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Supplementary Material

The “discard problem” in Mediterranean fisheries, in the face of the European Union landing obligation: the case of bottom trawl fishery and implications for management

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Table S1. Species specific annual landings as percentage of total landings during the whole study period (1995-2015), for the monitored commercial vessels of this study. (Vessel names are masked - values exceeding 25% are shown in bold).

% of landings in total landings during 1995-2015	Vessel ID	Hake	Red mullet	Deep water rose shrimp
	Vessel ITA1	6.3%	0.5%	
	Vessel ITA2	2.7%	14.9%	
	Vessel ITA3	37.7%	11.7%	
	Vessel ITA4	25.7%	1.1%	
	Vessel ITA5	15.0%	0.1%	
	Vessel ITA6	12.6%	0.0%	
	Vessel ITA7	36.0%	10.5%	
	Vessel ITA8	38.2%	0.9%	
Ligurian and north Tyrrhenian seas	Vessel ITA9	21.5%	28.0%	
	Vessel ITA10	4.7%	19.0%	
	Vessel ITA11	3.3%	0.0%	
	Vessel ITA12	2.0%	17.1%	
	Vessel ITA13	5.6%	4.5%	
	Vessel ITA14	8.5%	0.0%	
	Vessel ITA15	29.8%	0.4%	
	Vessel ITA16	12.6%	1.0%	
	<i>Average</i>	<i>21.1%</i>	<i>5.1%</i>	

(continued)

Table S1 Continued

% of landings in total landings during 1995-2015	Vessel ID	Hake	Red mullet	Deep water rose shrimp
Aegean Sea & Crete	Vessel GRC1	1.0%	5.4%	0.0%
	Vessel GRC2	40.0%	0.0%	31.7%
	Vessel GRC3	16.9%	2.2%	37.6%
	Vessel GRC4	1.4%	5.2%	0.0%
	Vessel GRC5	18.6%	4.6%	4.9%
	Vessel GRC6	14.4%	4.8%	41.1%
	Vessel GRC7	10.6%	2.2%	63.2%
	Vessel GRC8	8.8%	11.5%	10.0%
	Vessel GRC9	12.6%	8.3%	25.7%
	Vessel GRC10	16.3%	13.0%	4.3%
	Vessel GRC11	18.7%	1.9%	44.5%
	Vessel GRC12	35.4%	1.4%	29.5%
	Vessel GRC13	14.7%	0.0%	13.7%
	Vessel GRC14	30.1%	1.3%	25.9%
	Vessel GRC15	11.3%	15.2%	21.0%
	Vessel GRC16	46.9%	0.5%	29.9%
	Vessel GRC17	16.5%	3.1%	46.2%
	Vessel GRC18	11.6%	1.7%	55.7%
	Vessel GRC19	13.0%	7.7%	22.0%
	<i>Average</i>	<i>17.3%</i>	<i>4.6%</i>	<i>32.2%</i>

Table S2. List of non-commercial invertebrate species/taxa affected by the otter bottom trawlers of the Aegean Sea and Crete, Ligurian and north Tyrrhenian Sea. (Listed as 'Other invertebrates' in the manuscript).

Aegean Sea and Crete	Ligurian and north Tyrrhenian Sea
Anomura	<i>Acanthocardia aculeate</i>
<i>Aporrhais pespelecani</i>	<i>Acanthocardia echinata</i>
<i>Aporrhais</i> spp.	<i>Acanthocardia paucicostata</i>
Ascidia	<i>Acanthocardia spinosa</i>
Asteroidea	<i>Aequipecten opercularis</i>
<i>Aurelia aurita</i>	<i>Alcyonium palmatum</i>
Brachyura	<i>Anadara corbuloides</i>
<i>Cidaris cidaris</i>	<i>Antedon mediterranea</i>
Cnidaria	<i>Anthozoa indet.</i>
Corals	<i>Aphrodita aculeate</i>
<i>Echinaster sepositus</i>	<i>Aporrhais pespelecani</i>
Echinoidea	<i>Aporrhais serresianus</i>
<i>Echinus</i> spp.	<i>Armina tigrina</i>
<i>Goneplax rhomboides</i>	<i>Astropecten aranciacus</i>

(continued)

Table S2 Continued

Aegean Sea and Crete	Ligurian and north Tyrrhenian Sea
<i>Holothuria forskali</i>	<i>Astropecten bispinosus</i>
Holothuroidea	<i>Astropecten irregularis pentacanthus</i>
<i>Ophioderma</i> spp.	<i>Bivalvi</i> indet.
Ophiuridae	<i>Bolinus brandaris</i>
<i>Ostrea edulis</i>	<i>Buccinum corneum</i>
Other unidentified invertebrates	<i>Calliostoma granulatum</i>
<i>Paracentrotus lividus</i>	<i>Cassidaria</i> spp.
<i>Parastichopus regalis</i>	<i>Cavolinia tridentate</i>
Porifera	<i>Chlamys varia</i>
<i>Spongia officinalis</i>	<i>Cidaris cidaris</i>
<i>Spongia</i> spp.	<i>Codium bursa</i>
	<i>Echinaster sepositus</i>
	<i>Echinocardium cordatum</i>
	<i>Echinoidea</i> indet.
	<i>Echinus acutus</i>
	<i>Echinus melo</i>
	<i>Fusinus rostratus</i>
	<i>Galeodea (Cassidaria) echinofora</i>
	<i>Galeodea (Cassidaria) rugosa</i>
	<i>Glossus humanus</i>
	<i>Holothuria polii</i>
	<i>Holothuria tubulosa</i>
	<i>Hyalinoecia tubicola</i>
	<i>Isidella elongate</i>
	<i>Laetmonice hystrix</i>
	<i>Leptometra phalangium</i>
	<i>Marthasterias glacialis</i>
	<i>Microcosmus sabatieri</i>
	<i>Microcosmus</i> spp.
	<i>Mytilus galloprovincialis</i>
	<i>Nassarius mutabilis</i>
	<i>Naticarius hebreia</i>
	<i>Naticarius</i> spp.
	<i>Naticarius stercusmuscarum</i>
	<i>Neopycnodonte coclear</i>
	<i>Nudibranchi</i> indet.
	<i>Ocnus planci</i>
	<i>Oloturie</i> indet.
	<i>Ophiothrix fragilis</i>
	<i>Ophiura texturata</i>
	<i>Ophiuroidea</i> indet.
	<i>Opisthobranchi</i> spp.
	<i>Ostrea edulis</i>
	<i>Ostrea</i> spp.
	<i>Parastichopus regalis</i>

(continued)

Table S2 Continued

Aegean Sea and Crete	Ligurian and north Tyrrhenian Sea
	<i>Pecten jacobaeus</i>
	<i>Pennatula phosphorea</i>
	<i>Pennatula rubra</i>
	<i>Pennatula</i> spp.
	<i>Porifera</i> indet.
	<i>Posidonia oceanica</i>
	<i>Psammechinus microtuberculatus</i>
	<i>Pteria hirundo</i>
	<i>Pteroides griseum</i>
	<i>Pyrosoma atlanticum</i>
	<i>Rhizostoma pulmo</i>
	<i>Scaphander lignarius</i>
	<i>Schizaster canaliferus</i>
	<i>Spatangus purpureus</i>
	<i>Sphaerechinus granularis</i>
	<i>Sternaspis scutata</i>
	<i>Stylocidaris affinis</i>
	<i>Suberites domuncula</i>
	<i>Tethyaster subinermis</i>
	<i>Thenea muricata</i>
	<i>Trachythyone elongata</i>
	<i>Trachythyone tergestina</i>
	<i>Turritella communis</i>
	Gasteropod eggs

Table S3. Number of species/taxa discarded and marketed by major taxonomic group, by the otter bottom trawlers of the Aegean Sea and Crete, Ligurian and north Tyrrhenian Sea during the study period 1995-2015 (discarded and marketed species may overlap).

	Taxonomic groups	Discarded	Absolute values in kg	Marketed	Absolute values in kg
Aegean Sea and Crete	Fish	139	24181	123	46138
	Crustaceans	13	6948	20	33519
	Cephalopods	23	2107	16	13078
	Invertebrates (other than crustaceans & cephalopods)	15	6272	1	1
	Fish	151	7771	136	17490
N. Tyrrhenian & Ligurian Sea	Crustaceans	36	515	45	3825
	Cephalopods	26	215	29	4018
	Invertebrates (other than crustaceans & cephalopods)	69	742	19	81

Table S4a. Summarised results for the ‘best’ model selected for discarded CPUE of demersal species caught in the bottom trawl fishery of the Aegean Sea and Crete. *p*-values refer to the probabilities from an ANOVA F-ratio test. *df* are the estimated degrees of freedom.

GAM model

Family: Gamma

Link function: log

Formula:

DCPUEW + 0.1 ~ as.factor(year) + as.factor(season) + s(depth) + s(Longitude, k = 4) + s(Latitude, k = 4)

Parametric Terms:

	df	F	p-value
as.factor(year)	6	13.277	1.86e-14
as.factor(season)	2	5.665	0.00359

Approximate significance of smooth terms:

	edf	Ref.df	F	p-value
s(depth)	8.553	8.941	4.61	6.12e-06
s(Longitude)	2.595	2.885	15.27	4.26e-08
s(Latitude)	2.877	2.983	8.29	1.98e-05

Table S4b. Summarised results for the ‘best’ model selected for discarded CPUE of demersal species caught in the bottom trawl fishery of the Ligurian and north Tyrrhenian Sea. *p*-values refer to the probabilities from an ANOVA F-ratio test. *df* are the estimated degrees of freedom

GAM model

Family: Gamma

Link function: log

Formula:

DCPUEW + 0.1 ~ as.factor(year) + as.factor(season) + s(depth) +

s(Longitude, k = 4) + s(Latitude, k = 4)

Parametric Terms:

	df	F	p-value
as.factor(year)	5	4.448	0.000642
as.factor(season)	3	1.298	0.275427

Approximate significance of smooth terms:

	edf	Ref.df	F	p-value
s(depth)	7.969	8.722	4.767	5.81e-06
s(Longitude)	2.553	2.859	12.425	1.07e-06
s(Latitude)	2.815	2.969	14.581	7.35e-09

Table S5. Hauls sampled per area, year and depth stratum.

GSA22-23 Aegean Sea and Crete								
Depth stratum	2003	2004	2005	2006	2008	2013	2014	Total
0-100	30	81	59	45	19	55	157	446
100-200	19	62	74	60	21	19	68	323
200-300	2	27	12	11	6	10	40	108
300-400	2	3	11	2	1	6	27	52
>400				2	1	3	14	20
Total	53	173	156	120	48	93	306	949

GSA9 Ligurian and north Tyrrhenian seas								
Depth stratum	1995	1996	1998	1999	2001	2014	2015	Total
0-100	17	11	21	12	1	17	34	113
100-200	16	10	8	25	11	7	22	99
200-300	7	6	4	8	14		1	40
300-400	9	4	5	9	7	5	5	44
400-500	6	10	6		5	8	5	40
>500		1	1		2	4	4	12
Grand Total	55	42	45	54	40	41	71	348

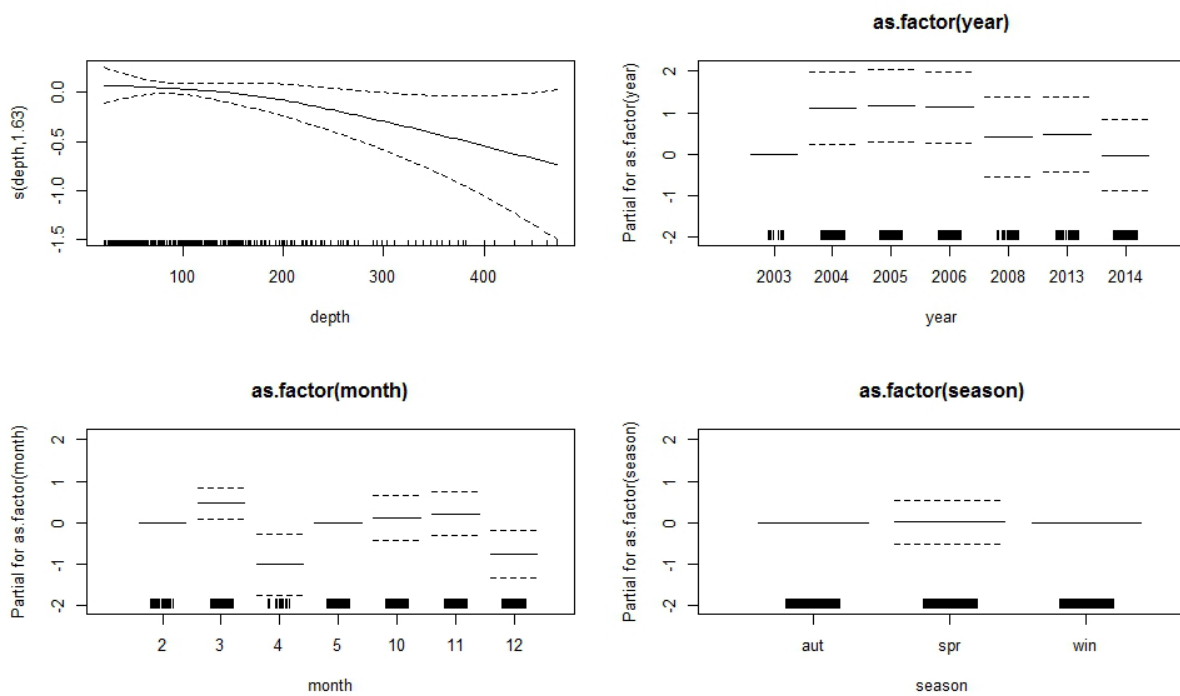


Fig. S1a: Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **invertebrate** catch in the bottom trawl fishery of the Aegean Sea and Crete. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points is shown by the 'rug' on the x-axis.

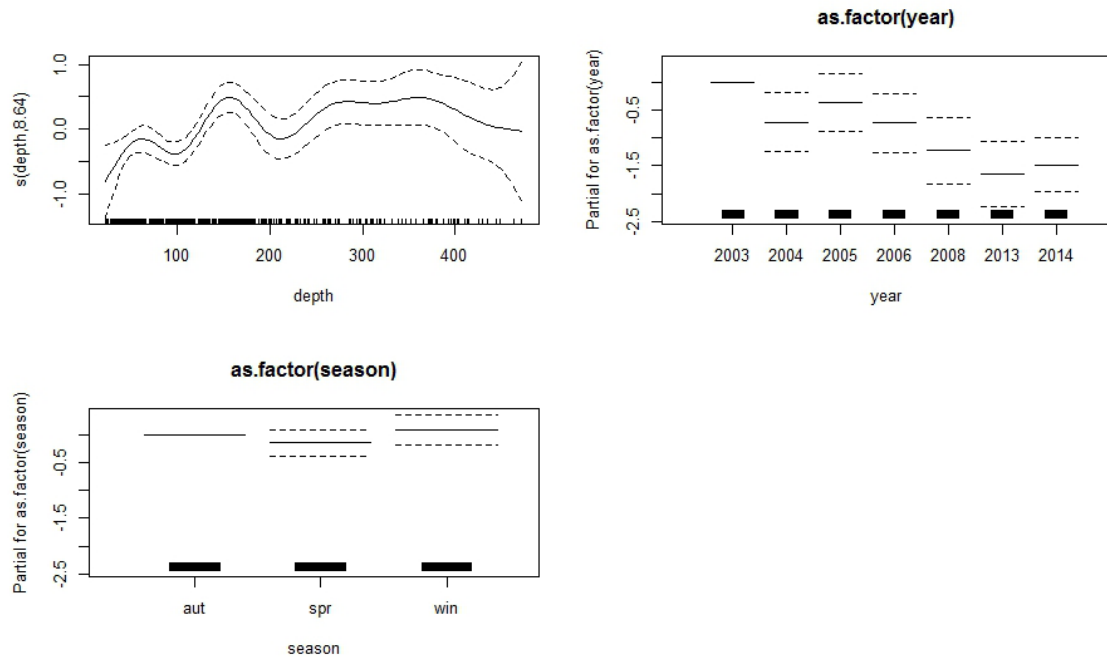


Fig. S1b: Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **elasmobranch** catch in the bottom trawl fishery of the Aegean Sea and Crete. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points is shown by the 'rug' on the x-axis.

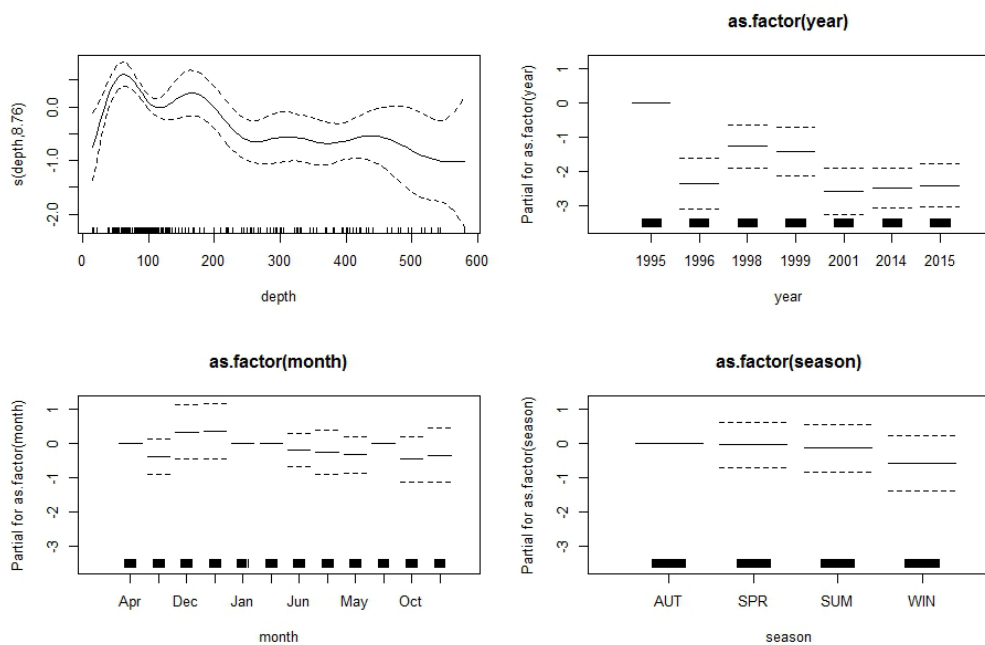


Fig. S2a: Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **invertebrate** catch in the bottom trawl of the Ligurian and north Tyrrhenian Sea. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points is shown by the 'rug' on the x-axis.

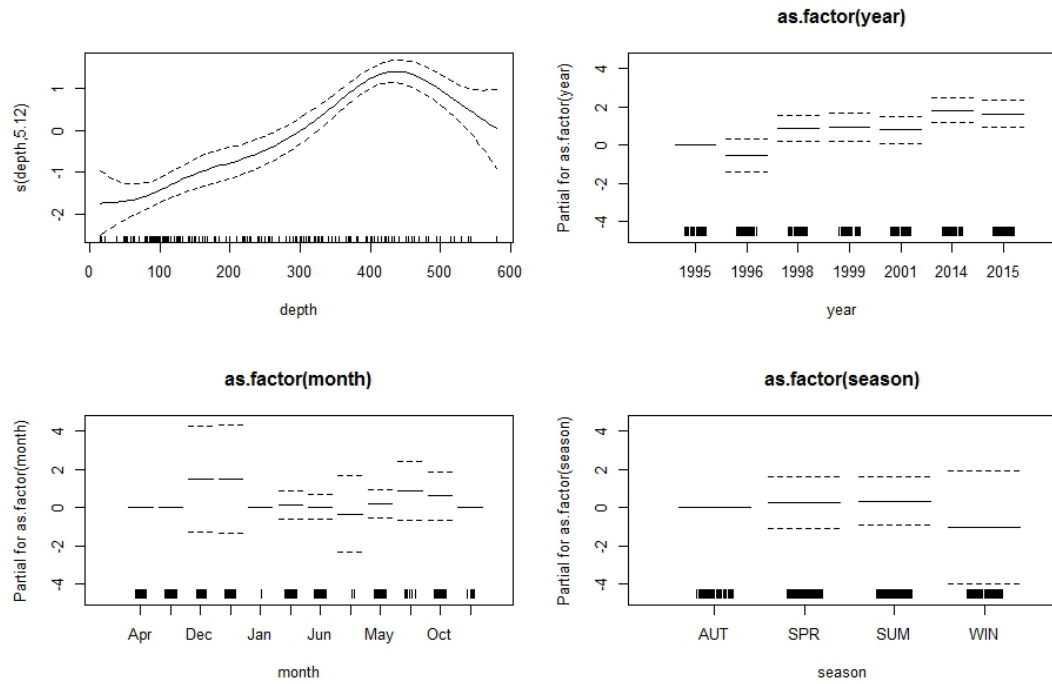
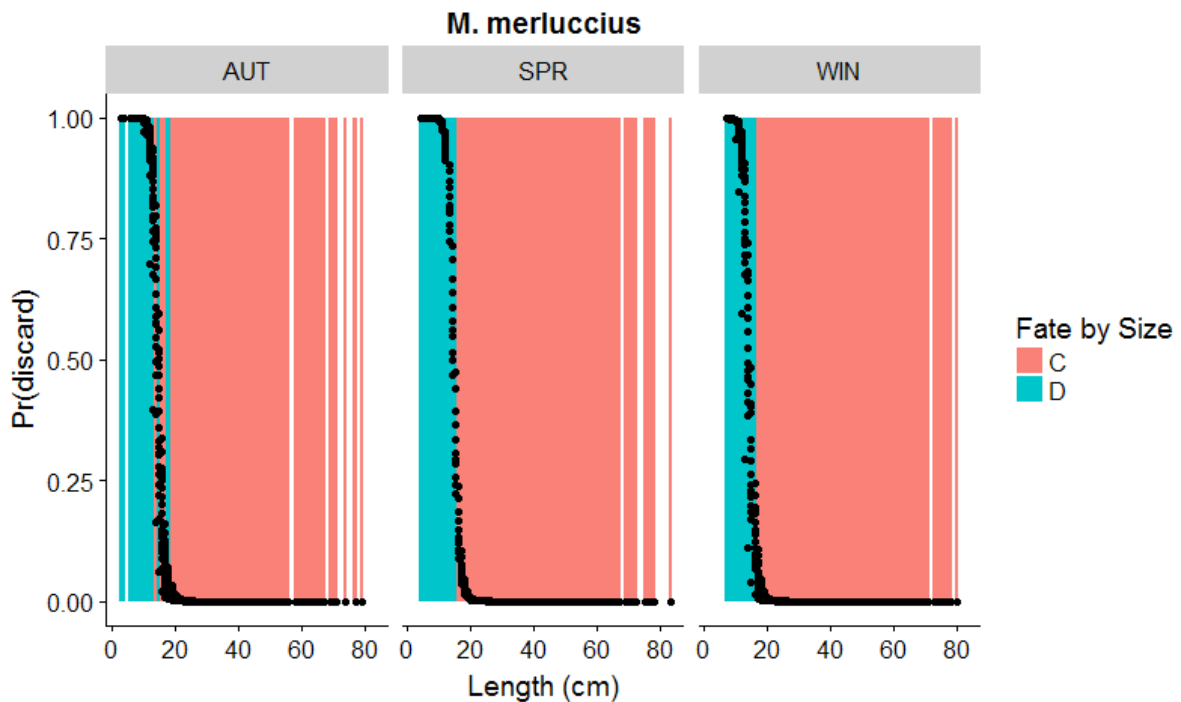


Fig. S2b: Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **elasmobranch** catch in the bottom trawl fishery of the Ligurian and north Tyrrhenian Sea. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points is shown by the ‘rug’ on the x-axis.

AEGEAN SEA and CRETE

Merluccius merluccius (MCRS = 20 cm)



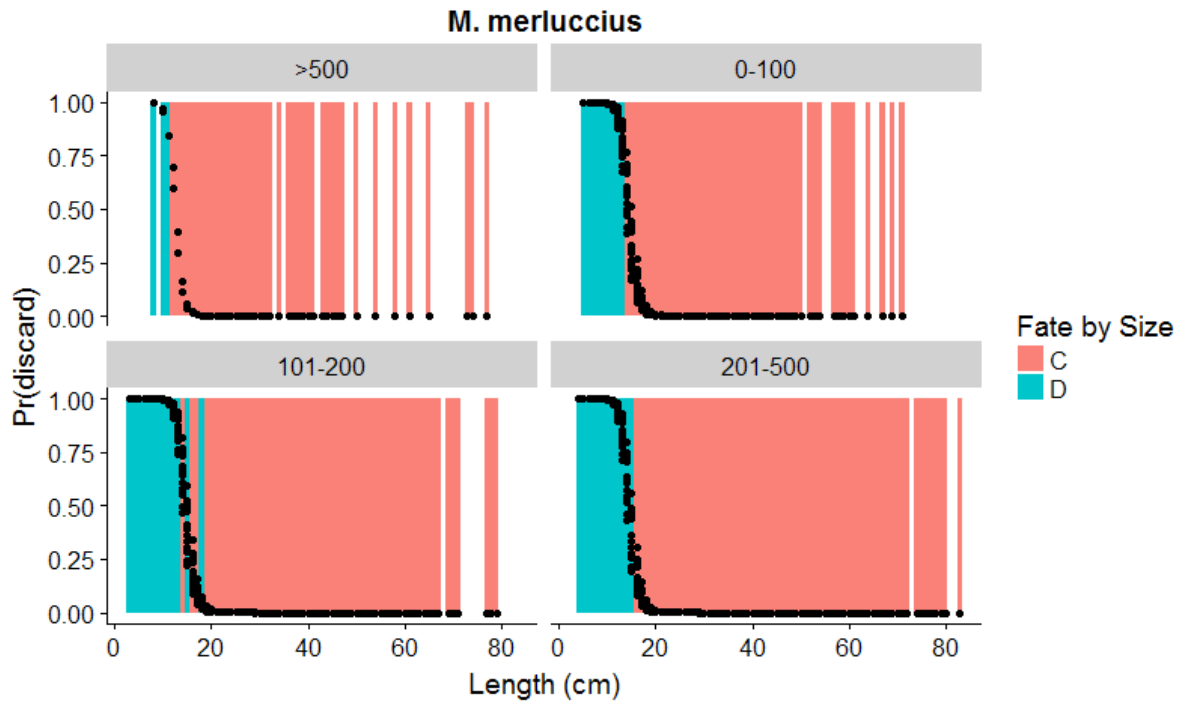


Fig. S3a: GAM derived discard probability by total length with super-imposed discard ogive for hake (top-by season, bottom-by depth stratum).

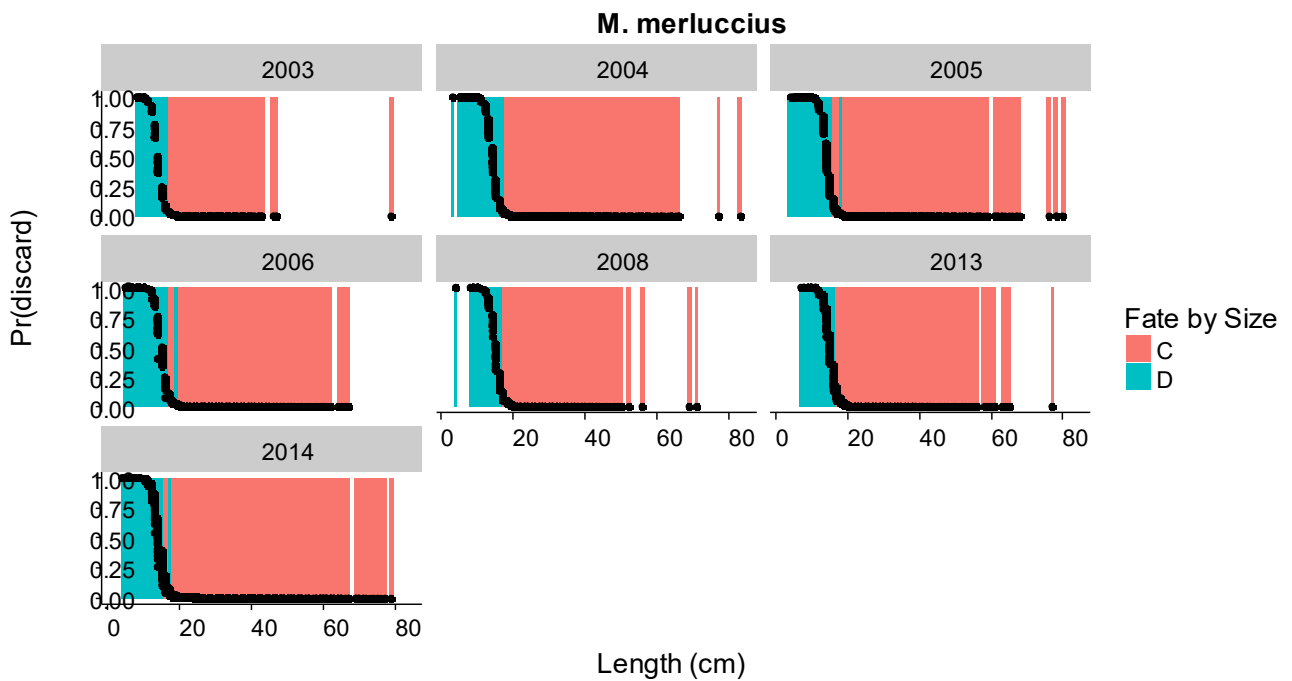


Fig. S3b: GAM derived discard probability by total length with super-imposed discard ogive for hake (by year).

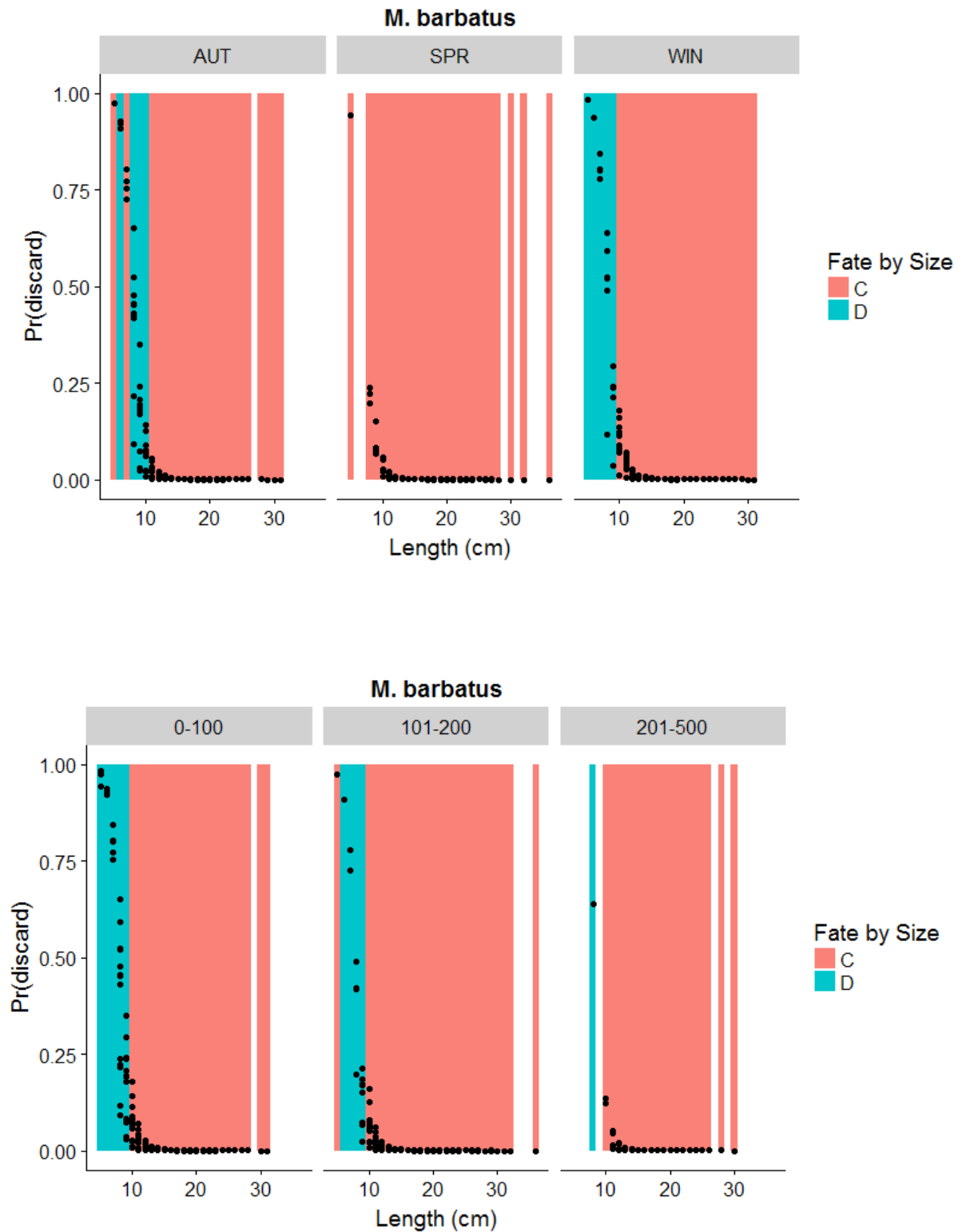


Fig. S3c: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top- by season, bottom-by depth stratum).

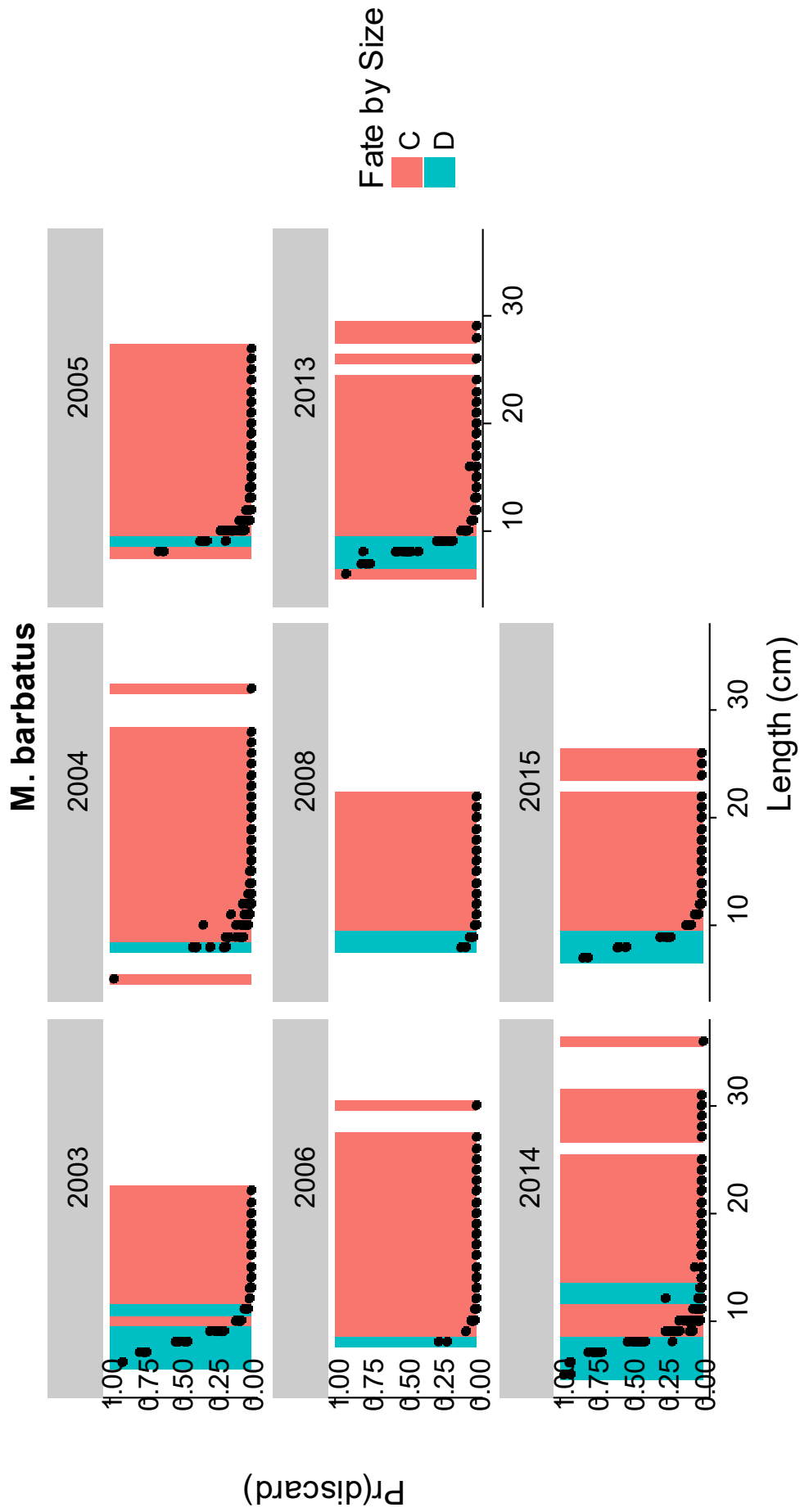


Fig. S3d: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (by year).

Trachurus trachurus (MCRS=15 cm)

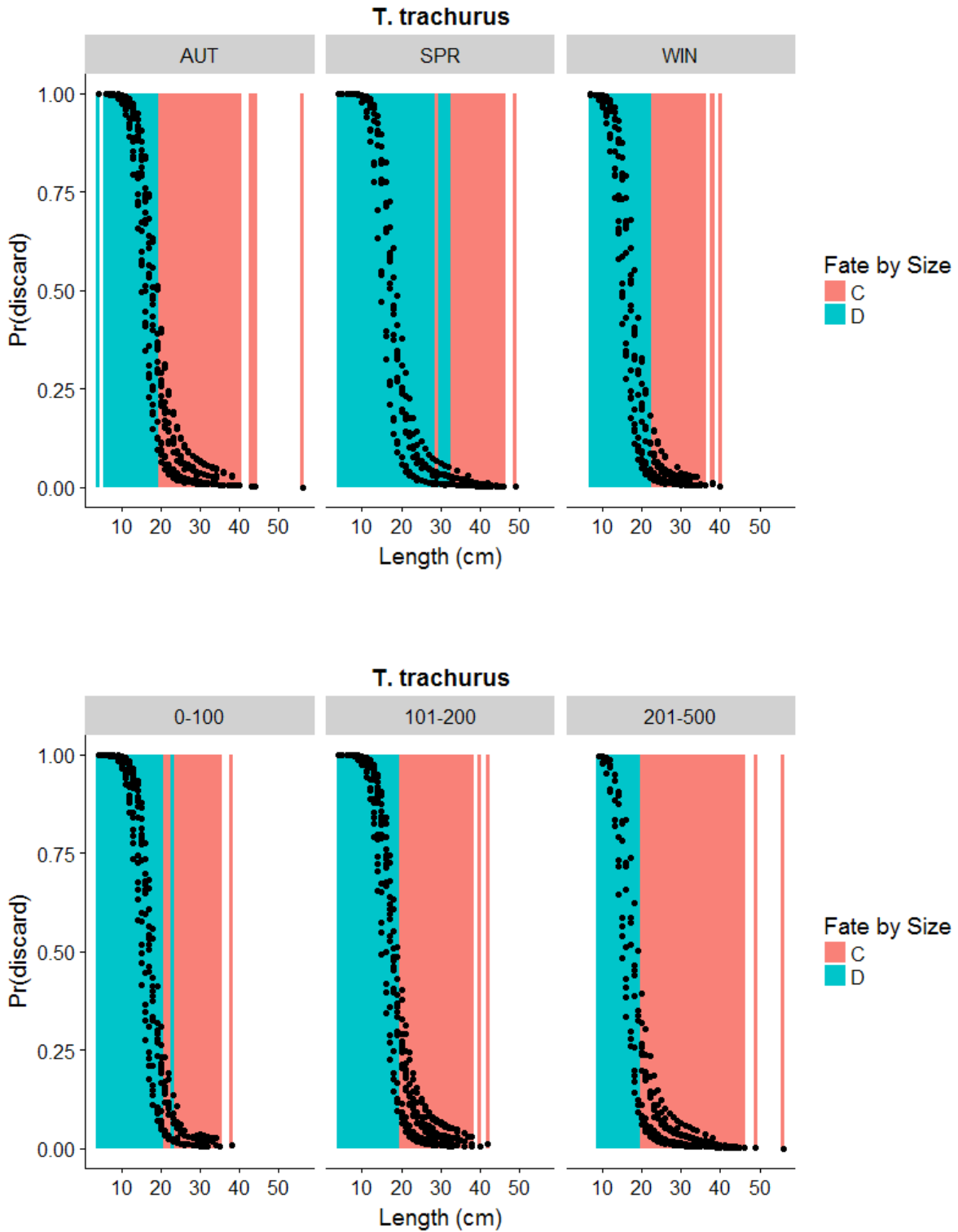


Fig. S3e: GAM derived discard probability by total length with super-imposed discard ogive for horse mackerel (top-global, mid-by season, bottom-by depth stratum).

Parapenaeus longirostris (MCRS = 20mm)

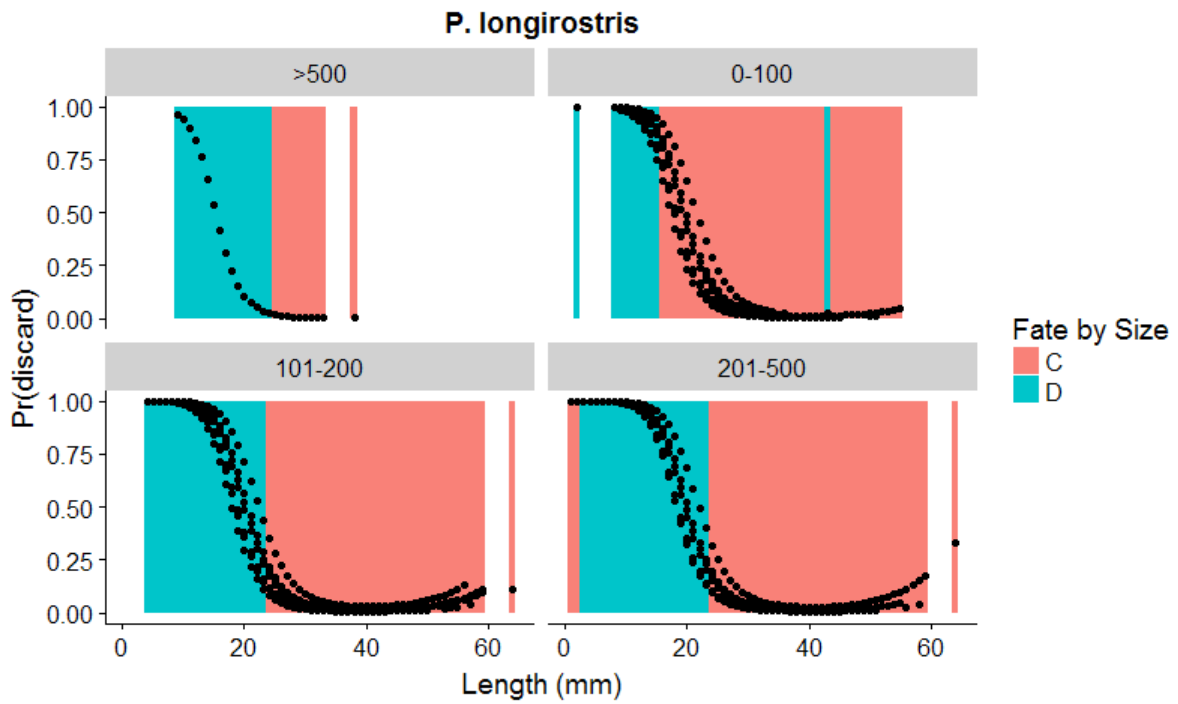


Fig. S3f: GAM derived discard probability by total length with super-imposed discard ogive for deep-water rose shrimp (by depth stratum).

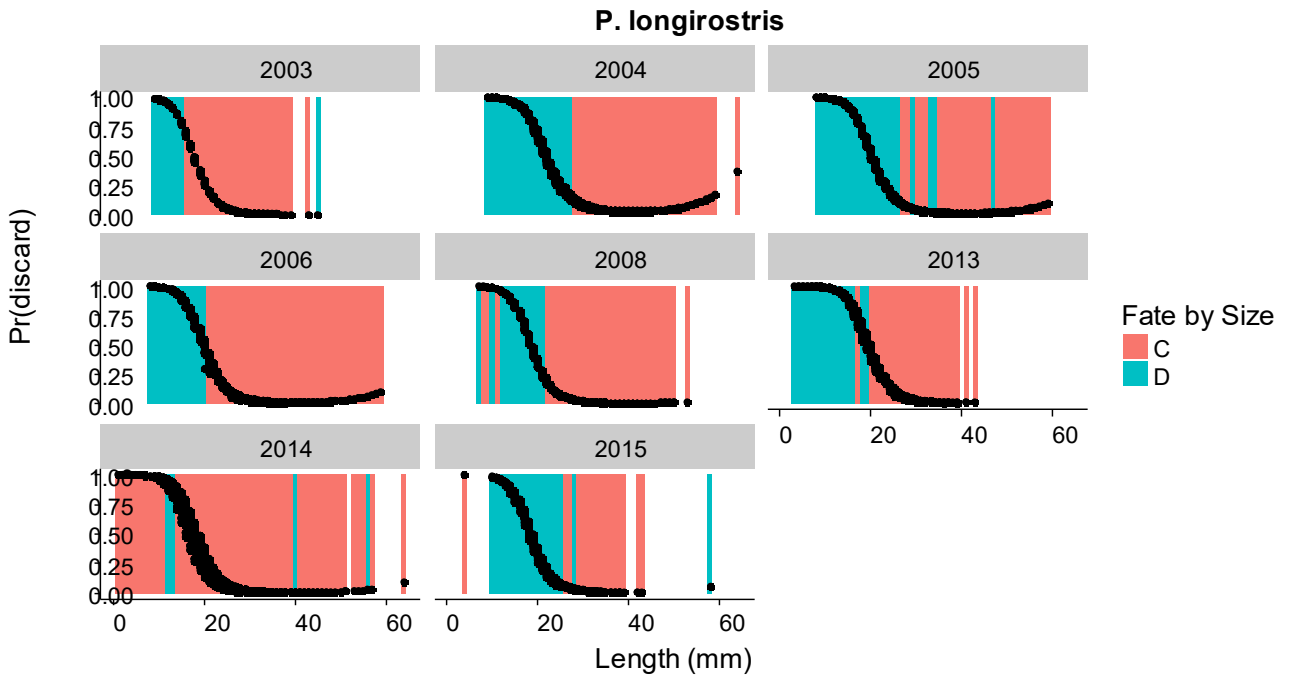


Fig.S3g: GAM derived discard probability by total length with super-imposed discard ogive for deep water rose shrimp (by year).

Lophius budegassa (currently no MCRS - old MCRS =30 cm)

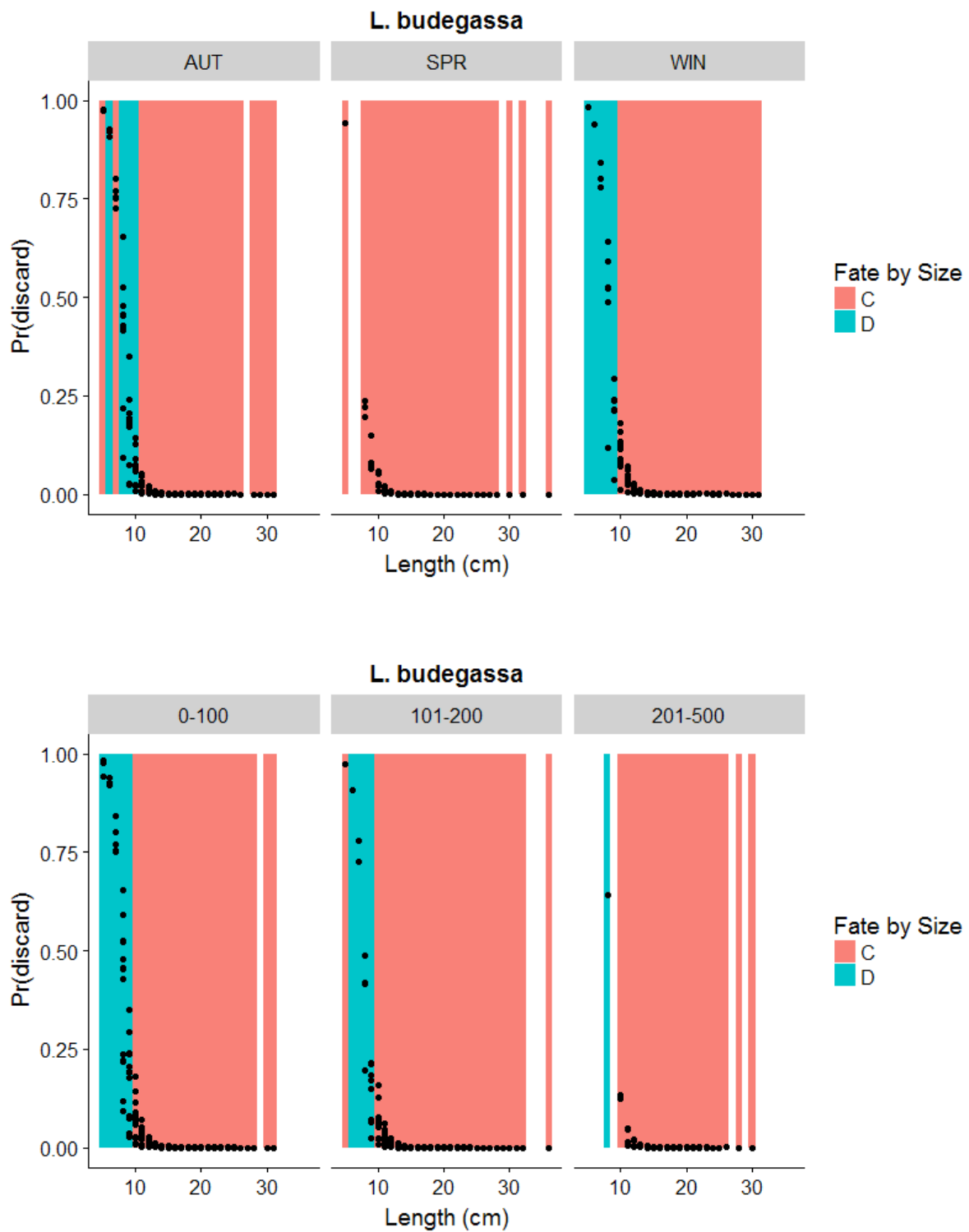


Fig. S3h: GAM derived discard probability by total length with super-imposed discard ogive for anglerfish (top- by season, bottom-by depth stratum).

L. budegassa

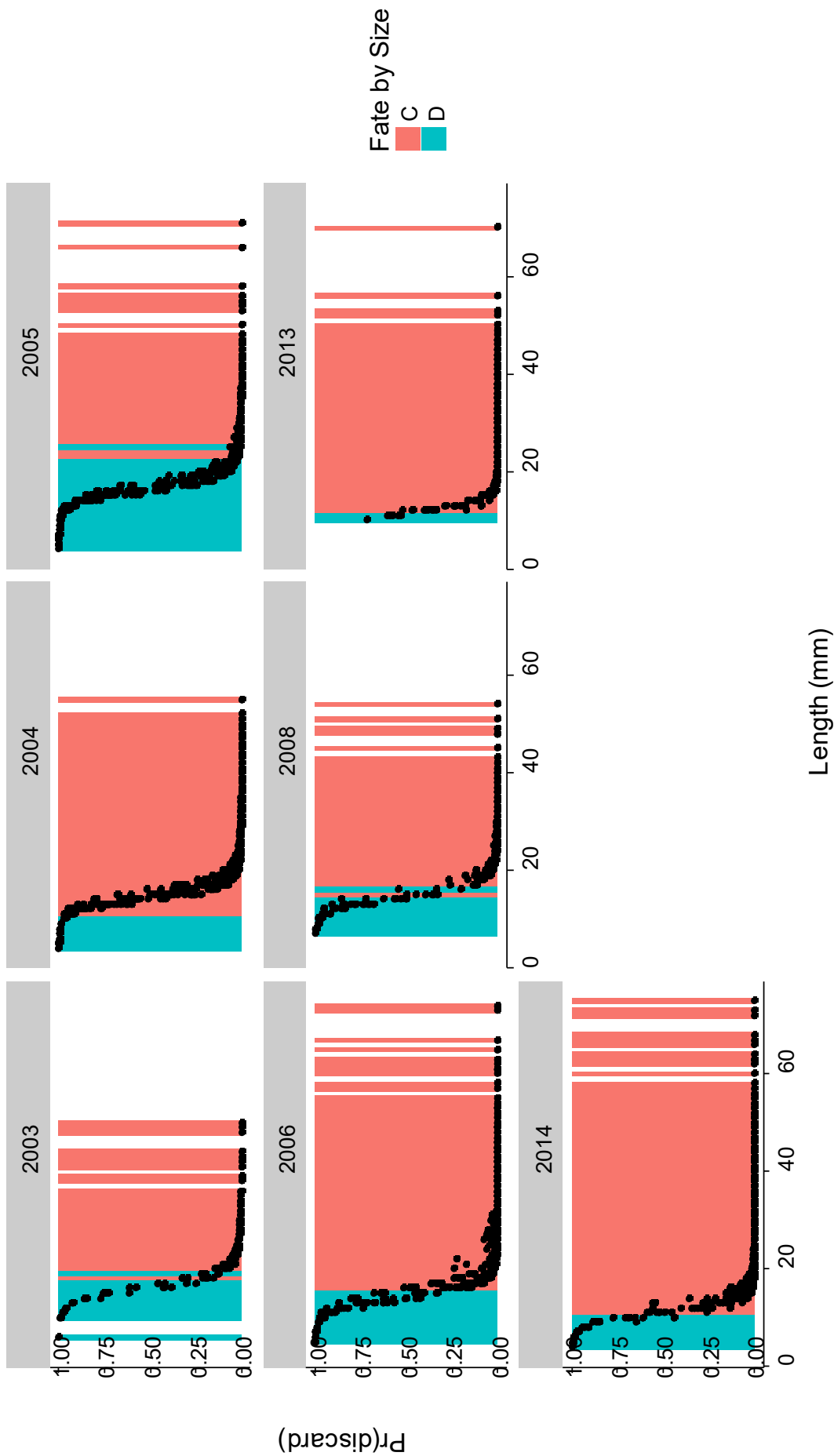


Fig. S3i: GAM derived discard probability by total length with super-imposed discard ogive for anglerfish (by year).

Boops boops (MCRS= 10 cm)

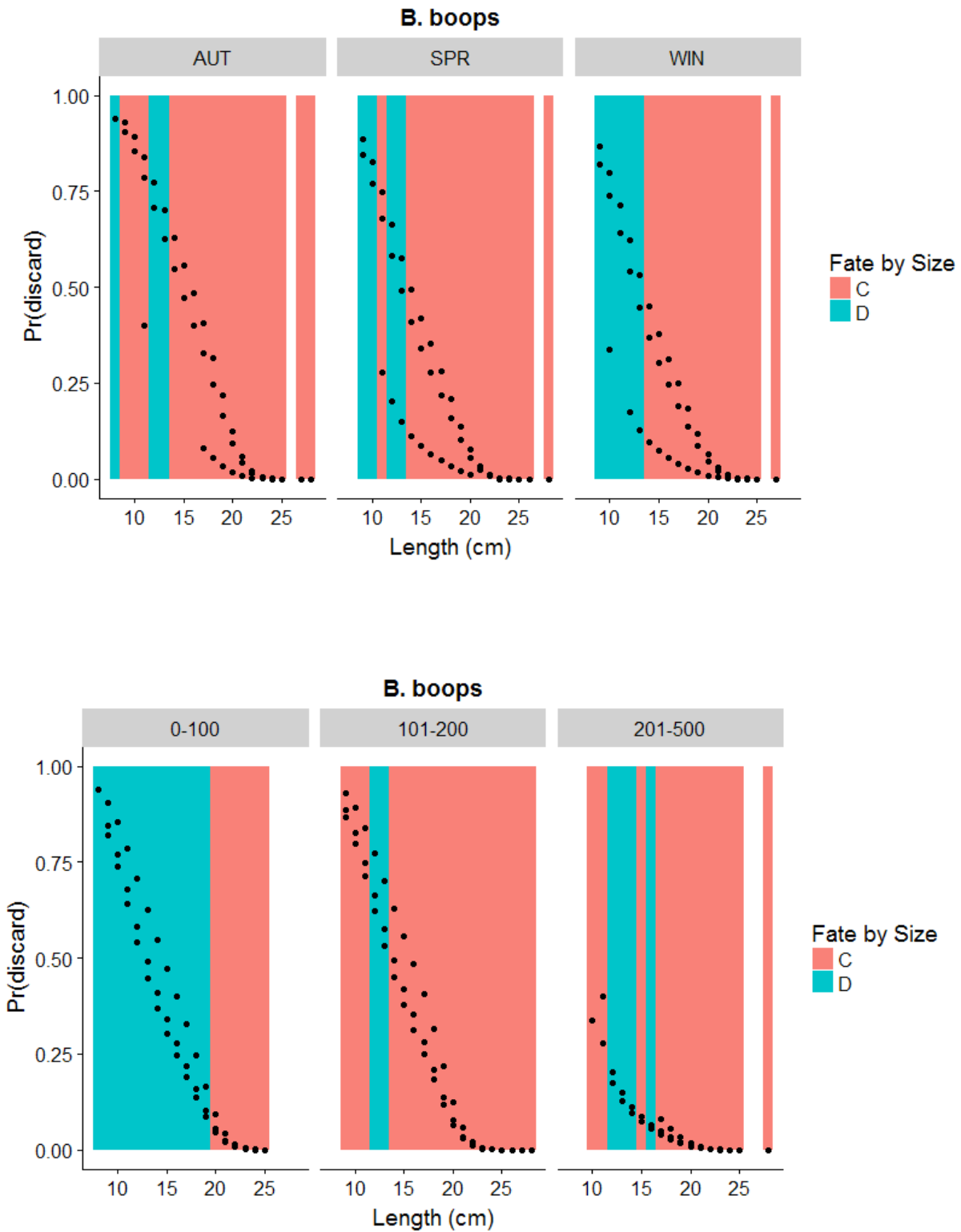


Fig. S3j: GAM derived discard probability by total length with super-imposed discard ogive for bogue (top-global, mid-by season, bottom-by depth stratum).

LIGURIAN & NORTH TYRRHENIAN SEA

Merluccius merluccius (MCRS=20cm)

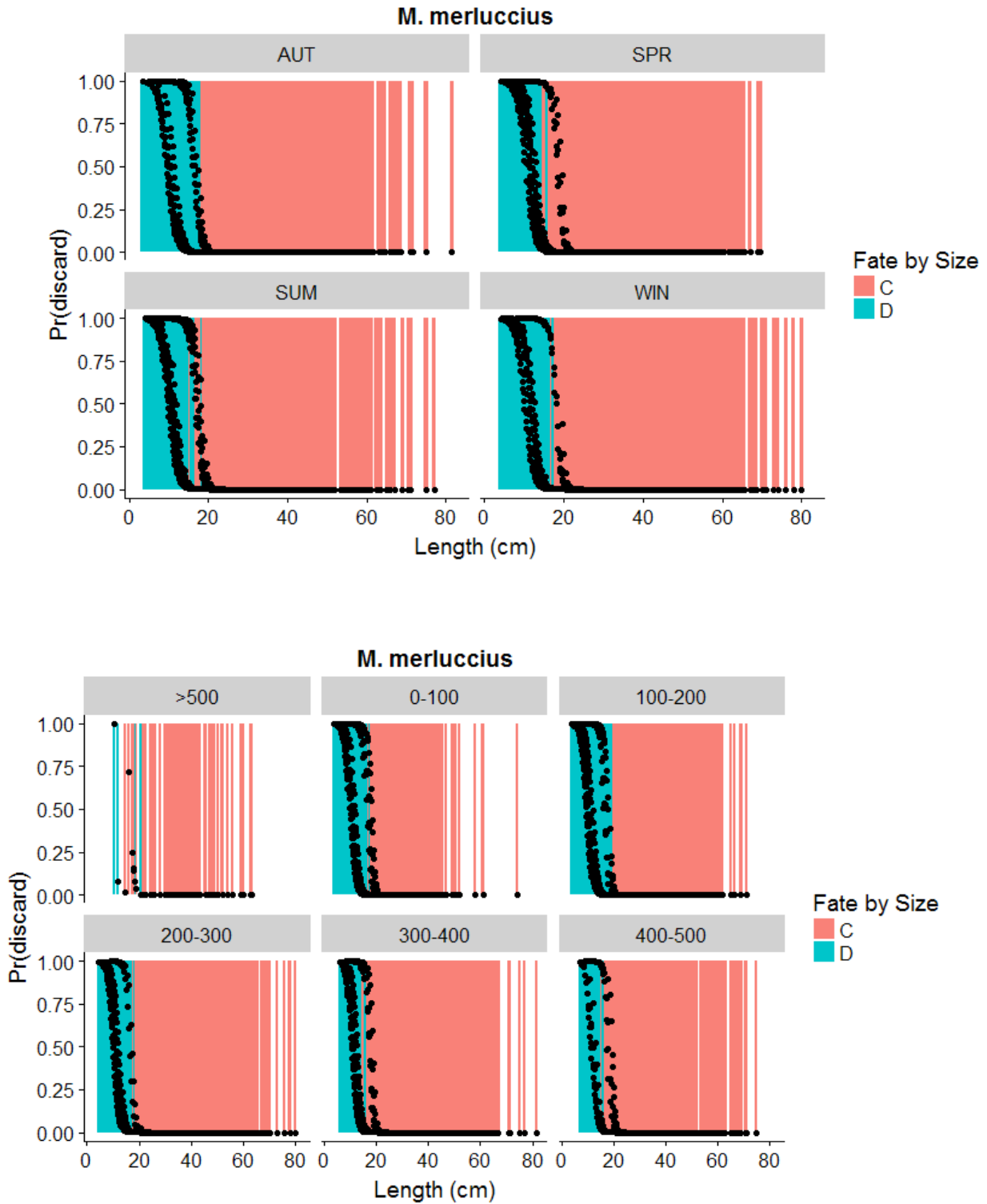


Fig. S4a: GAM derived discard probability by total length with super-imposed discard ogive for hake (top - by season, bottom - by depth stratum).

M. merluccius

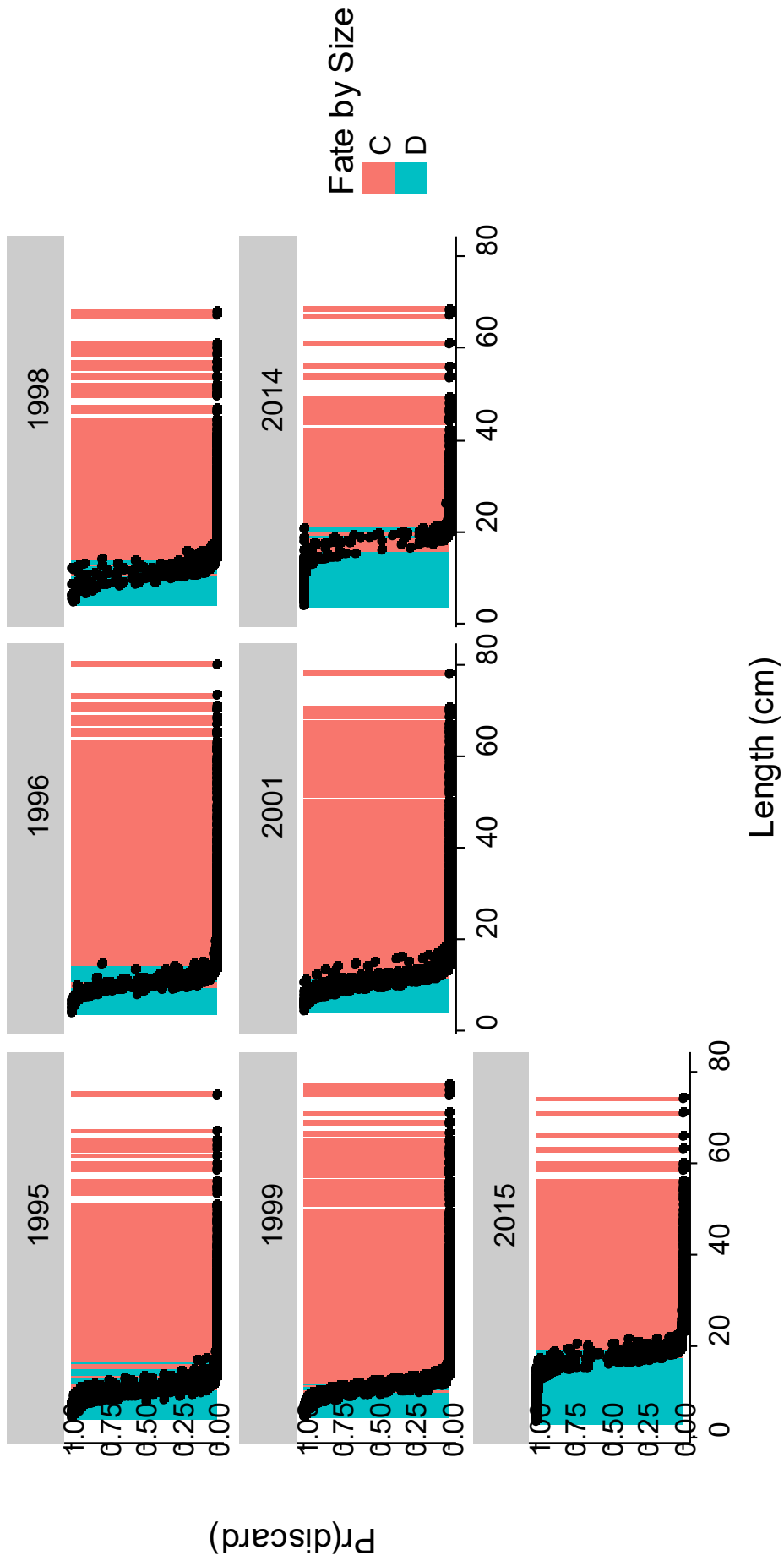


Fig. S4b: GAM derived discard probability by total length with super-imposed discard ogive for hake (by year).

Parapenaeus longirostris (MCRS=20mm)

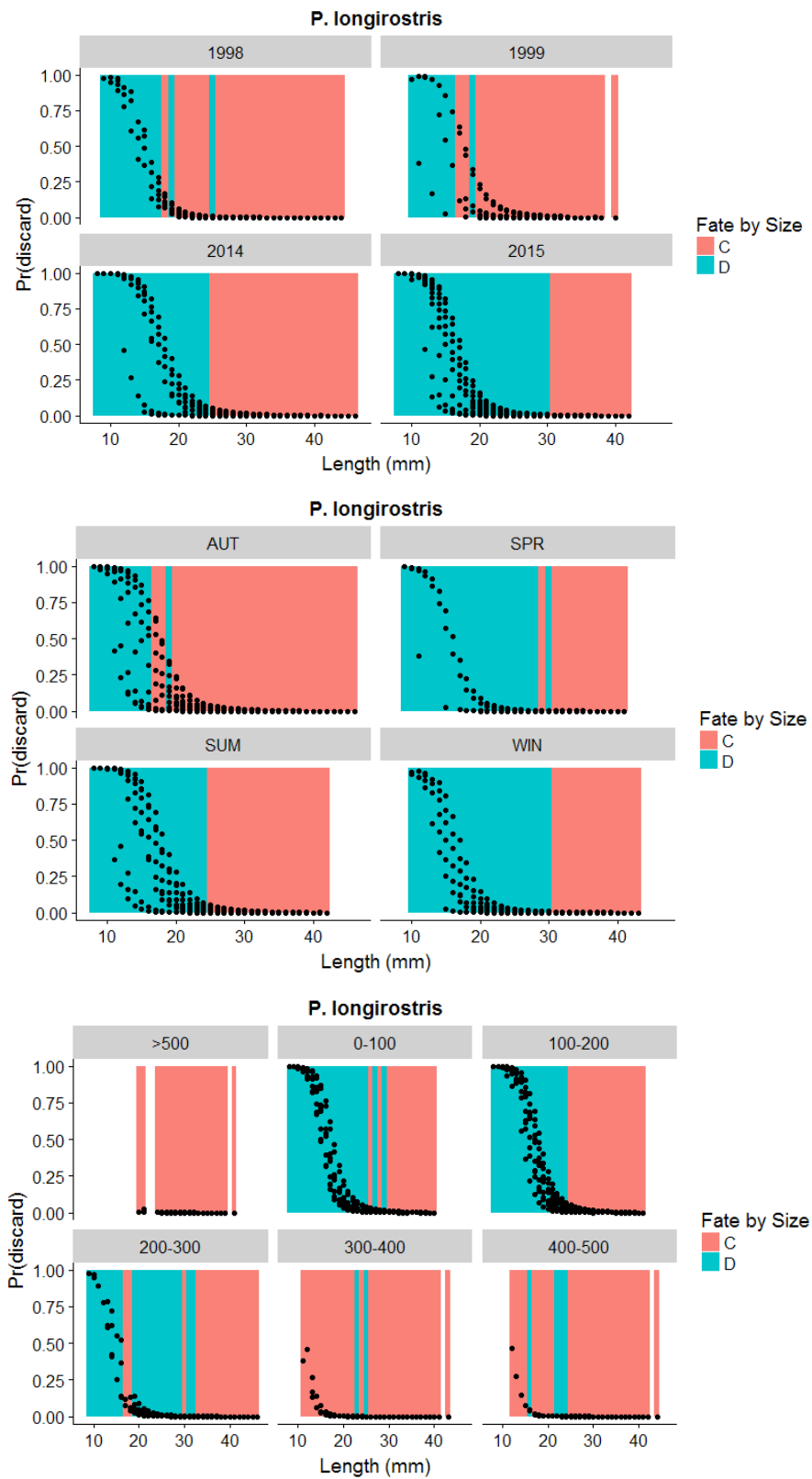


Fig. S4c: GAM derived discard probability by total length with super-imposed discard ogive for deep-water rose shrimp (top-by year, mid-by season and bottom-by depth stratum).

Trachurus trachurus (MCRS=15cm)

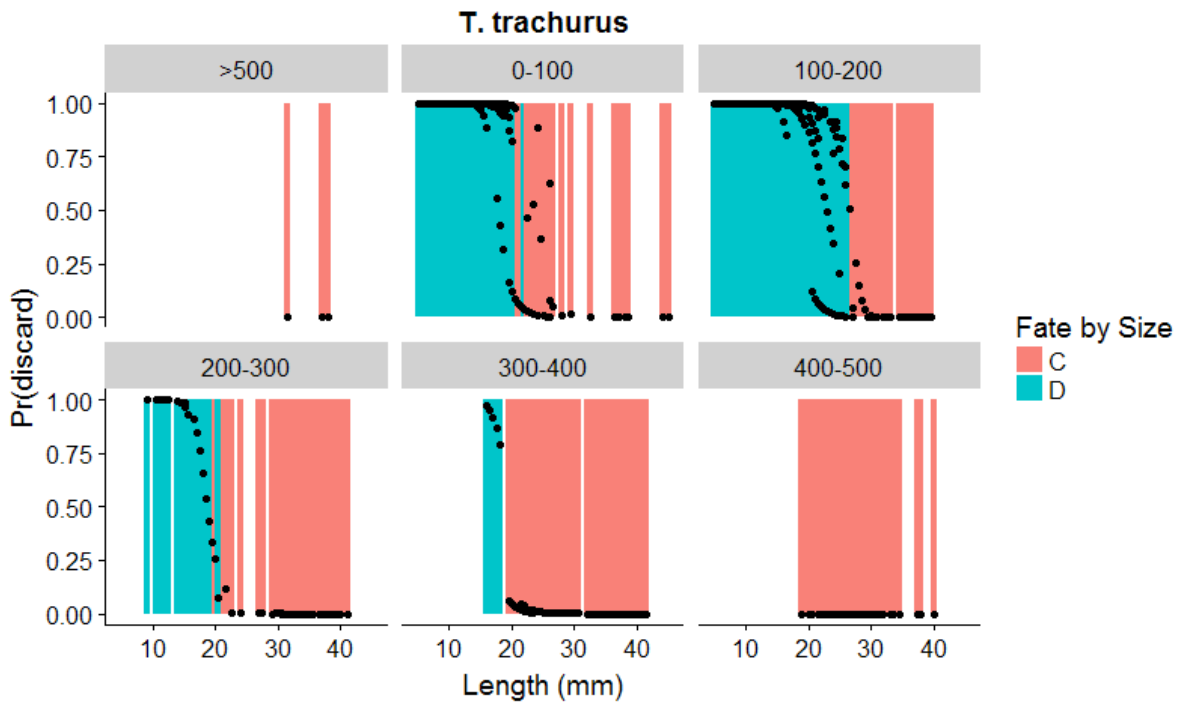
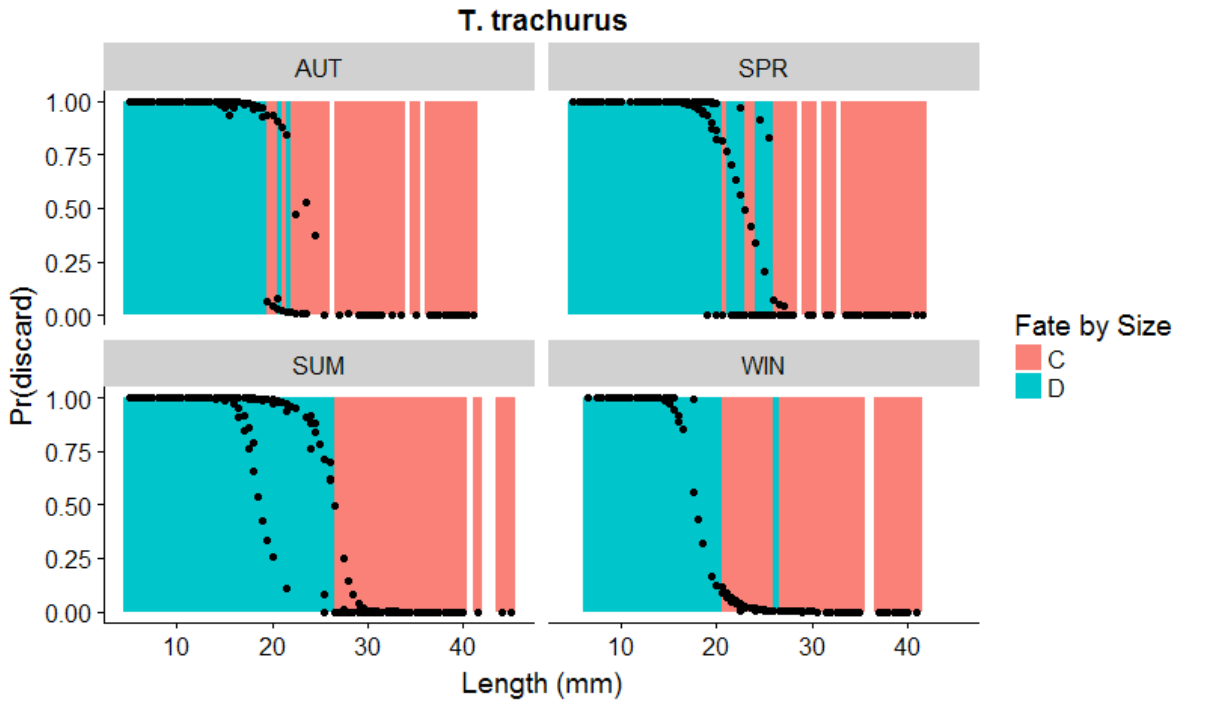


Fig. S4d: GAM derived discard probability by total length with super-imposed discard ogive for horse mackerel (top-by season, bottom-by depth stratum).

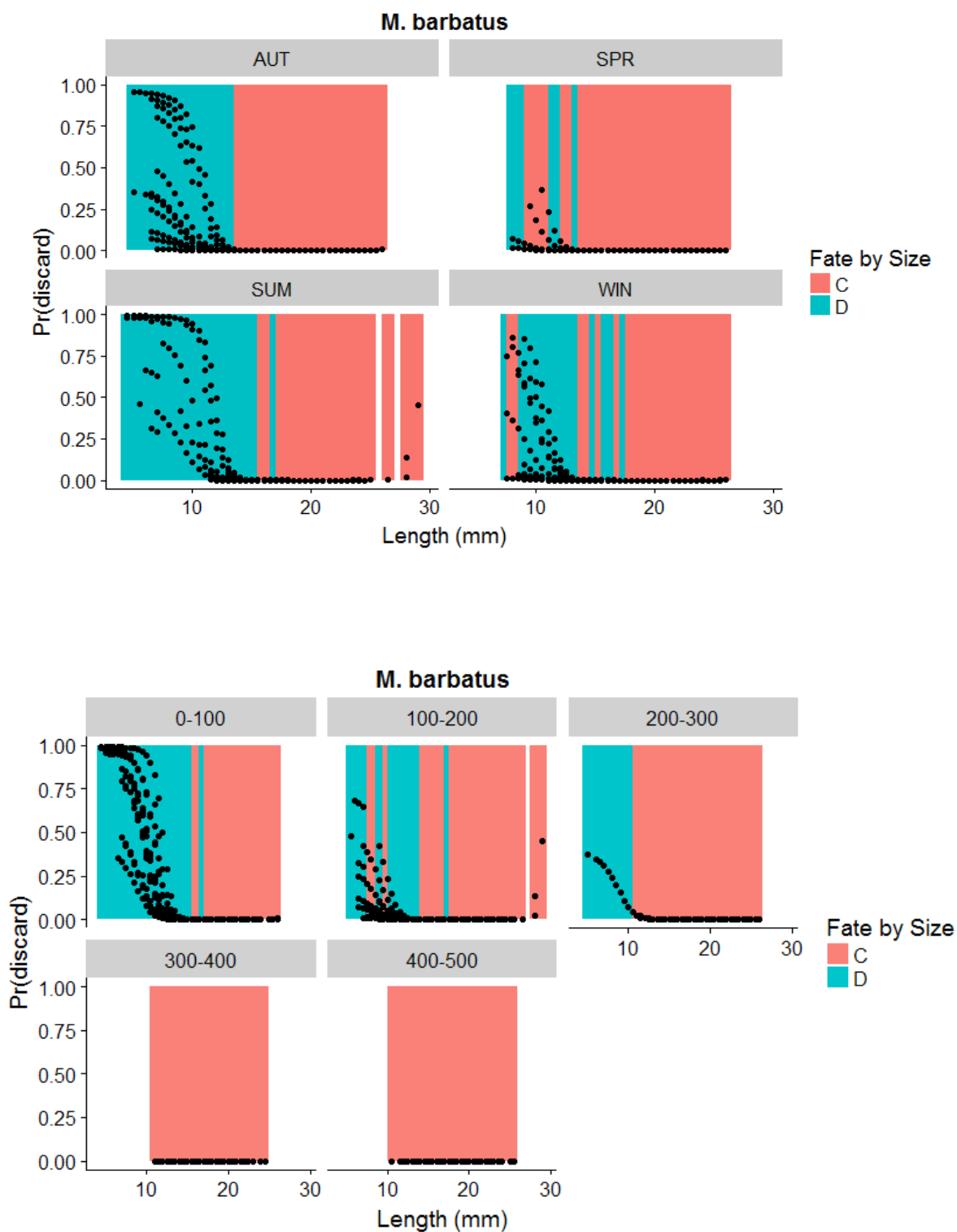


Fig. S4e: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top-by season, bottom-by depth stratum).

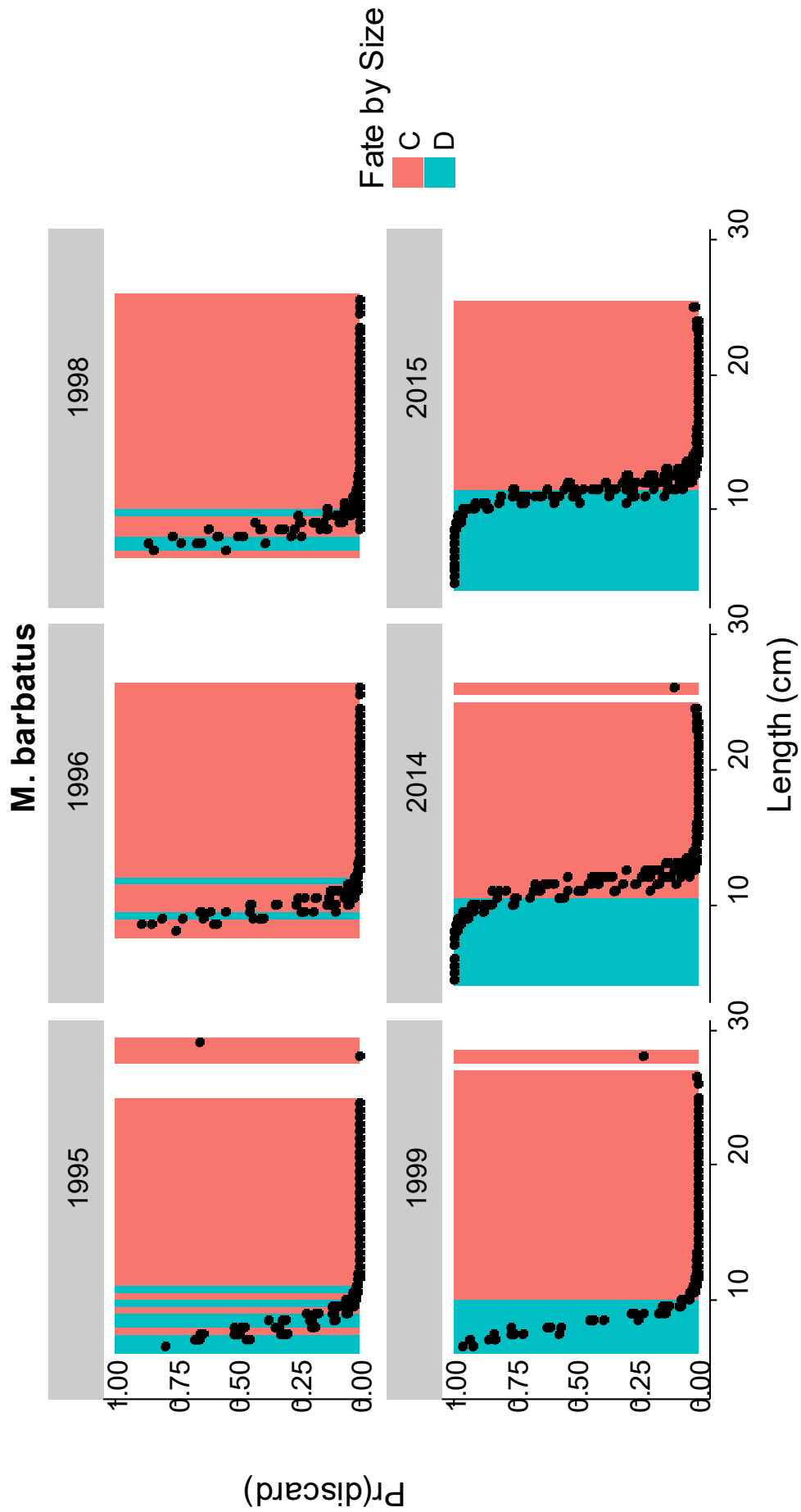


Fig. S4f: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (by year).

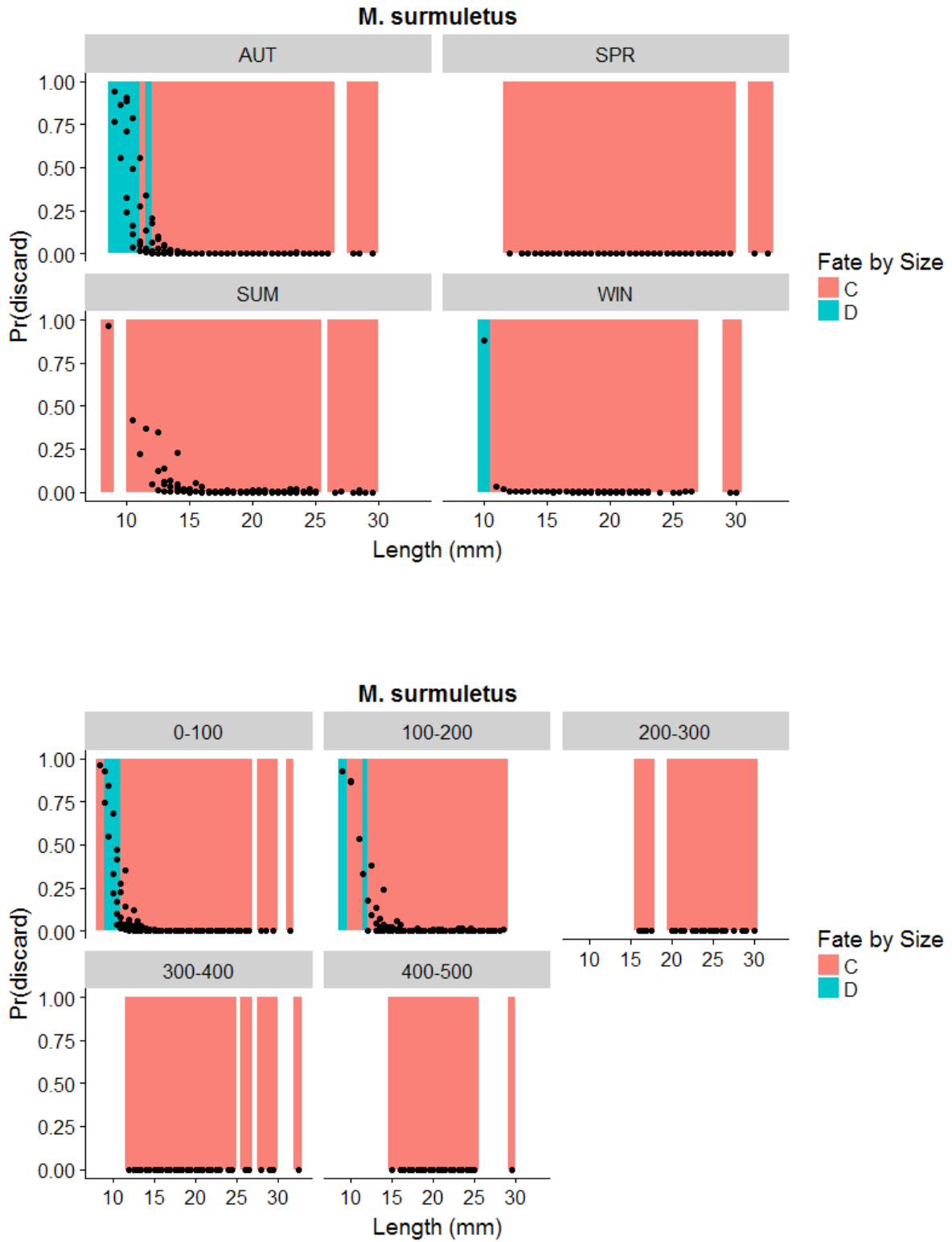


Fig. S4g: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top-by season, bottom-by depth stratum).

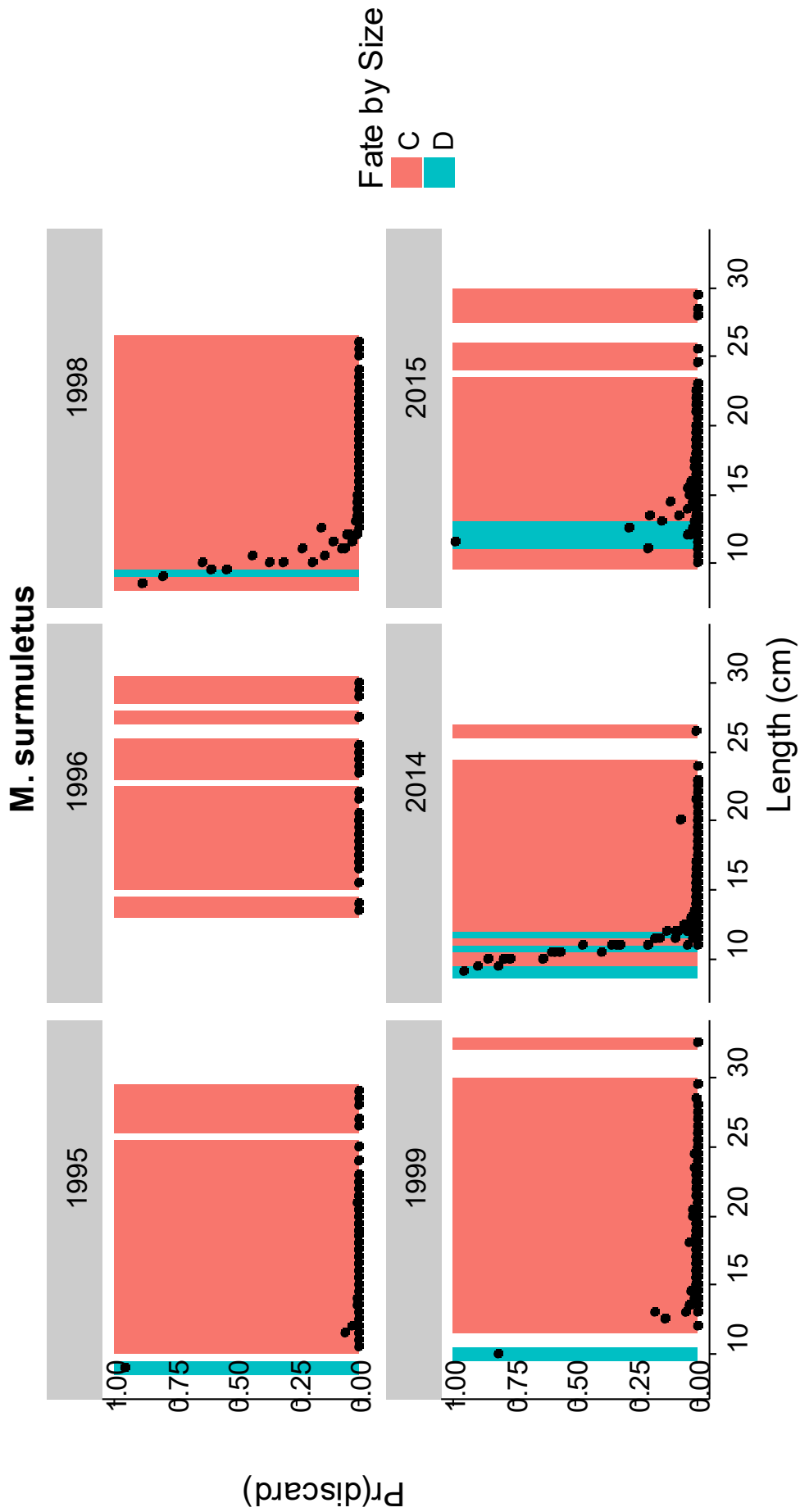


Fig. S4h: GAM derived discard probability by total length with super-imposed discard ogive for striped red mullet (by year).

Boops boops

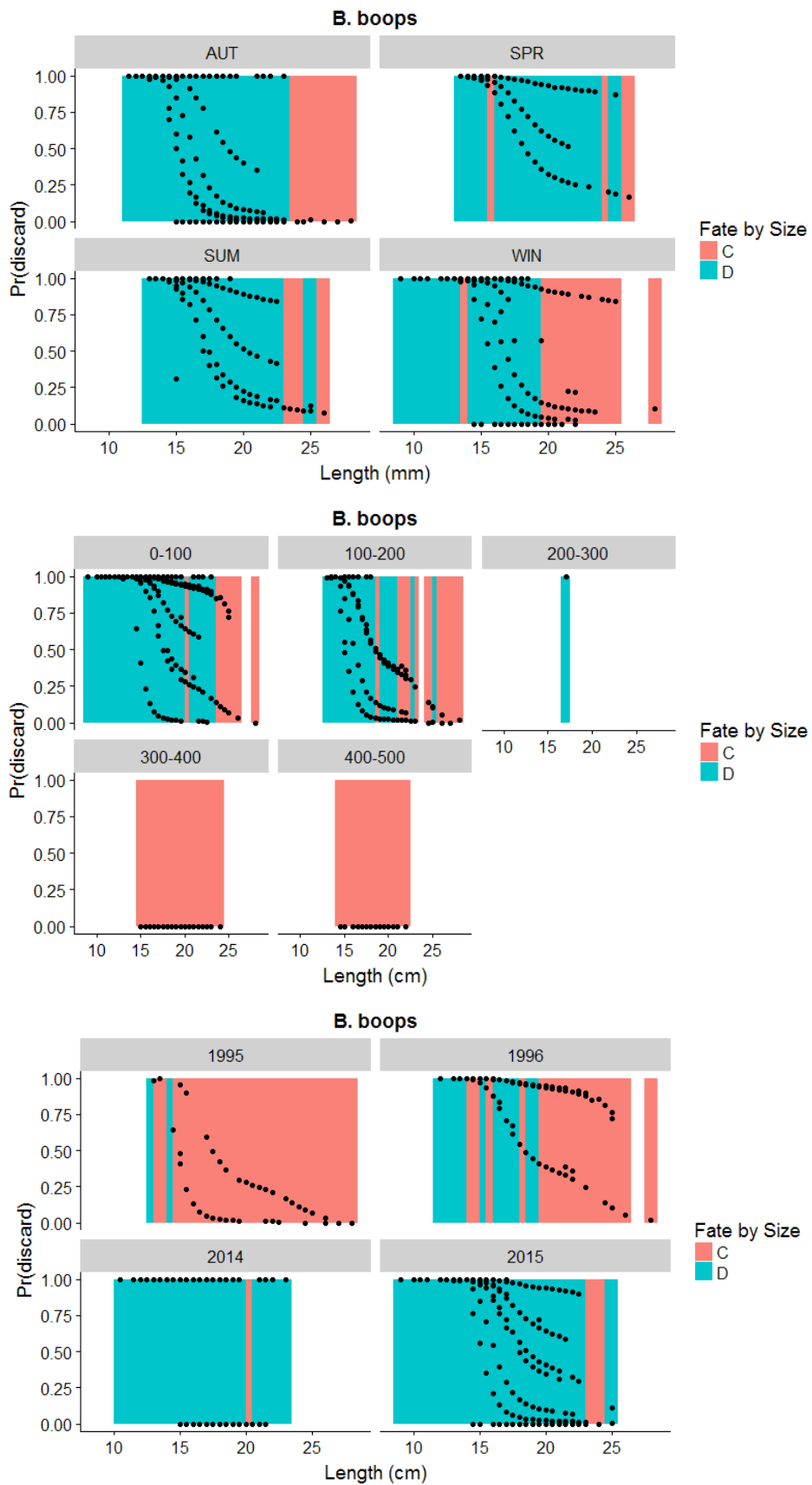


Fig. S4i: GAM derived discard probability by total length with super-imposed discard ogive for bogue (top-by season, mid-by depth stratum, bottom-by Year)