean

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Background

Two traditional methods for analysing tag-recapture data:

- Petersen method to estimate abundance
  - Requires only a single tagging event
  - Provides estimate of population size based on

    # recaptures / sample size = # releases / pop'n size

  - In fisheries, catch data constitute sample size examined for tags
- Brownie method to estimate mortality rates
  - Requires tagging the same cohort in consecutive time periods
  - Compares return rates over time from consecutive release events to provide estimates of mortality rates
  - Allows for separation of fishing mortality from natural mortality
  - Unlike Petersen approach, does not require the sample size examined for tags (i.e. catch) to be known

Background

Integrating the Brownie and Petersen approaches:

- Provides simultaneous estimates of fishing mortality rates (F), natural mortality rates (M), and population size (P)
- Improves accuracy and precision of parameter estimates

Basic Brownie-Petersen (BP) model

Experimental design requirements:

- Fish from a given cohort are tagged in consecutive time periods (i.e. at consecutive ages)
- They are caught in subsequent time periods and recaptured tags are returned
- Estimates of catch-at-age in each time period are available

* *The model is presented for a single cohort, but extension to multiple cohorts is straightforward*

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Basic Brownie-Petersen (BP) model

Key assumptions

- Tag reporting rates known (or estimates available)
- No tag shedding or tag-related mortality (or estimates available)
- Complete mixing of tagged and untagged fish
- Ages at release known accurately
- Catch-at-age estimates unbiased and independent

Brownie component (multinomial likelihood)

Tag-return data

Release age	Number releases	Number of returns at age 1	2	3	4	5	Number not returned	
1	N_1	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	$N_1 - R_{1\bullet}$	← Multinomial(N_1, $\boldsymbol{p}_1$)
2	N_2		R_{22}	R_{23}	R_{24}	R_{25}	$N_2 - R_{2\bullet}$	← Multinomial(N_2, $\boldsymbol{p}_2$)
3	N_3			R_{33}	R_{34}	R_{35}	$N_3 - R_{3\bullet}$	← Multinomial(N_3, $\boldsymbol{p}_3$)

- Tag returns by age corresponding to fish tagged at age i are modelled as multinomial
- Probabilities of return are functions of: natural mortality rates, fishing mortality rates, reporting rates, shedding rates
- Total tag-return likelihood (L_{tag}) is the product of the multinomial likelihoods over all release ages

Petersen component (Gaussian likelihood)

Catch data

Size of cohort	Number caught at age 1	2	3	4	5
P_1	C_1	C_2	C_3	C_4	C_5

- Catch of age j fish modelled as Gaussian with:
    - expected catch the function of: natural mortality rates, fishing mortality rates, and abundance (in first time period of tagging)
    - catch variance assumed known
- Assuming independence, the total catch likelihood (L_{catch}) is just the product of the Gaussian likelihoods over all ages

Overall likelihood

- Assuming tag-return data and catch data are independent

$$L_{total} = L_{tag} \times L_{catch}$$

- Maximize under following constraints
  - reporting and shedding rates known
  - catch variance known
  - *M* is constant after the oldest age of tagging
- Parameters estimates obtained for
  - *M* by age (with above constraint)
  - *F* by age
  - *P*

Application to yellowfin

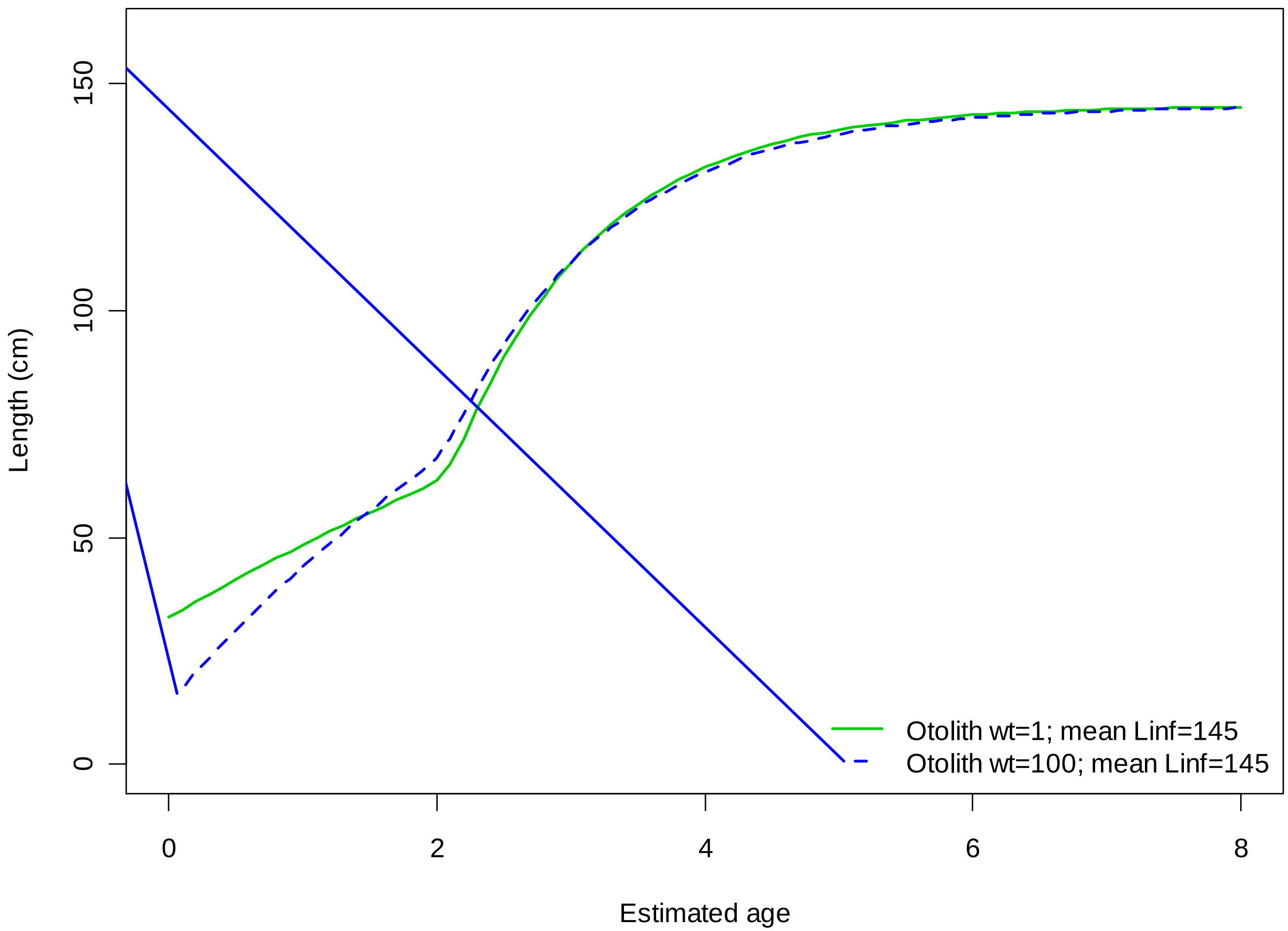
Basic BP model extended to include:

- incomplete mixing in first (1 or 2) time periods after tagging (by allowing *F* to differ for tagged and untagged fish in these time periods)
- multiple cohorts, with assumption that *M* varies only with age, but *F* varies with time period and age (no assumptions about selectivity)

Application to yellowfin

- Only RTTP-IO tagging data included
- Ages at release and age composition of catches estimated from length using updated VB log k growth curve and cohort slicing
- Use a half-year time-step (Jan-Jun, Jul-Dec)

Growth curve for estimating age

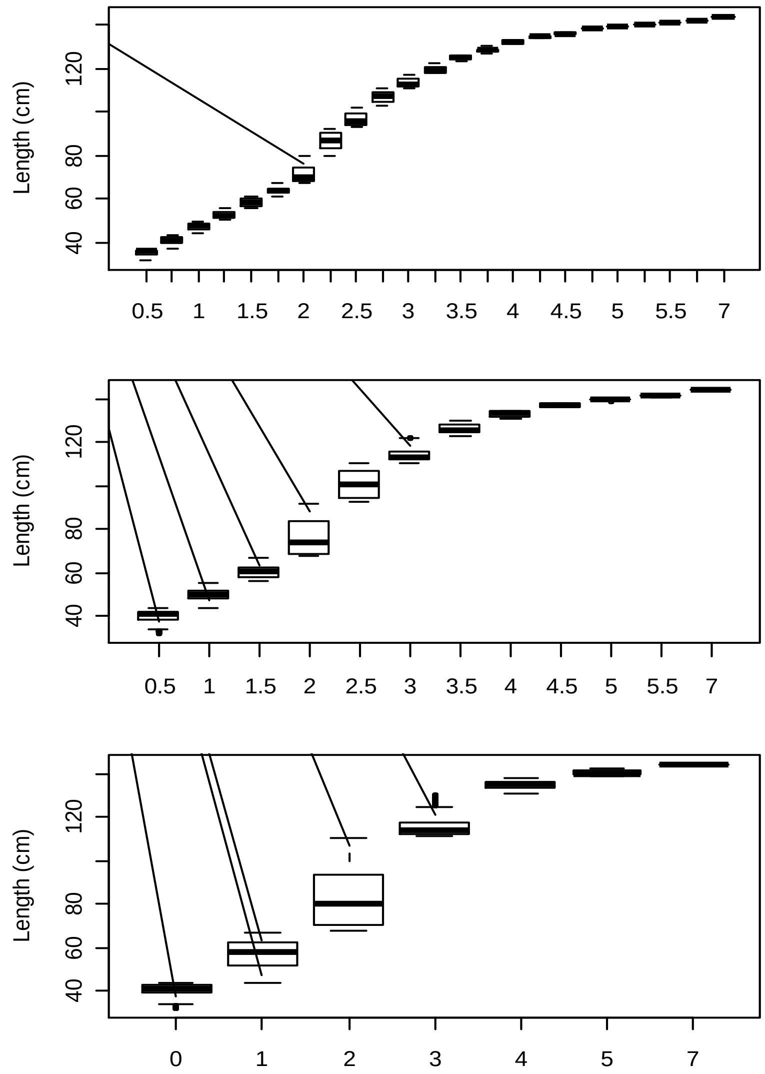


Comparison of different time periods

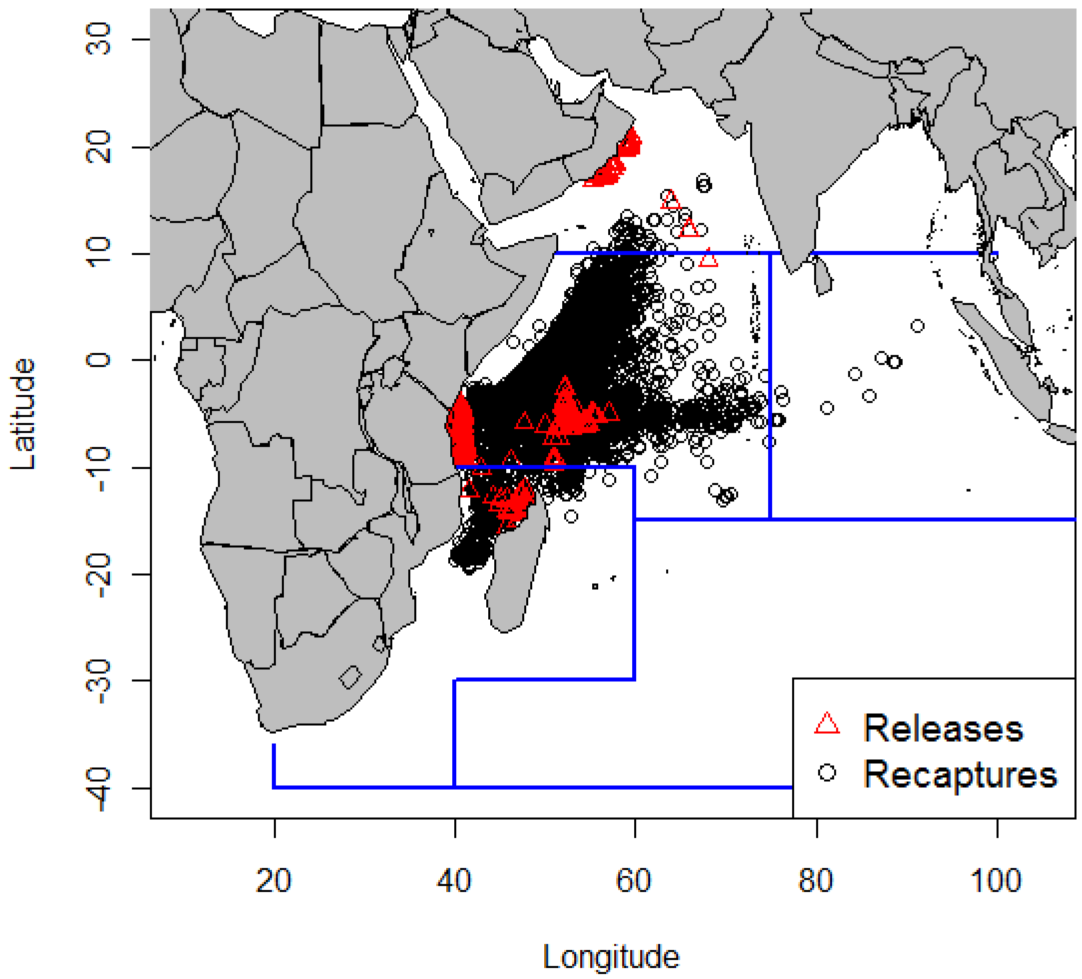
Quarterly

Half-year

Annual



Yellowfin RTTP-IO release and purse-seine return locations



Percent returns by release area

INT=international, KEN=Kenya, MAD=Madagascar,OMA=Oman, SEY=Seychelles, TAN=Tanzania. (Only countries with>100 releases are included.)

Release country	Number releases	Percent returns ≤90 days	Percent returns >90 days
INT	316	1.9	10.8
KEN	803	9.5	14.0
MAD	393	11.7	11.0
OMA	2748	0.0	1.1
SEY	3093	1.5	14.2
TAN	43770	3.4	14.7

NOTE low returns from Oman releases (suggestive of non-mixing)

Application to yellowfin

- Two “extreme” assumptions about mixing:
  1. YFT are fully mixed across the Indian Ocean
  2. YFT are fully mixed within the core purse seine (PS) area, but do not mix with fish from other areas (no emigration or immigration)

Tag-recapture data

Model includes data from:

- Cohorts 2003.5 to 2006.5
- Release ages 0.5 to 2.5
- Recapture ages 0.5 to 5.5

Tag-return data for cohort 2004.5 (i.e. fish born in second half of 2004)

	Release	Release	Number	Number returns by age											
Cohort	age	period	releases	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0+
2004.5	0.5	2005.0	6	0	1	0	0	0	0	0	0	0	0	0	0
2004.5	1.0	2005.5	1083	0	5	42	19	28	23	17	6	2	0	1	1
2004.5	1.5	2006.0	10546	0	0	110	624	445	304	220	103	60	25	19	12
2004.5	2.0	2006.5	1499	0	0	0	64	141	68	40	14	7	2	3	4
2004.5	2.5	2007.0	826	0	0	0	0	2	6	3	1	2	0	0	1

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Reporting rate estimates

- Fishery-specific reporting rates:
  - Seychelles PS: estimates from tag seeding
  - At-sea PS: assumed to equal 1
  - All other fisheries: assumed to equal 0 (and any tag returns omitted)
- Fisheries have different age compositions, so need to calculate age-specific reporting rates
- Reporting rate at age *a* = weighted average of fishery-specific reporting rates (with weights equal to proportion of catch belonging to age *a* in each fishery)

Reporting rates for cohort 2004.5

	Age										
Mixing	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
Entire IO	0.18	0.33	0.39	0.16	0.32	0.40	0.37	0.29	0.27	0.16	0.06
PS area	0.54	0.53	0.89	0.92	0.97	0.98	0.94	0.96	0.96	0.97	0.97

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Tag shedding estimates

- Probability of retaining a tag as a function of time since release τ was assumed to be

$$Q(\tau) = \xi e^{-\Omega \tau}$$

ξ = fraction of tags retained immediately after tagging

Ω = continuous rate of shedding

- Estimated values estimated by Gaertner and Hallier (2012): ξ=0.977 and Ω=0.039 (per year)

Catch data (in millions)

- Catch at age data estimated by:
  - Scaling up sample length-frequency data to total catch in each time period-quarter-fishery (for combinations without any length samples, length distribution from adjacent years used)
  - Ages estimated from length using assumed growth curve and cohort slicing
- Assume CV of 30% for all catch estimates

Catch data for cohort 2004.5

	Number caught by age (in millions)										
Cohort	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
2004.5	0.50	5.98	1.75	1.59	1.09	0.85	0.85	0.33	0.21	0.13	0.12

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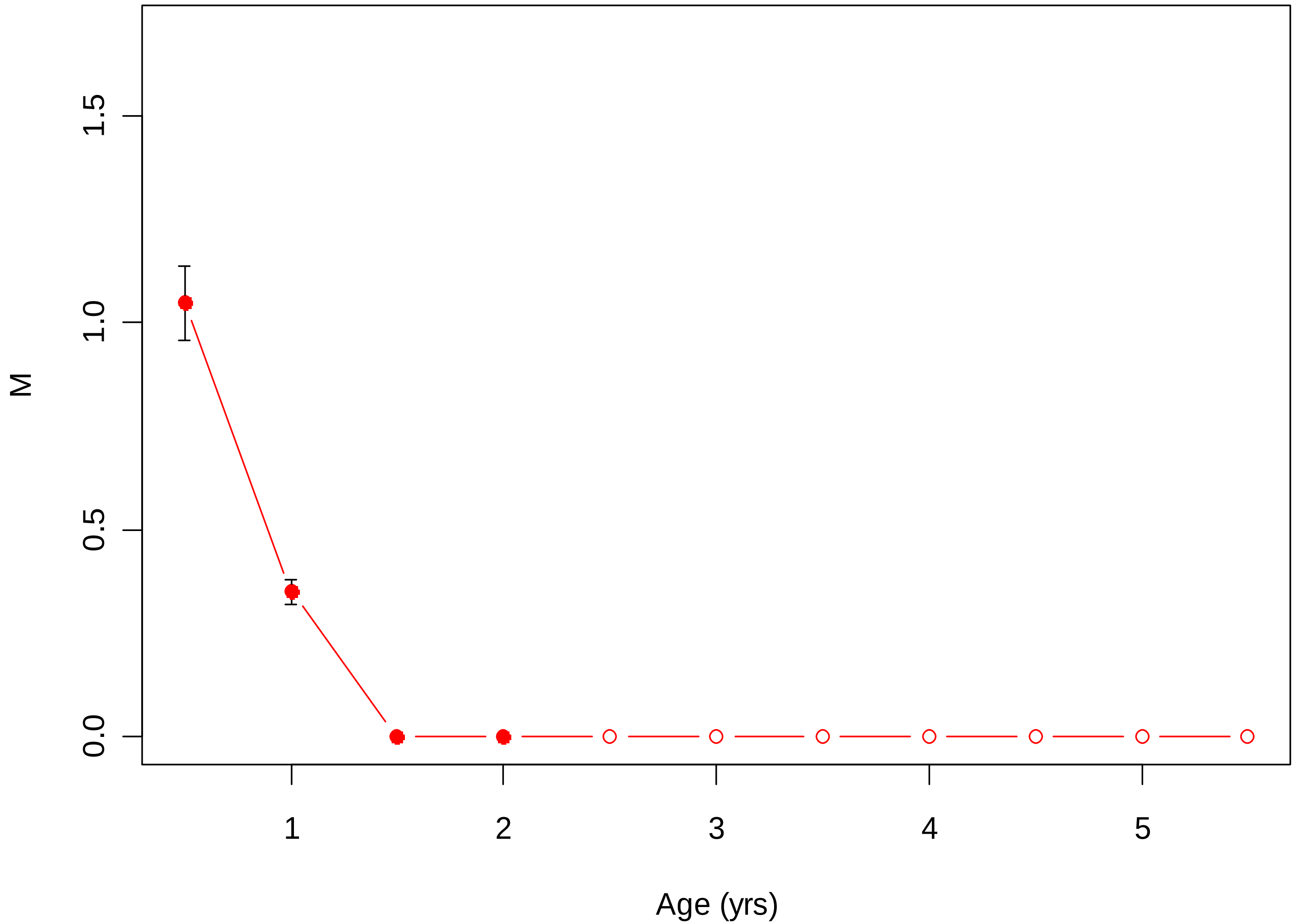
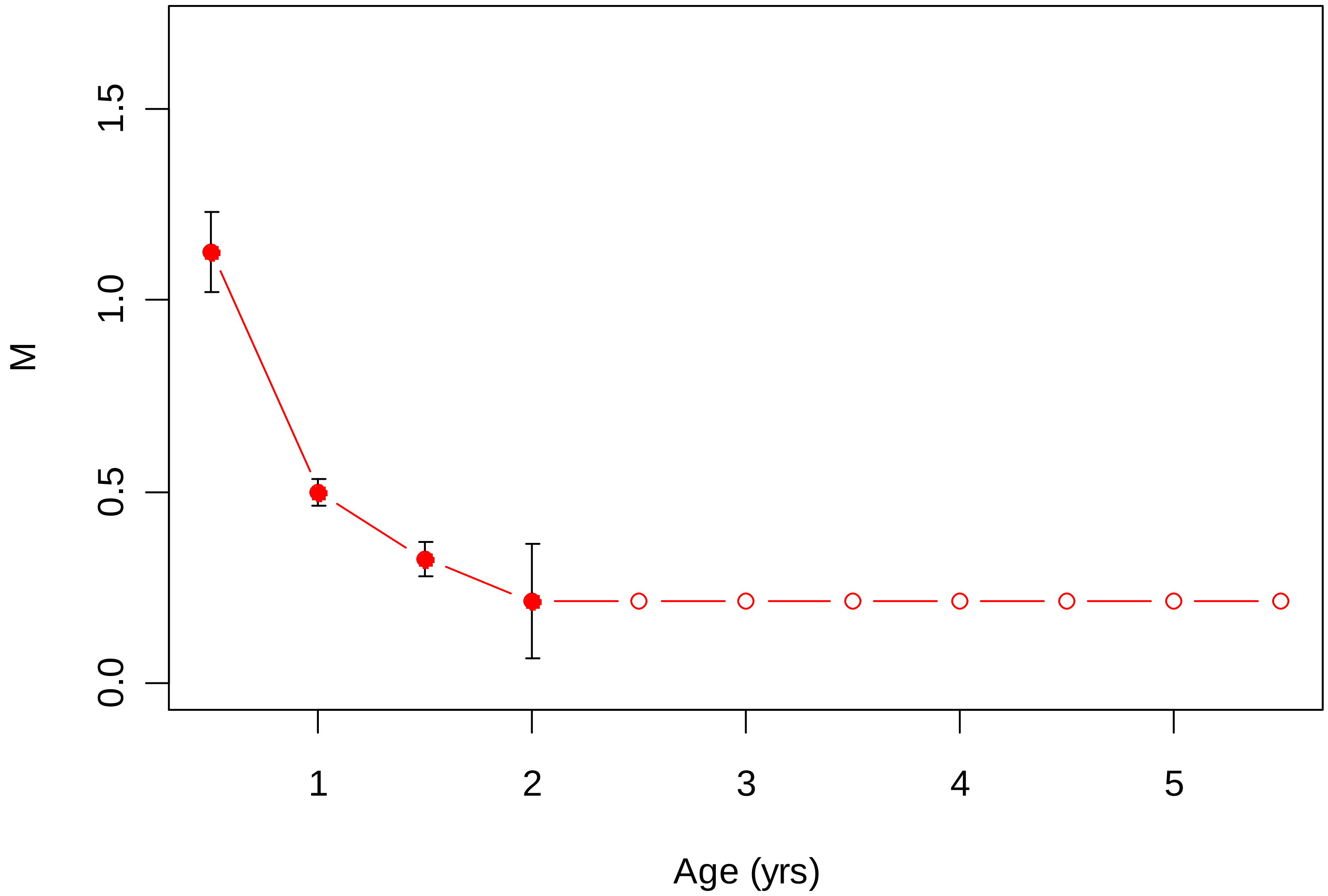
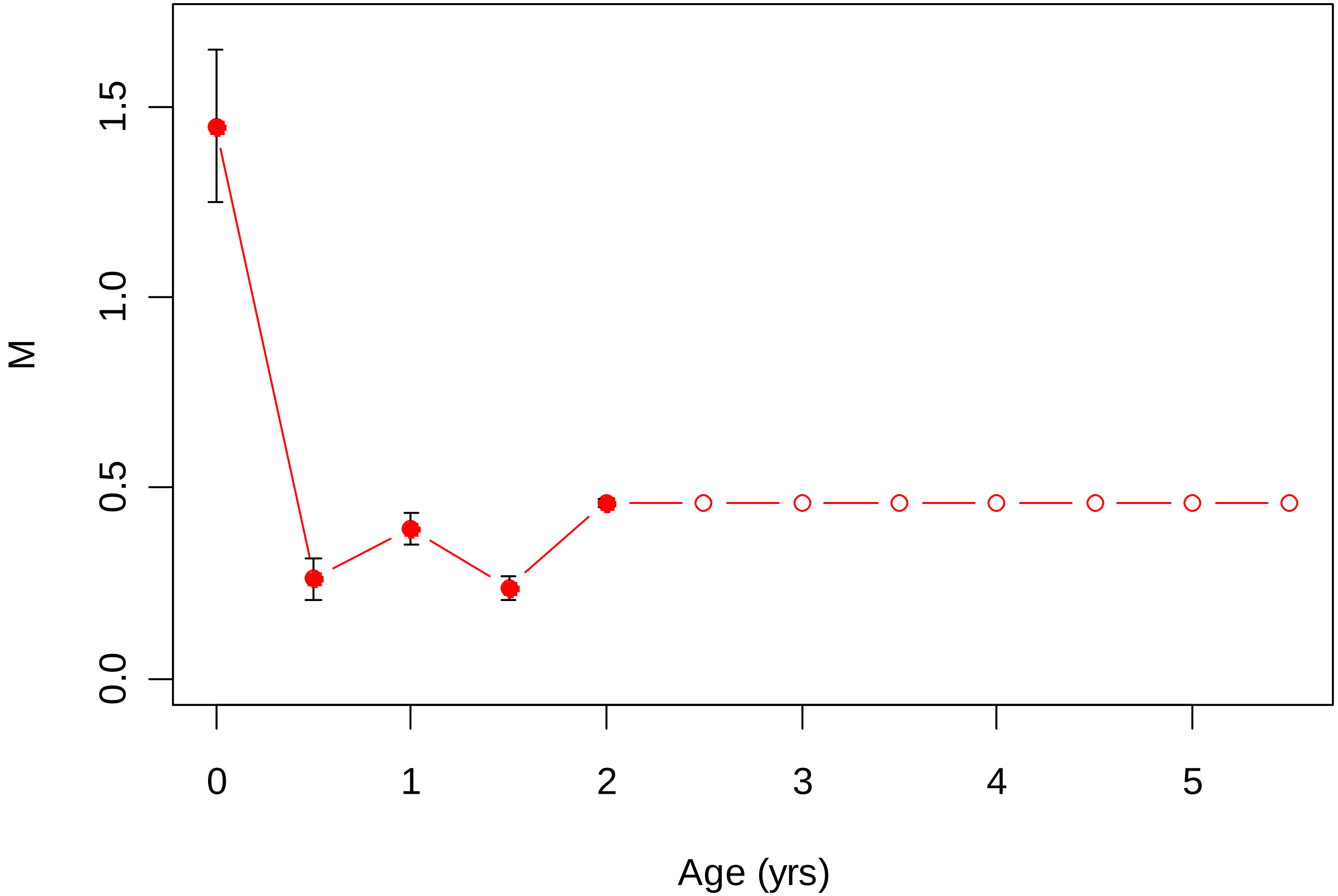
Natural mortality results: Full mixing



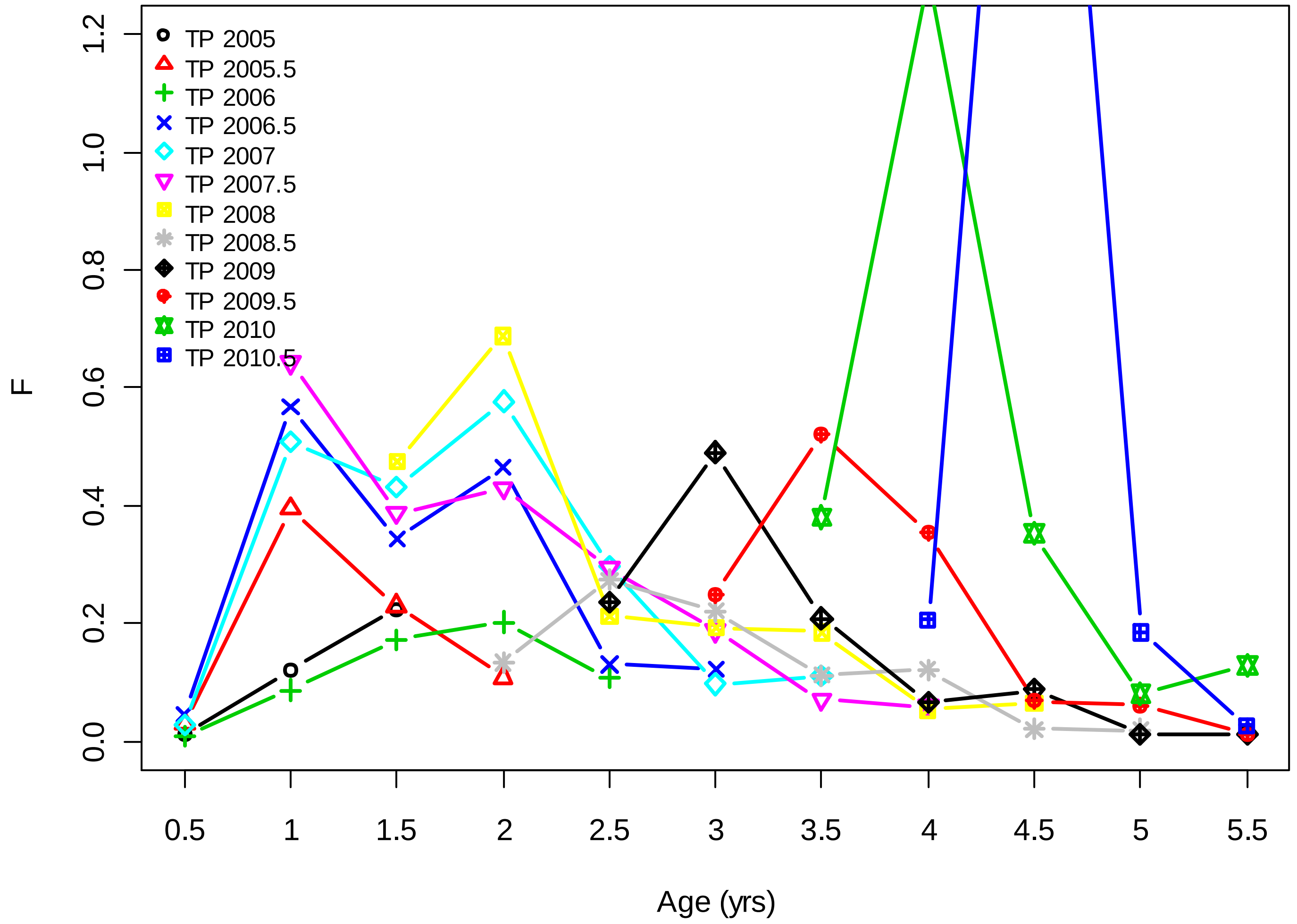
Natural mortality results:
PS area mixing



Natural mortality results: PS area mixing, alternative growth



Fishing mortality results: Full mixing



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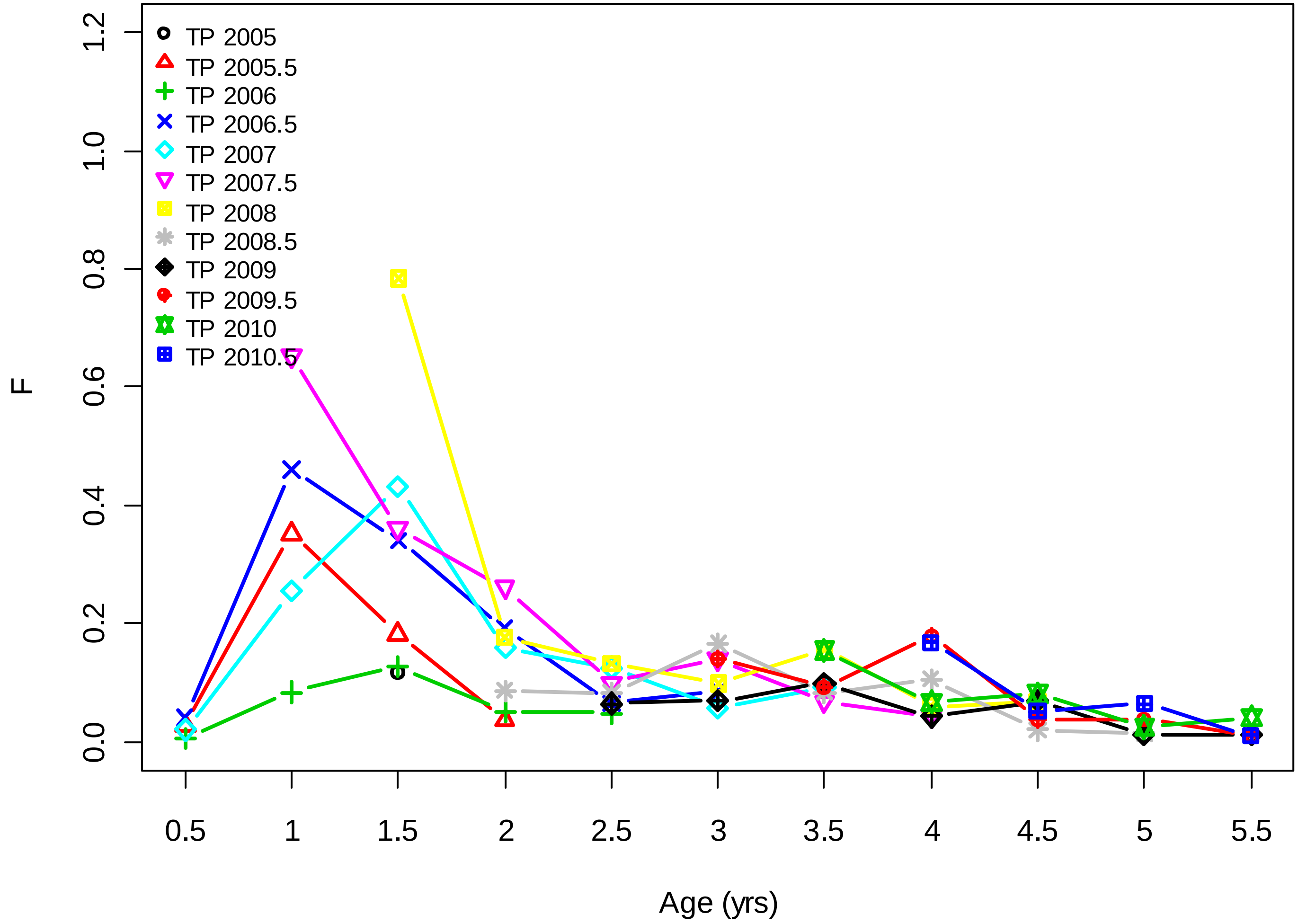
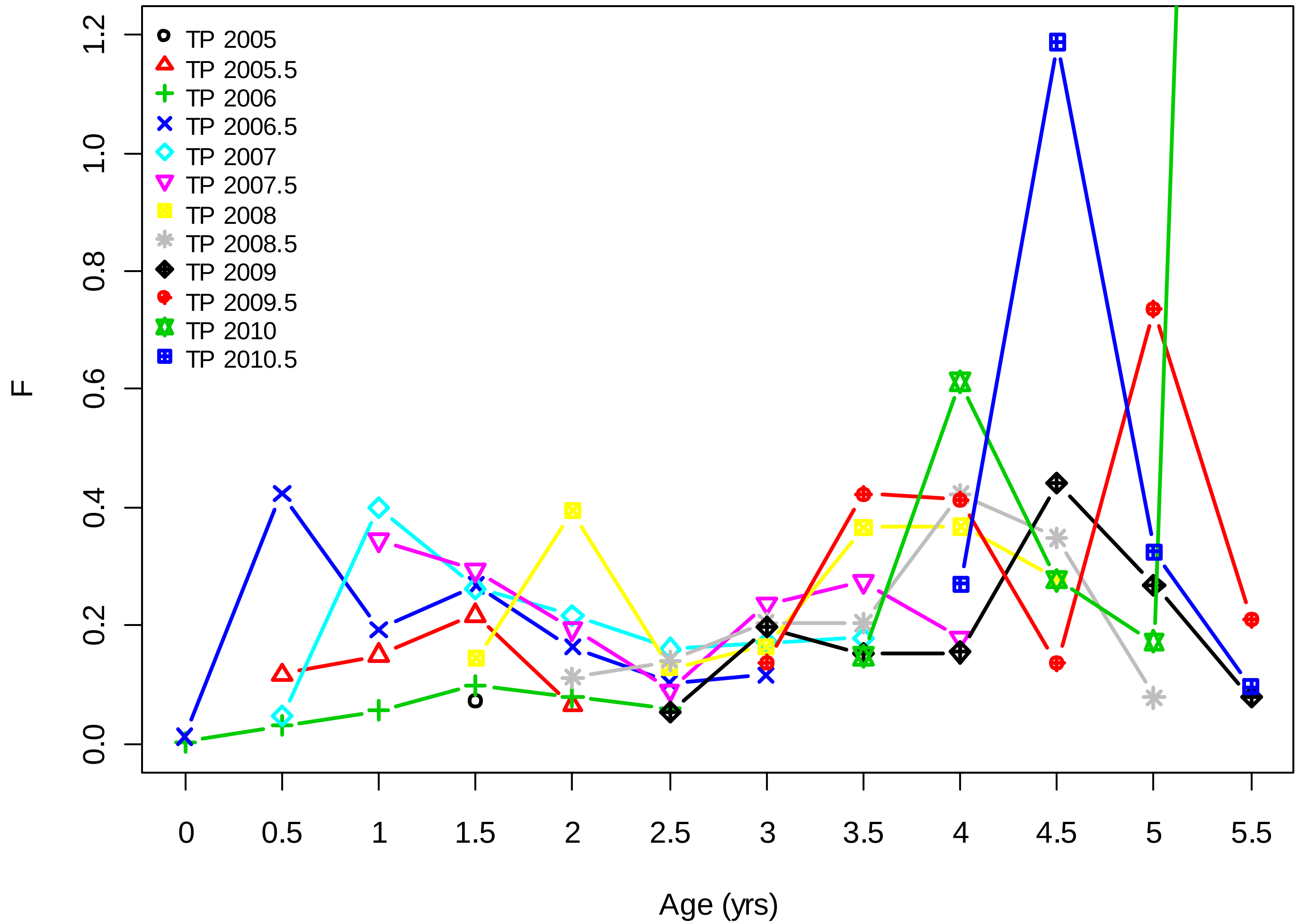
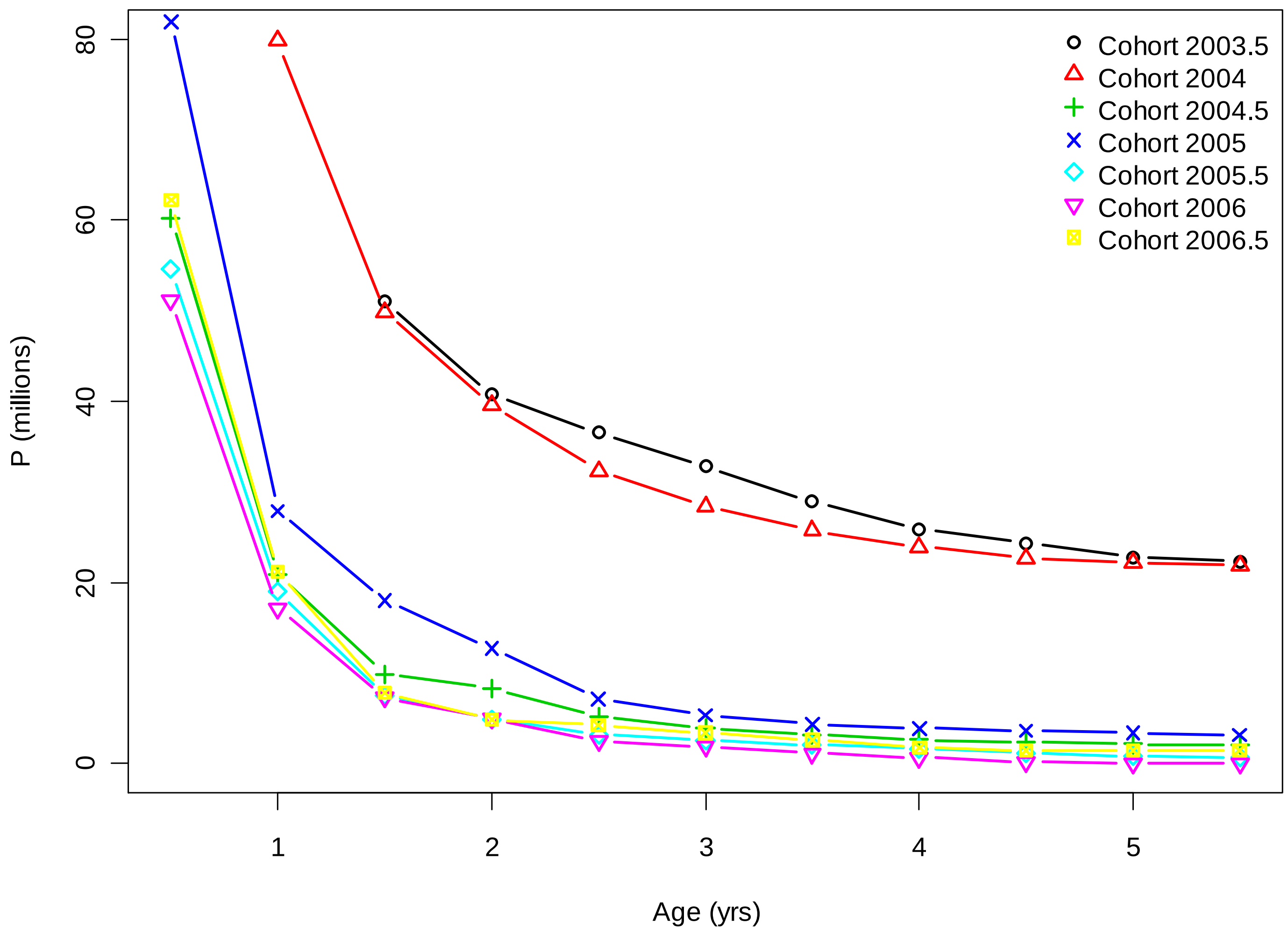
Fishing mortality results:
PS area mixing



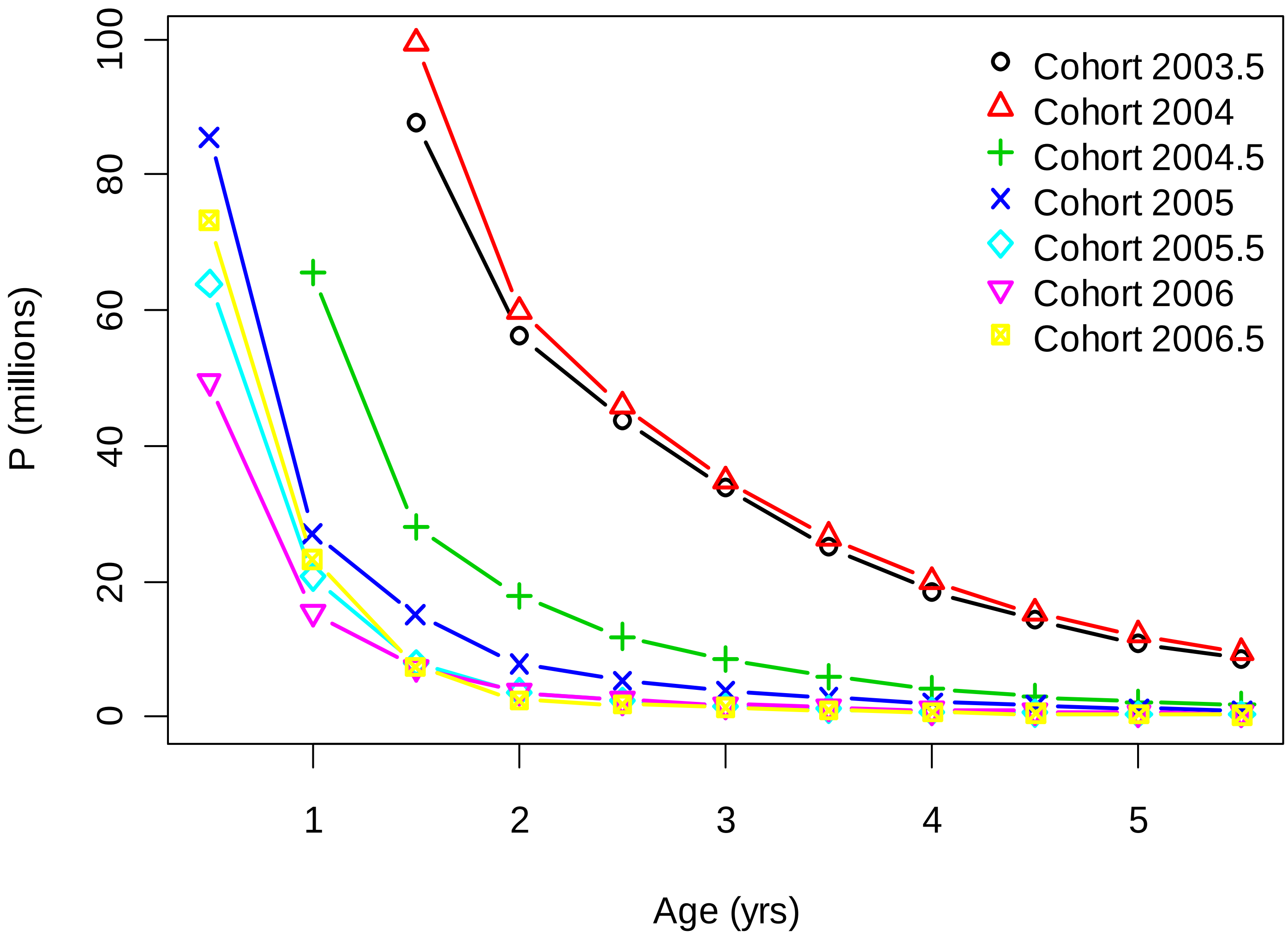
Fishing mortality results:
PS area mixing, alternative growth



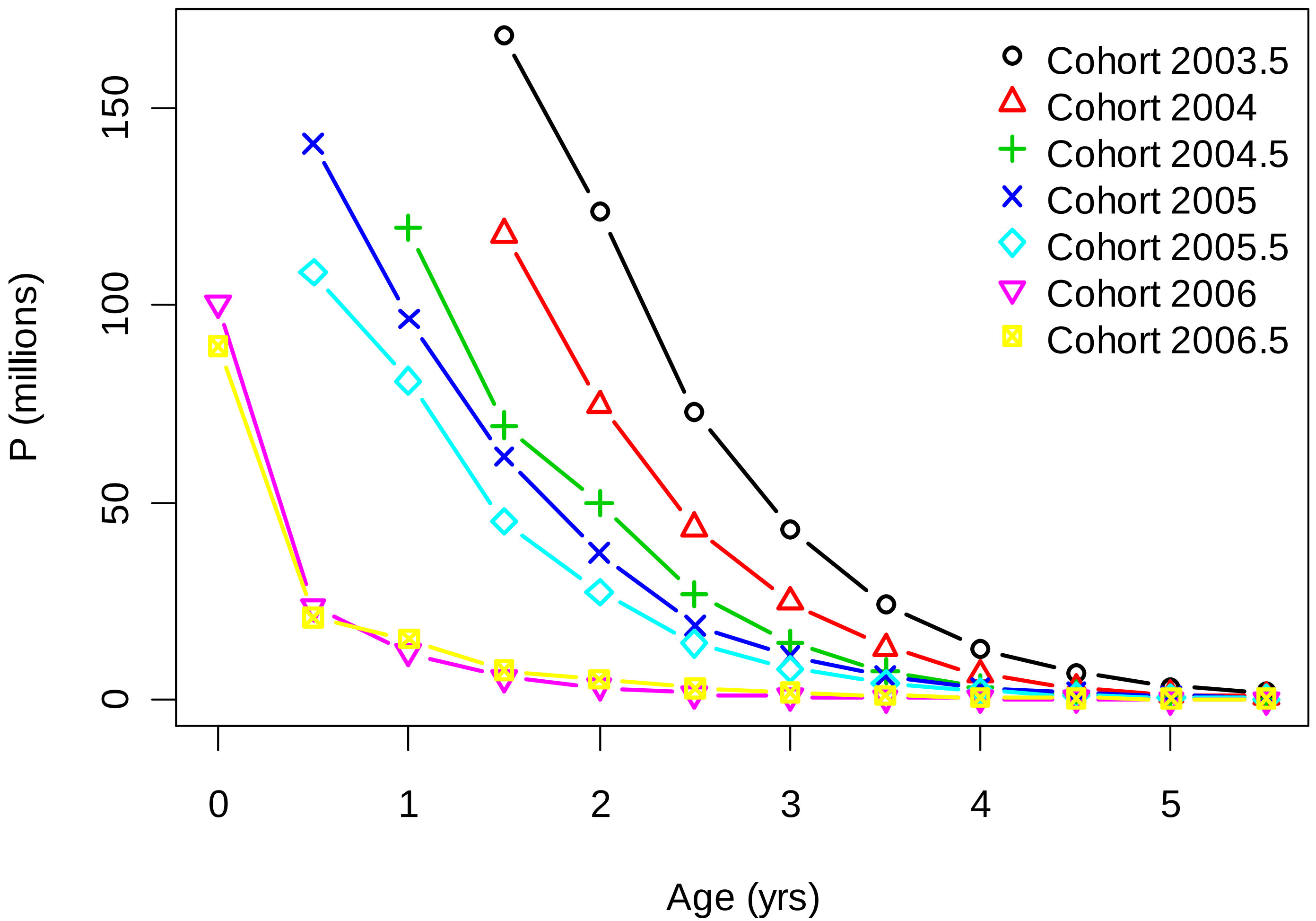
Population size results: Full mixing



Population size results:
PS area mixing



Population size results:
PS area mixing, alternative growth curve



Discussion

- Large uncertainties exist in the data and model assumptions
- Evidence suggests need for a spatial model
- When full mixing does not occur and a non-spatial model is used, get biased parameter estimates (bias large when movement between regions is low)
- BUT, spatial model requires *conventional* tagging in all regions in order for all parameters to be estimable – *or else need archival tagging*

Eveson, Laslett, and Polacheck (2009) *A spatial model for estimating mortality rates, abundance and movement probabilities from fishery tag-recovery data.* Environmental and Ecological Statistics Series, Vol. 3.

Eveson, Basson and Hobday (2011) *Using electronic tag data to improve parameter estimates in a tag-based spatial fisheries assessment model.* Can. J. Fish. Aquat. Sci. 69: 869-883.

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MFCL Area 2 estimates