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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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Supplementary Material

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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
Ligurian and north Tyrrhenian seas	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%	
	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%	
	Average	*21.1%*	*5.1%*	

(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%
	Average	*17.3%*	*4.6%*	***32.2%***

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	*Acanthocardia aculeate*
Aporrhais pespelecani	*Acanthocardia echinata*
Aporrhais spp.	*Acanthocardia paucicostata*
Ascidia	*Acanthocardia spinosa*
Asteroidea	*Aequipecten opercularis*
Aurelia aurita	*Alcyonium palmatum*
Brachyura	*Anadara corbuloides*
Cidaris cidaris	*Antedon mediterranea*
Cnidaria	*Anthozoa indet.*
Corals	*Aphrodita aculeate*
Echinaster sepositus	*Aporrhais pespelecani*
Echinoidea	*Aporrhais serresianus*
Echinus spp.	*Armina tigrina*
Goneplax rhomboides	*Astropecten aranciacus*

(continued)

Table S2 Continued

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

(continued)

Table S2 Continued

Aegean Sea and Crete	Ligurian and north Tyrrhenian Sea
	Pecten jacobaeus
	Pennatula phosphorea
	Pennatula rubra
	Pennatula spp.
	Porifera indet.
	Posidonia oceanica
	Psammechinus microtuberculatus
	Pteria hirundo
	Pteroides griseum
	Pyrosoma atlanticum
	Rhizostoma pulmo
	Scaphander lignarius
	Schizaster canaliferus
	Spatangus purpureus
	Sphaerechinus granularis
	Sternaspis scutata
	Stylocidaris affinis
	Suberites domuncula
	Tethyaster subinermis
	Thenea muricata
	Trachythyone elongata
	Trachythyone tergestina
	Turritella communis
	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
	Cepaholopods	23	2107	16	13078
	Invertebrates (other than crustaceans & cephalopods)	15	6272	1	1
N. Tyrrhenian & Ligurian Sea	Fish	151	7771	136	17490
	Crustaceans	36	515	45	3825
	Cepaholopods	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	4.26–e-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**

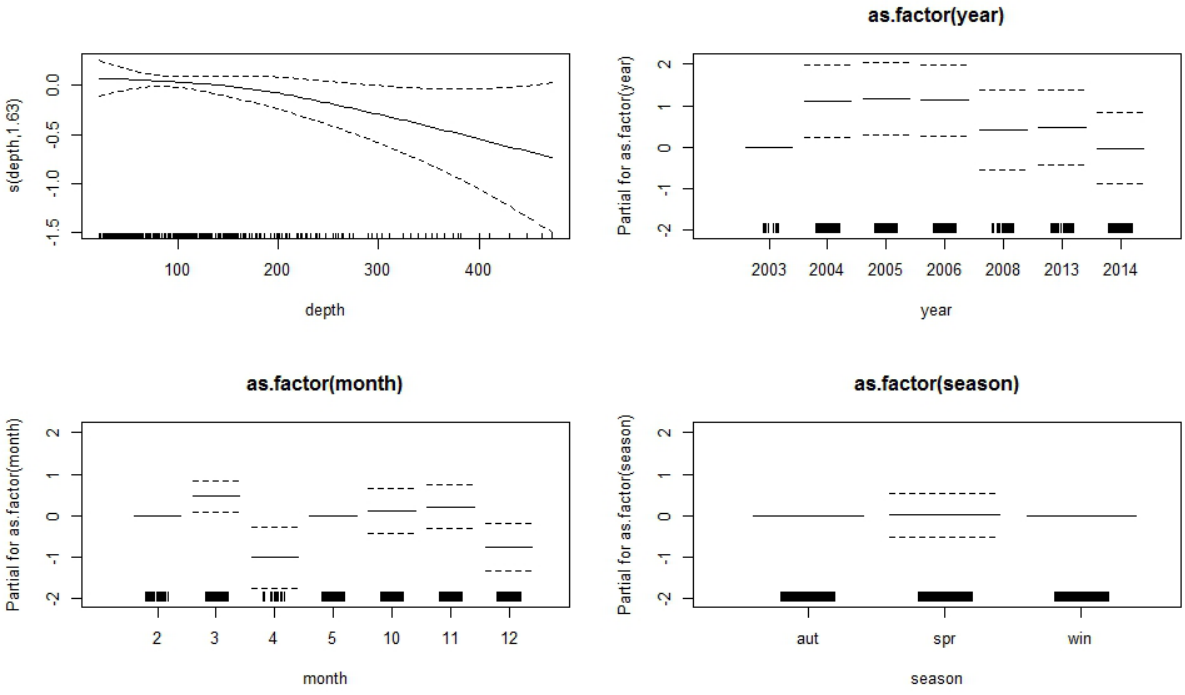


***Fig. S1a*:** Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **invertebrate** catch in the bottom trawl fishery of the Aegean Sea and Crete. Dashed lines indicate two standard errors above and below the estimates. Relative density of data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

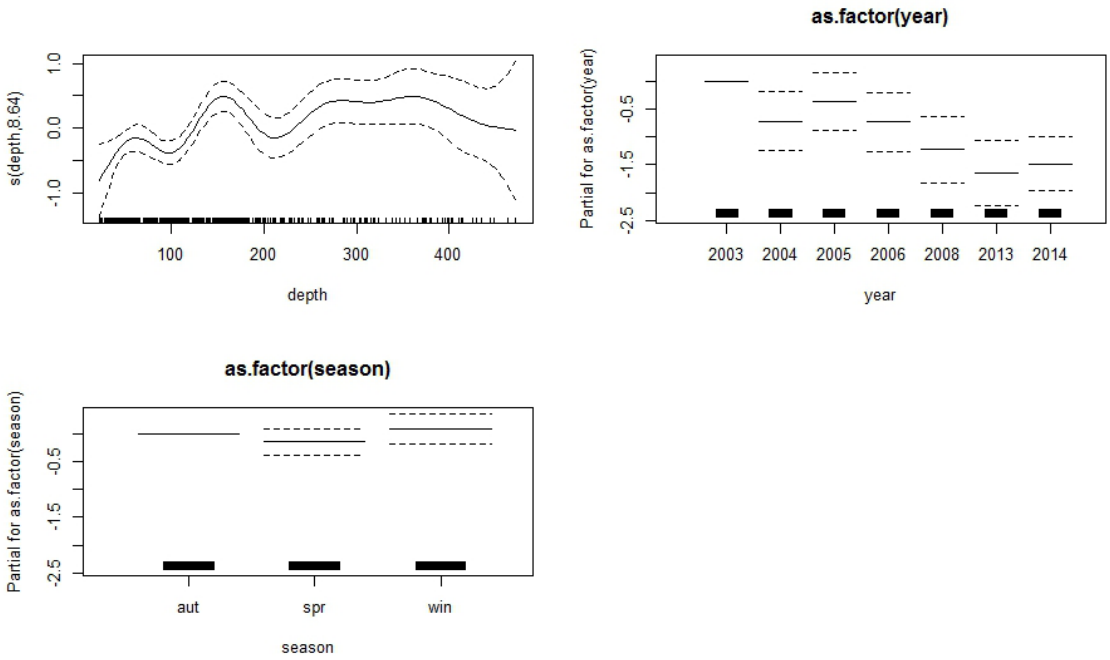


***Fig. S1b*:** Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **elasmobranch** catch in the bottom trawl fishery of the Aegean Sea and Crete. Dashed lines indicate two standard errors above and below the estimates. Relative density of data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

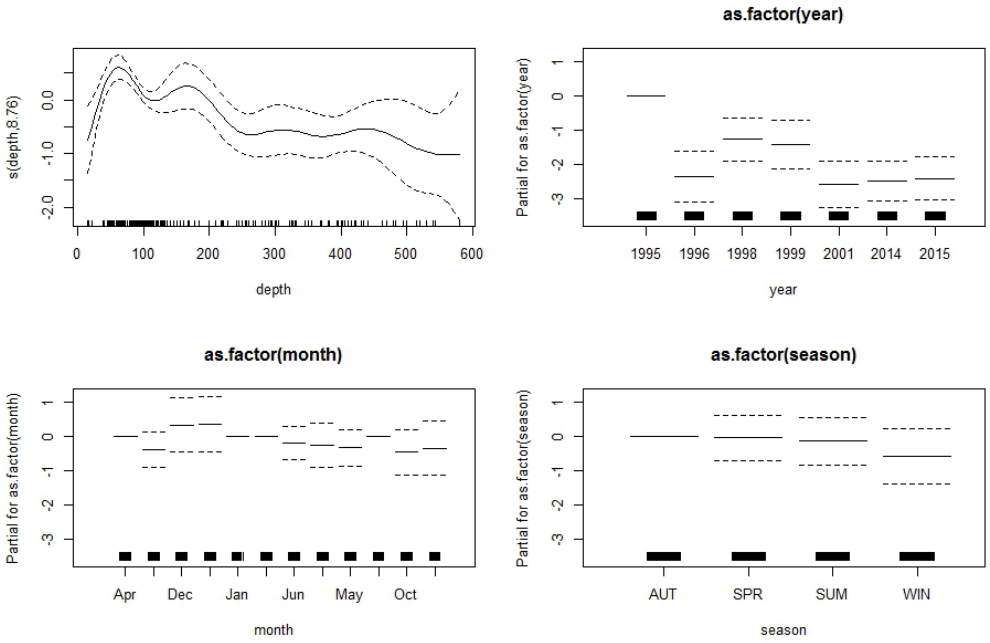


***Fig. S2a*:** Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **invertebrate** catch in the bottom trawl of the Ligurian and north Tyrrhenian Sea. Dashed lines indicate two standard errors above and below the estimates. Relative density of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

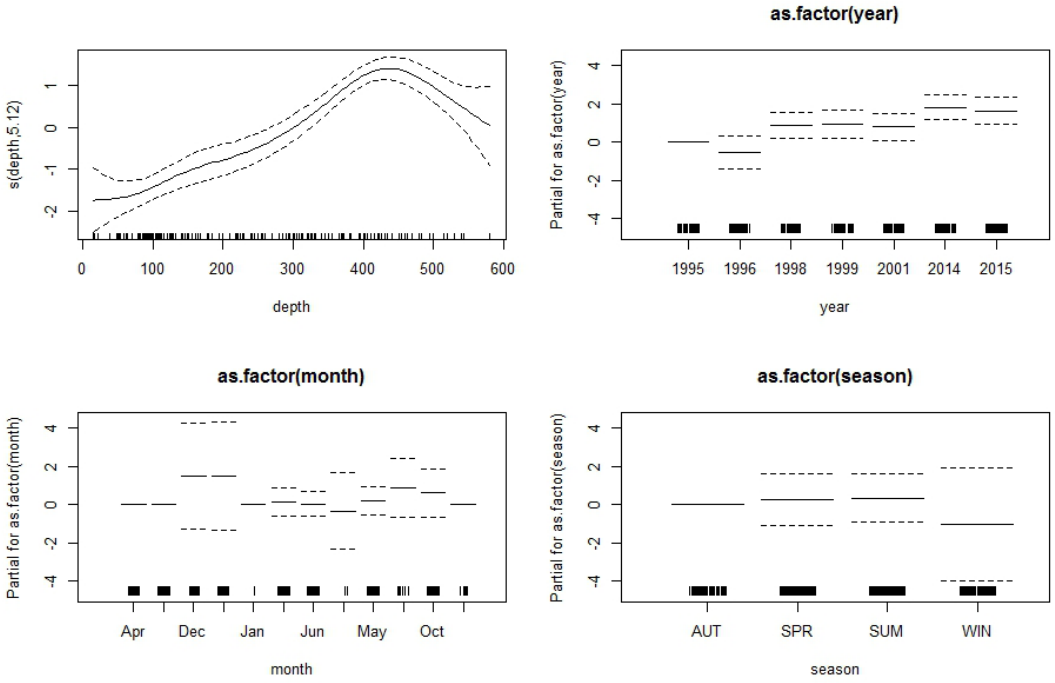
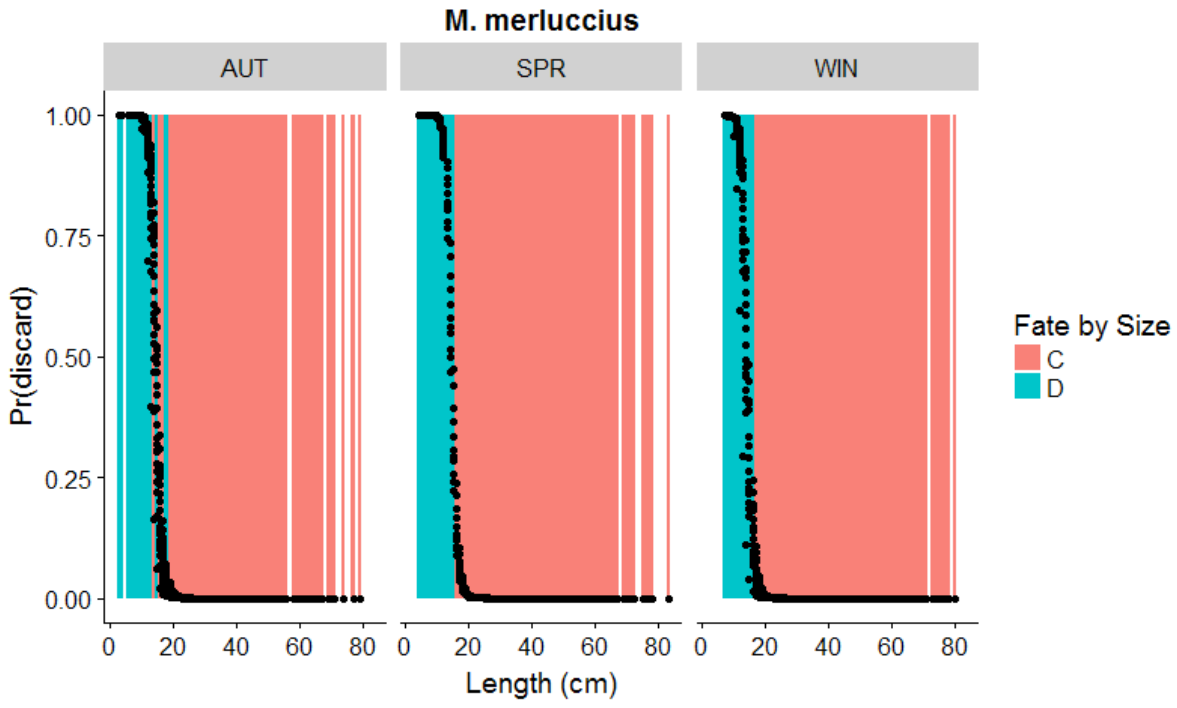


Fig. S2b: Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **elasmobranch** catch in the bottom trawl fishery of the Ligurian and north Tyrrhenian Sea. Dashed lines indicate two standard errors above and below the estimates. Relative density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

AEGEAN SEA and CRETE

Merluccius merluccius (MCRS = 20 cm)



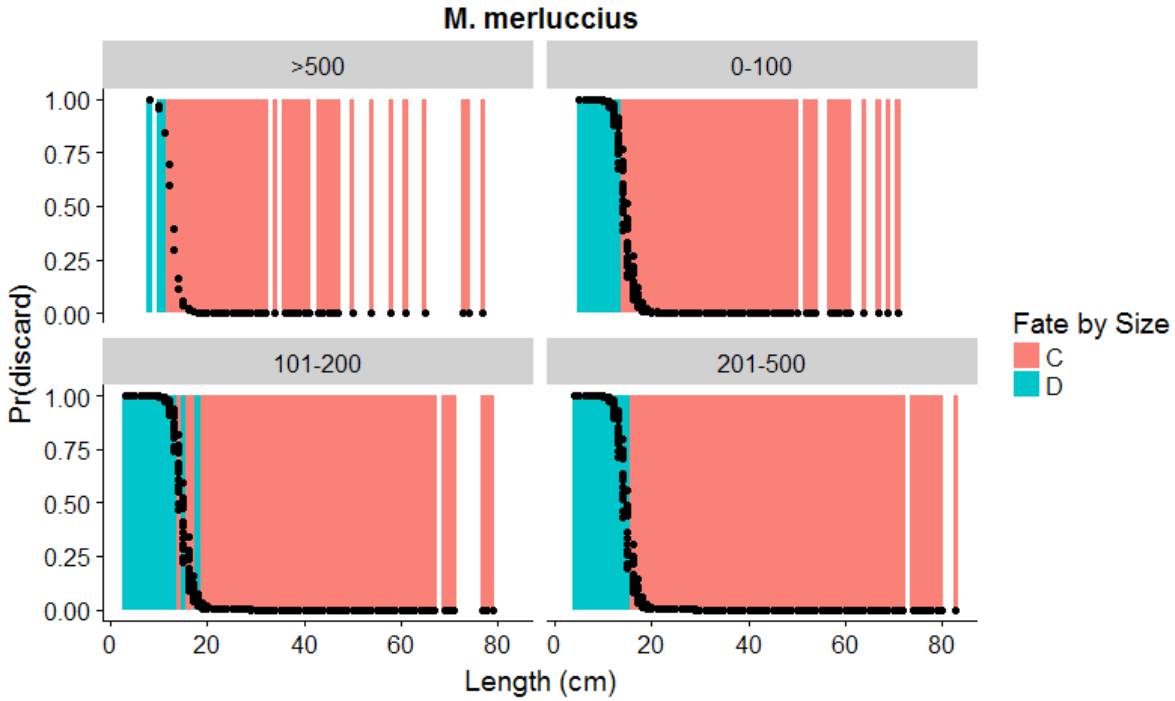


***Fig. S3a*:** GAM derived discard probability by total length with super-imposed discard ogive for hake (top-by season, bottom-by depth stratum).

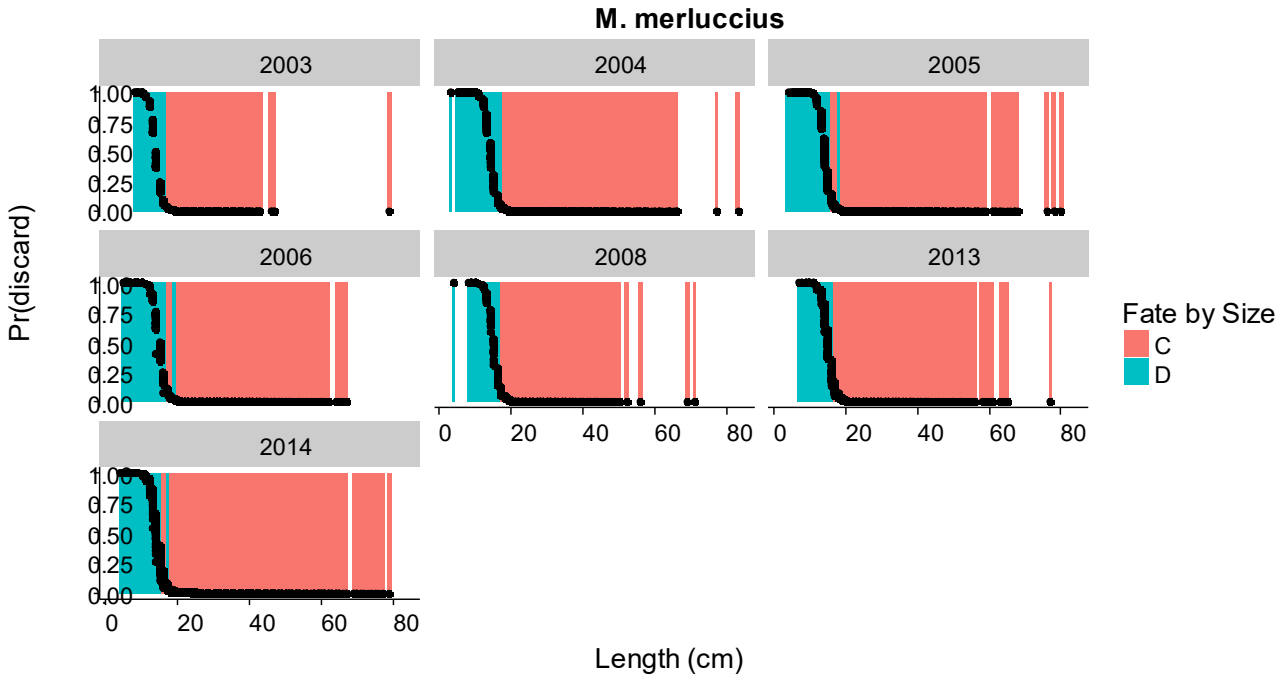


Fig. S3b: GAM derived discard probability by total length with super-imposed discard ogive for hake (by year).

Mullus barbatus (MCRS= 11c

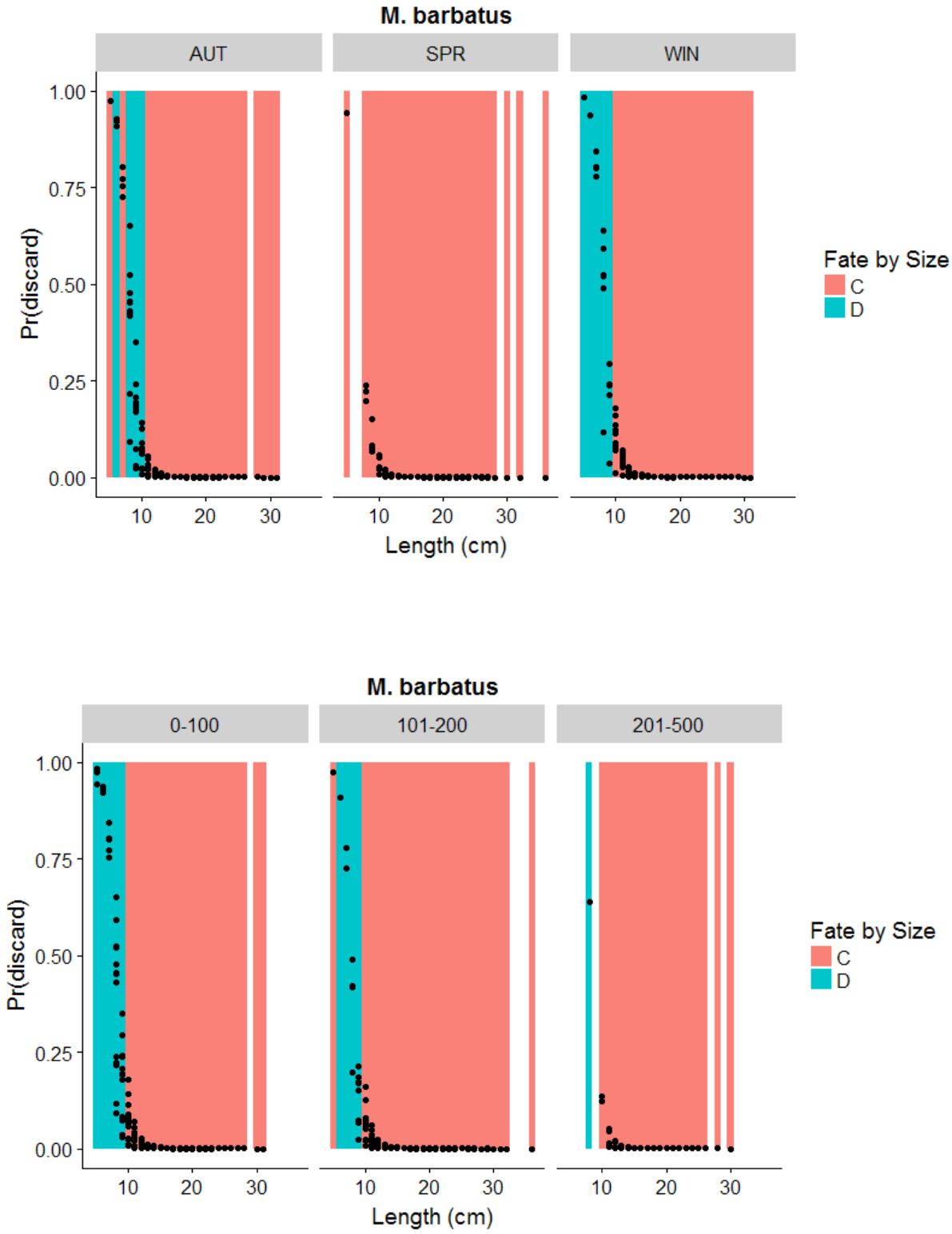


Fig. S3c: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top- by season, bottom-by depth stratum).

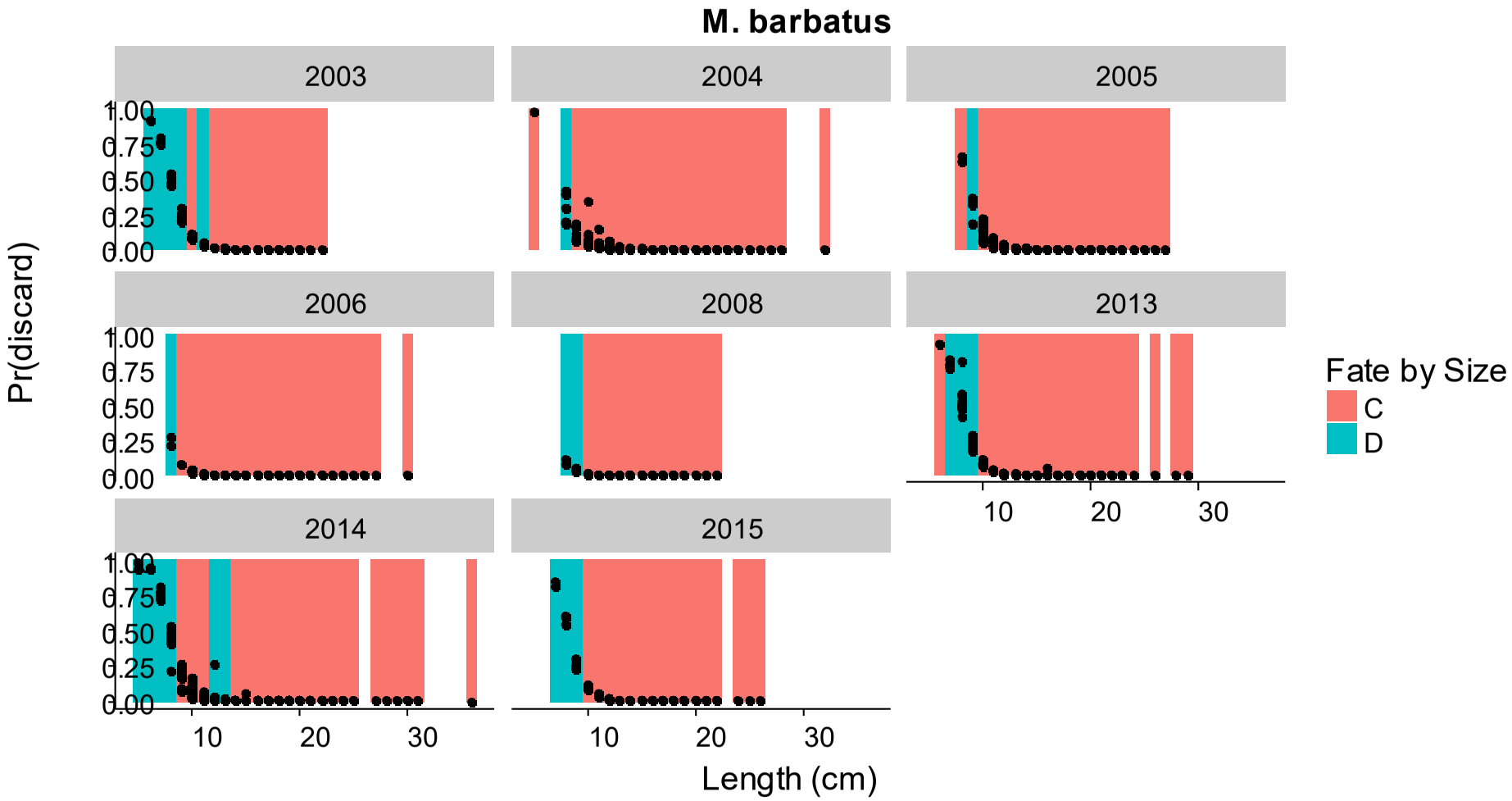


Fig. S3d: GAM derived discard probability by total length with super-imposed discard ogive for red mulet (by year).

Trachurus trachurus (MCRS=15 cm)

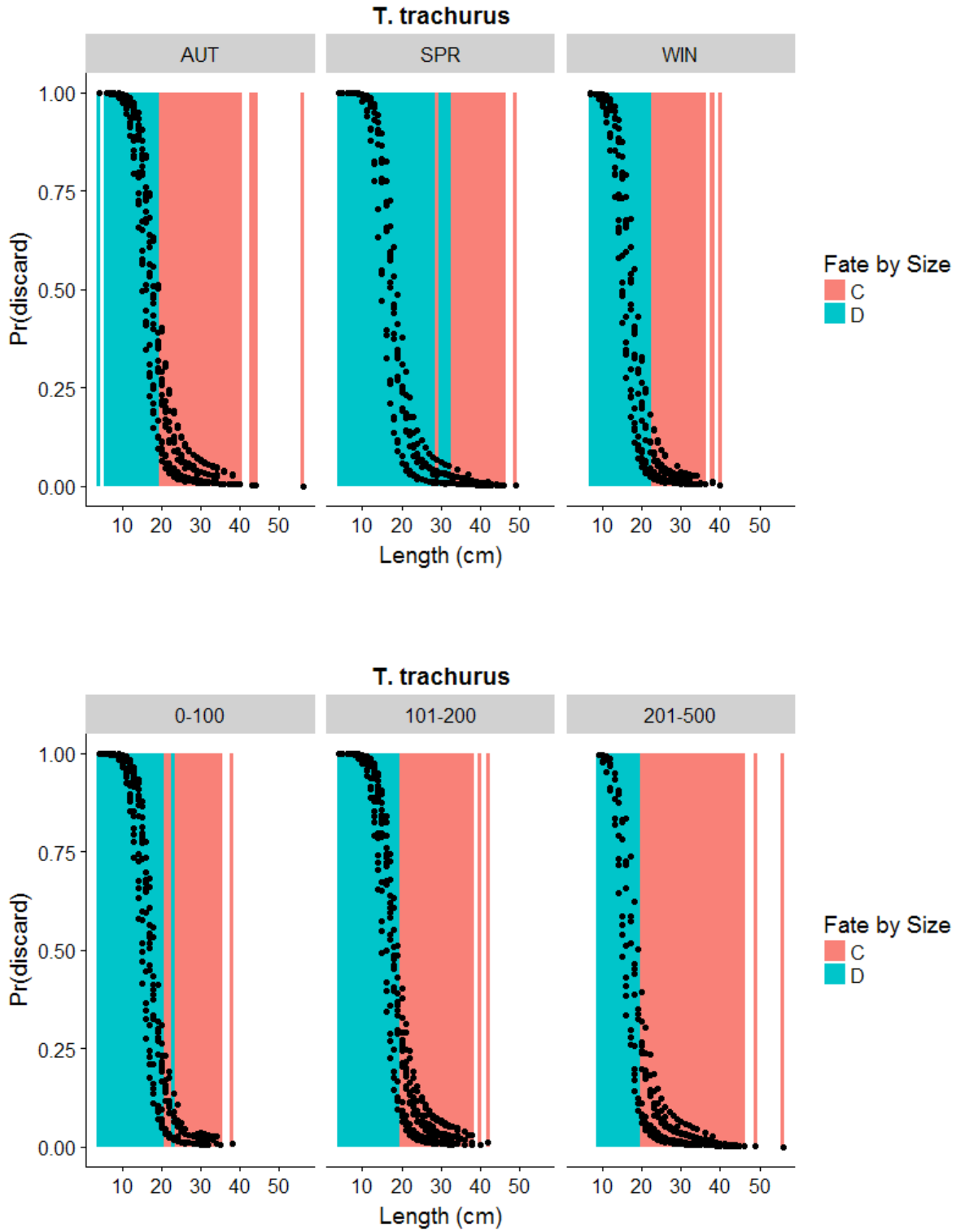


***Fig. S3e*:** GAM derived discard probability by total length with super-imposed discard ogive for horse mackerel (top-global, mid-by season, bottom-by depth stratum).

Parapenaeus longirostris (MCRS = 20mm)

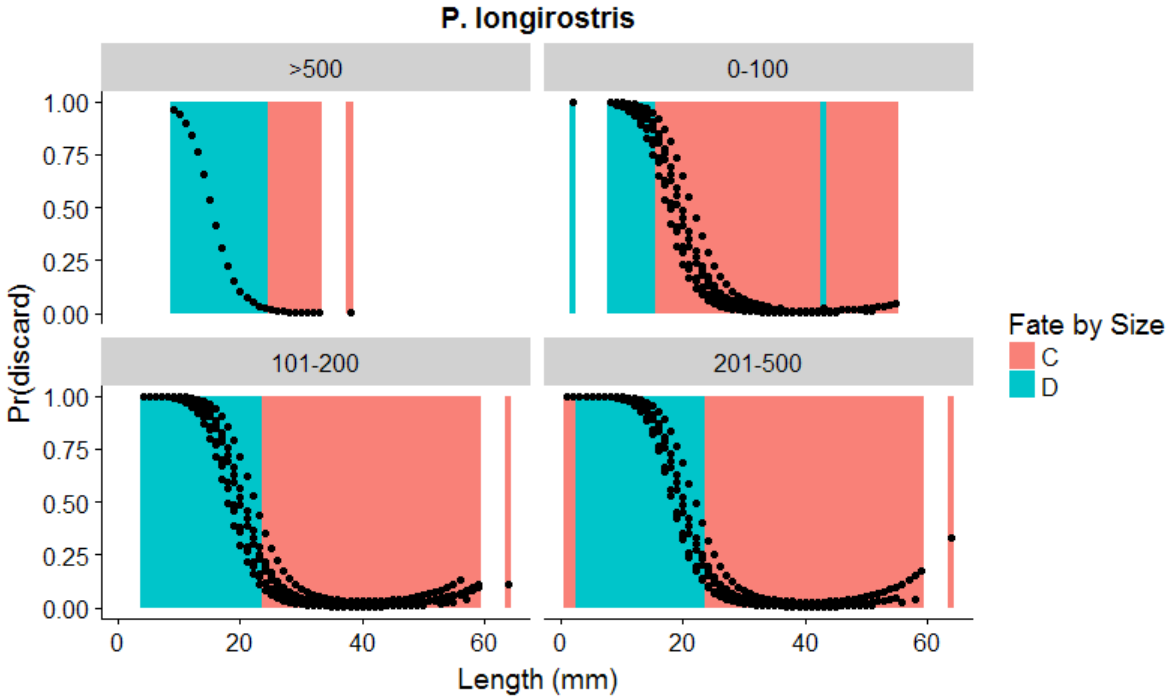


***Fig. S3f*:** GAM derived discard probability by total length with super-imposed discard ogive for deep-water rose shrimp (by depth stratum).

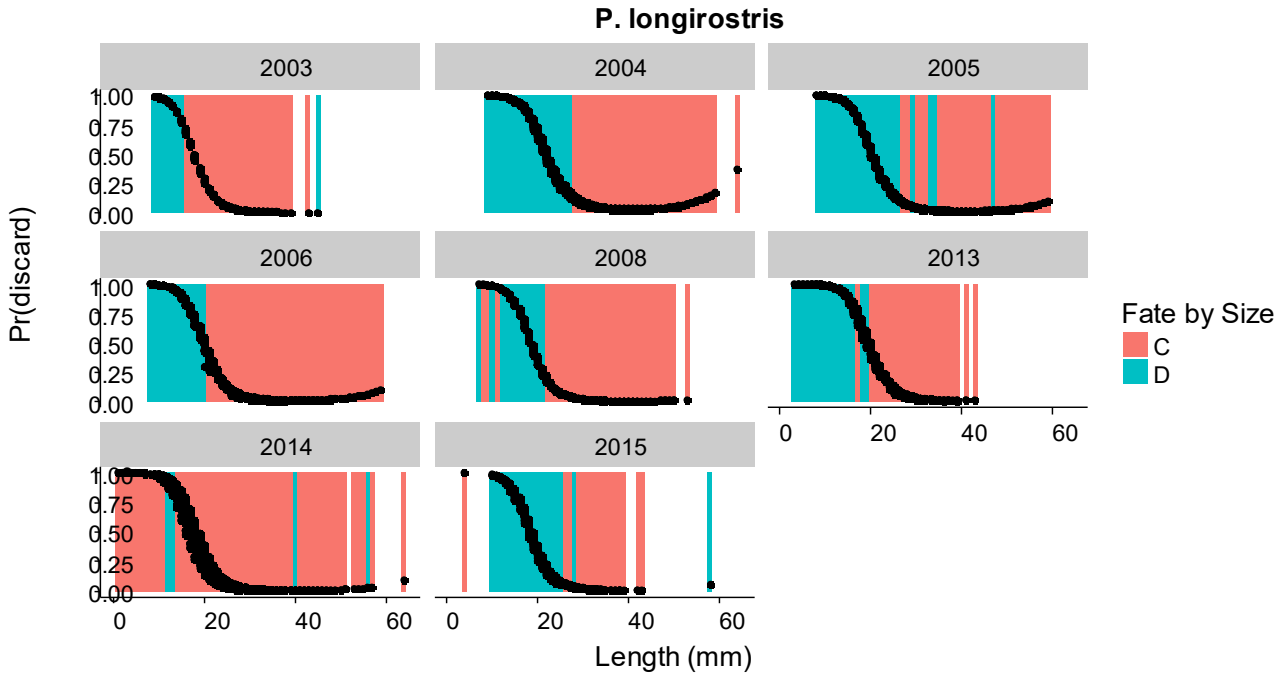


***Fig.S3g*:** GAM derived discard probability by total length with super-imposed discard ogive for deep water rose shrimp (by year).

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

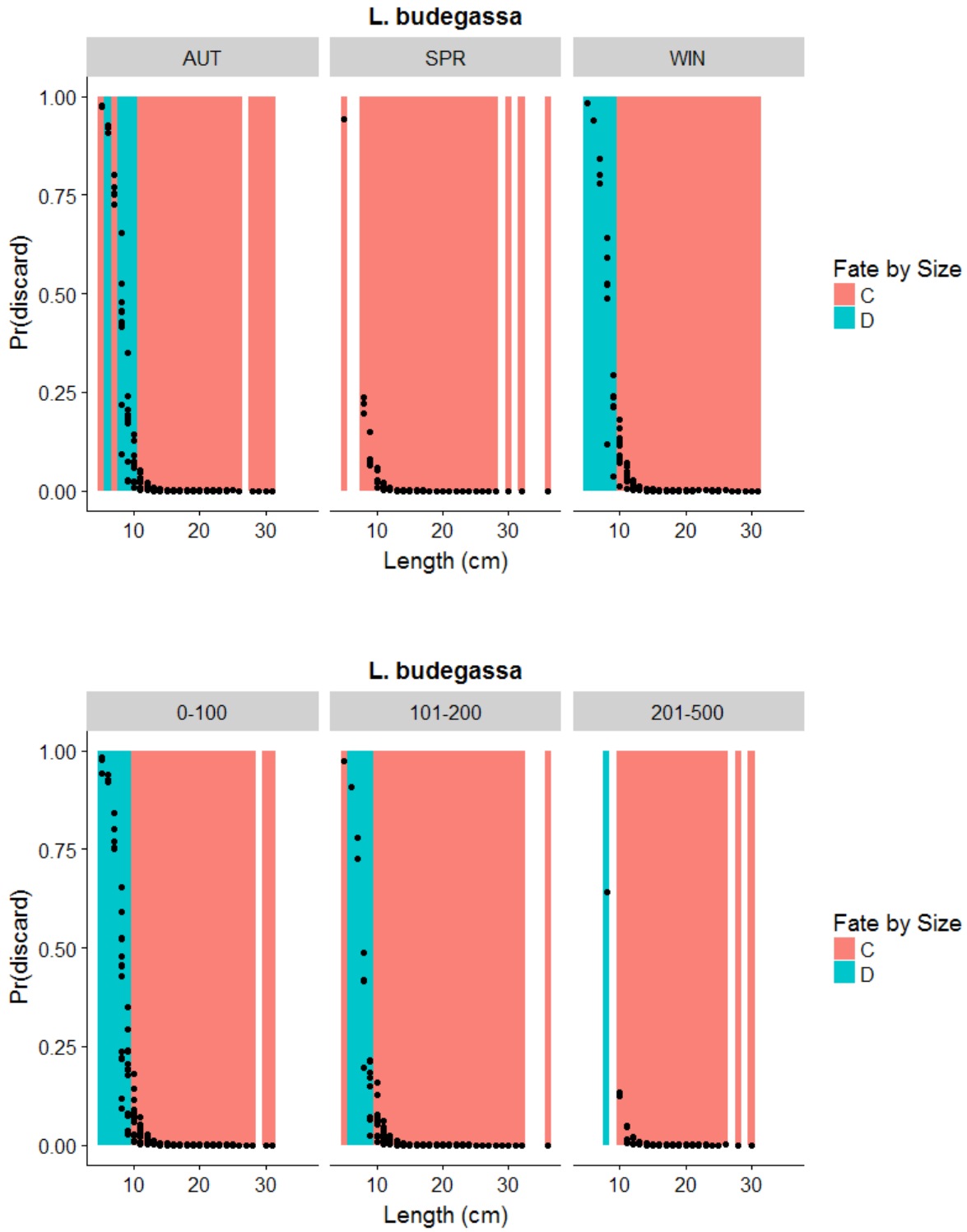


Fig. S3h: GAM derived discard probability by total length with super-imposed discard ogive for anglerfish (top- by season, bottom-by depth stratum).

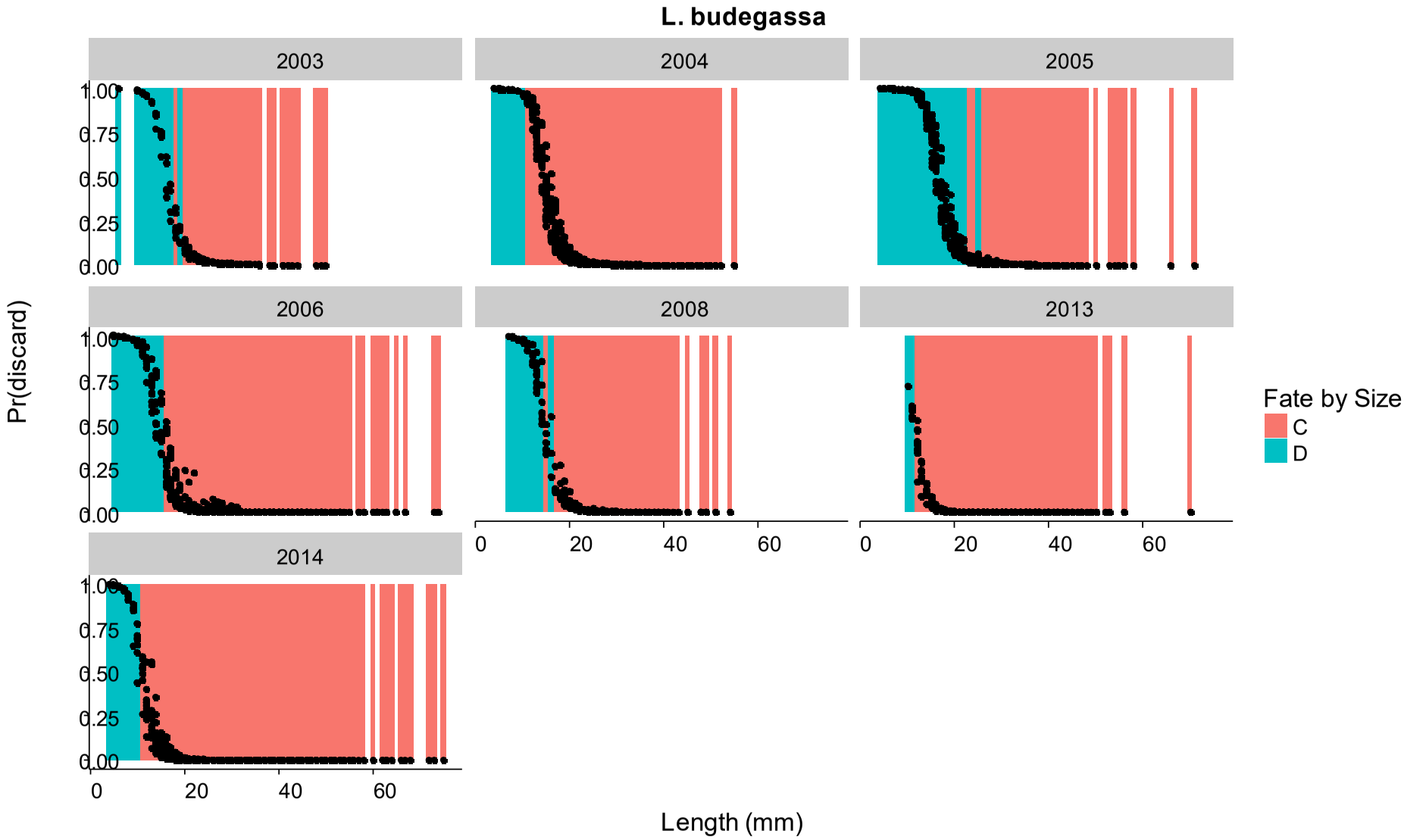


Fig. S3i: GAM derived discard probability by total length with super-imposed discard ogive for anglerfish (by year).

Boops boops (MCRS= 10 cm)

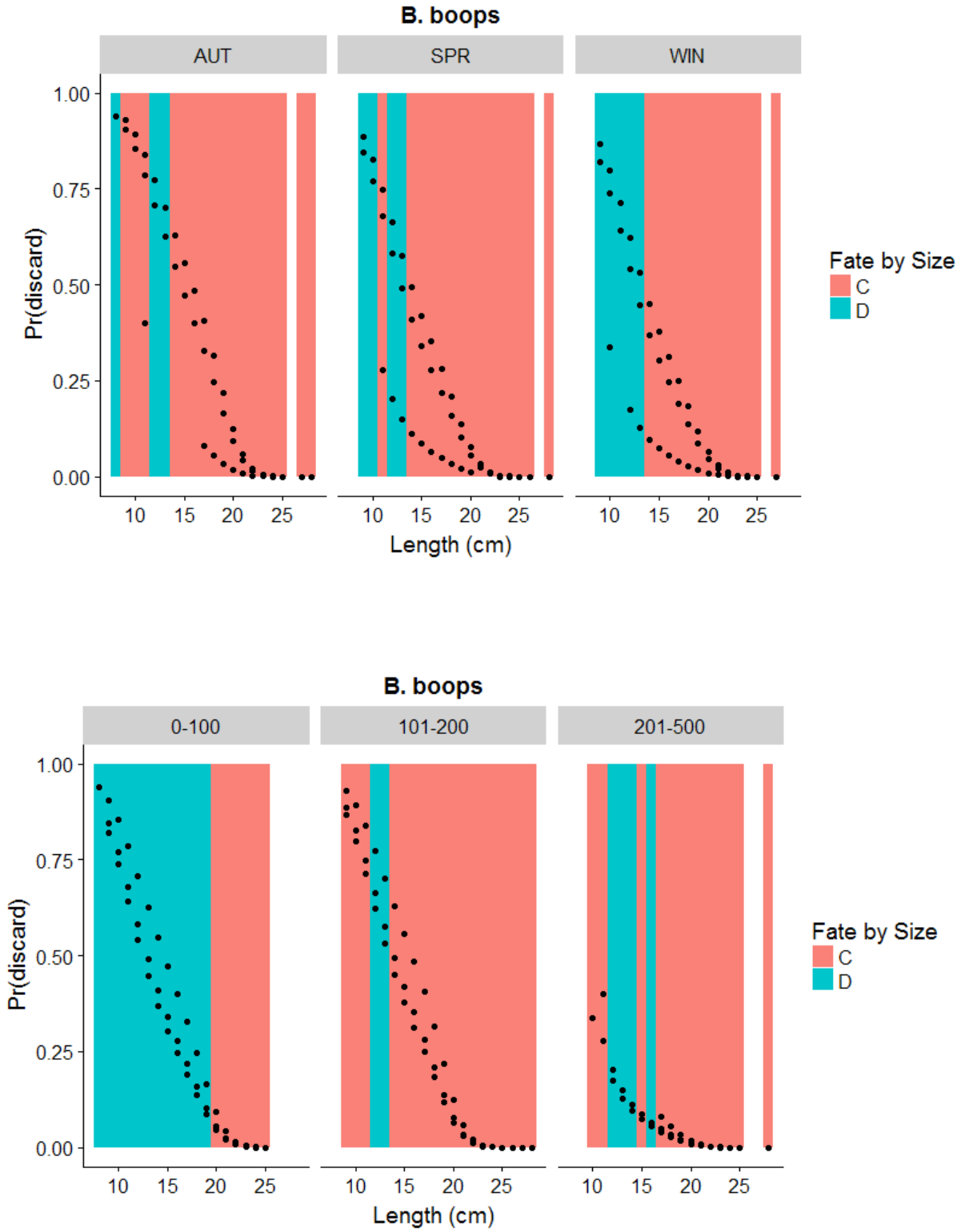


Fig. S3j: GAM derived discard probability by total length with super-imposed discard ogive for bogue (top-global, mid-by season, bottom-by depth stratum).

Merluccius merluccius (MCRS=20cm)

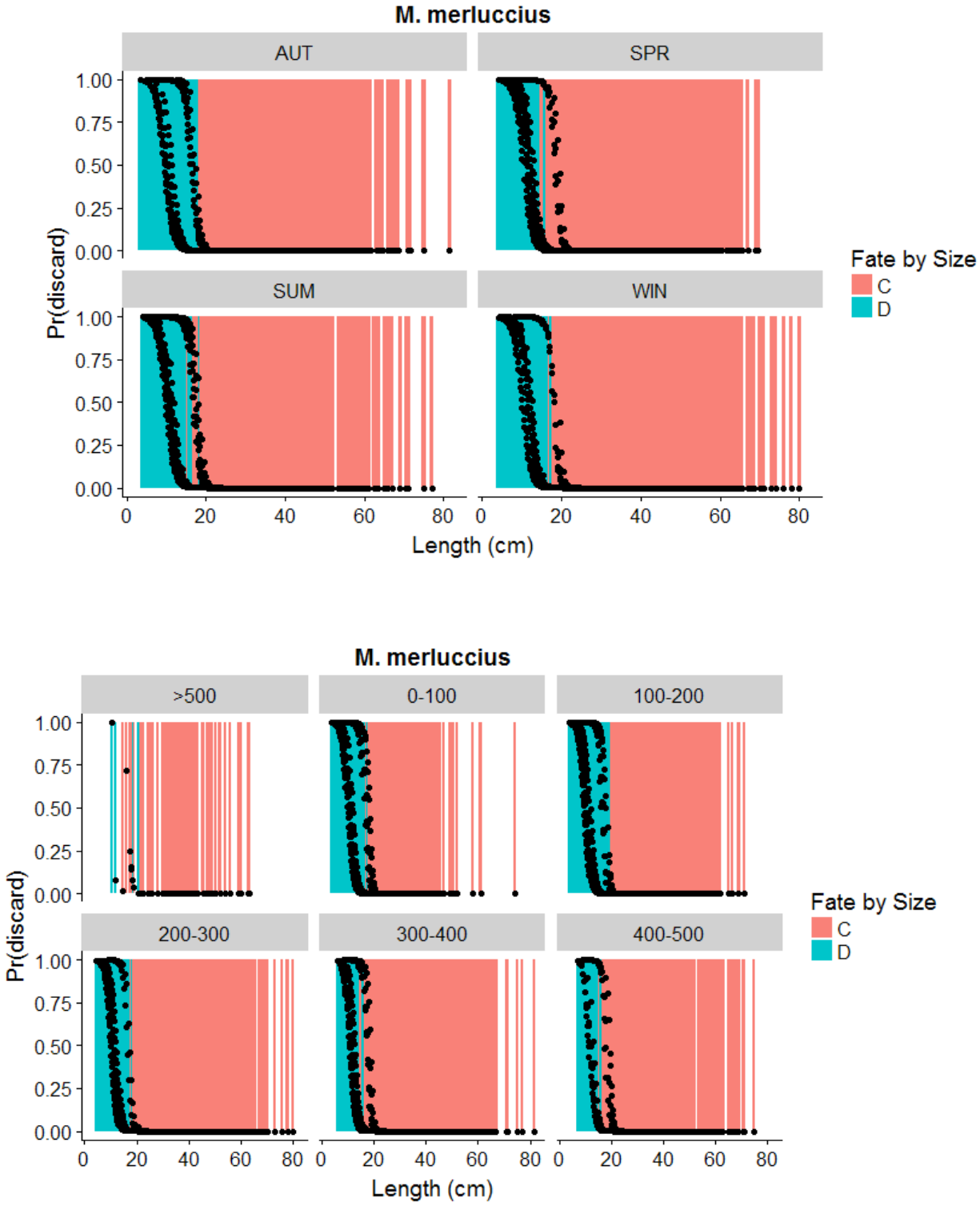


Fig. S4a: GAM derived discard probability by total length with super-imposed discard ogive for hake (top - by season, bottom - by depth stratum).

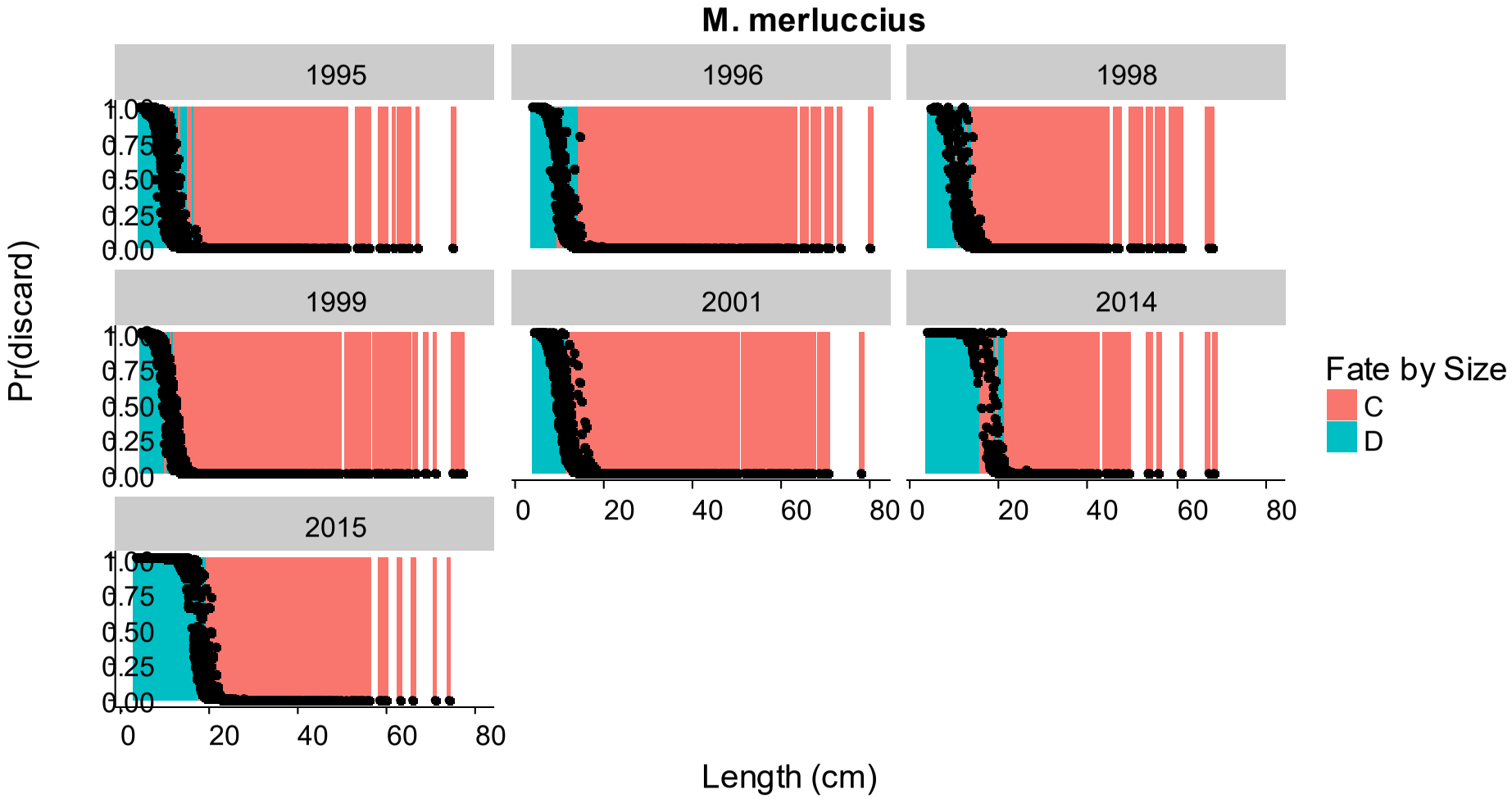


Fig. S4b: GAM derived discard probability by total length with super-imposed discard ogive for hake (by year).

Parapenaeus longirostris (MCRS=20mm)

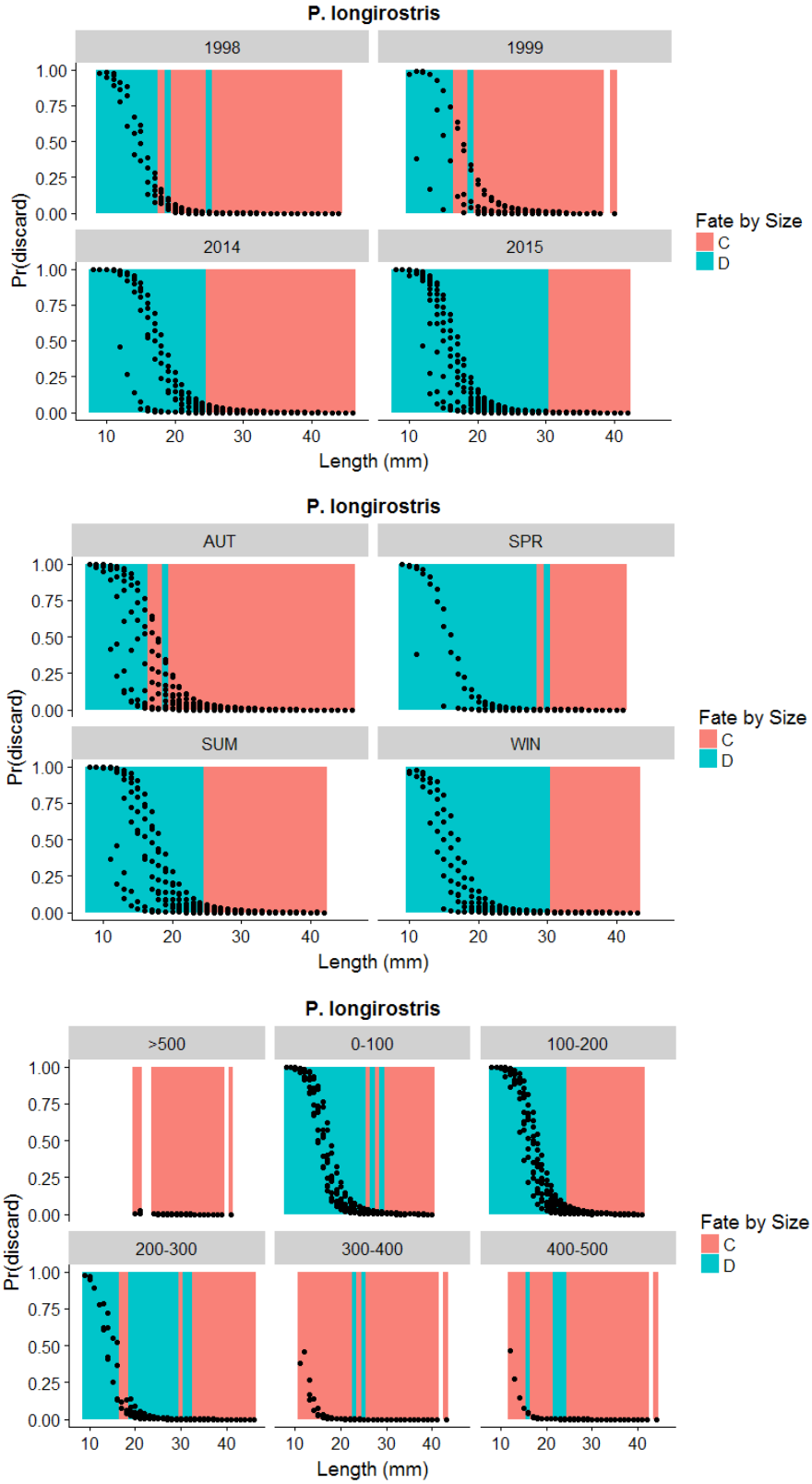


Fig. S4c: GAM derived discard probability by total length with super-imposed discard ogive for deep-water rose shrimp (top-by year, mid-by season and bottom-by depth stratum).

Trachurus trachurus (MCRS=15cm)

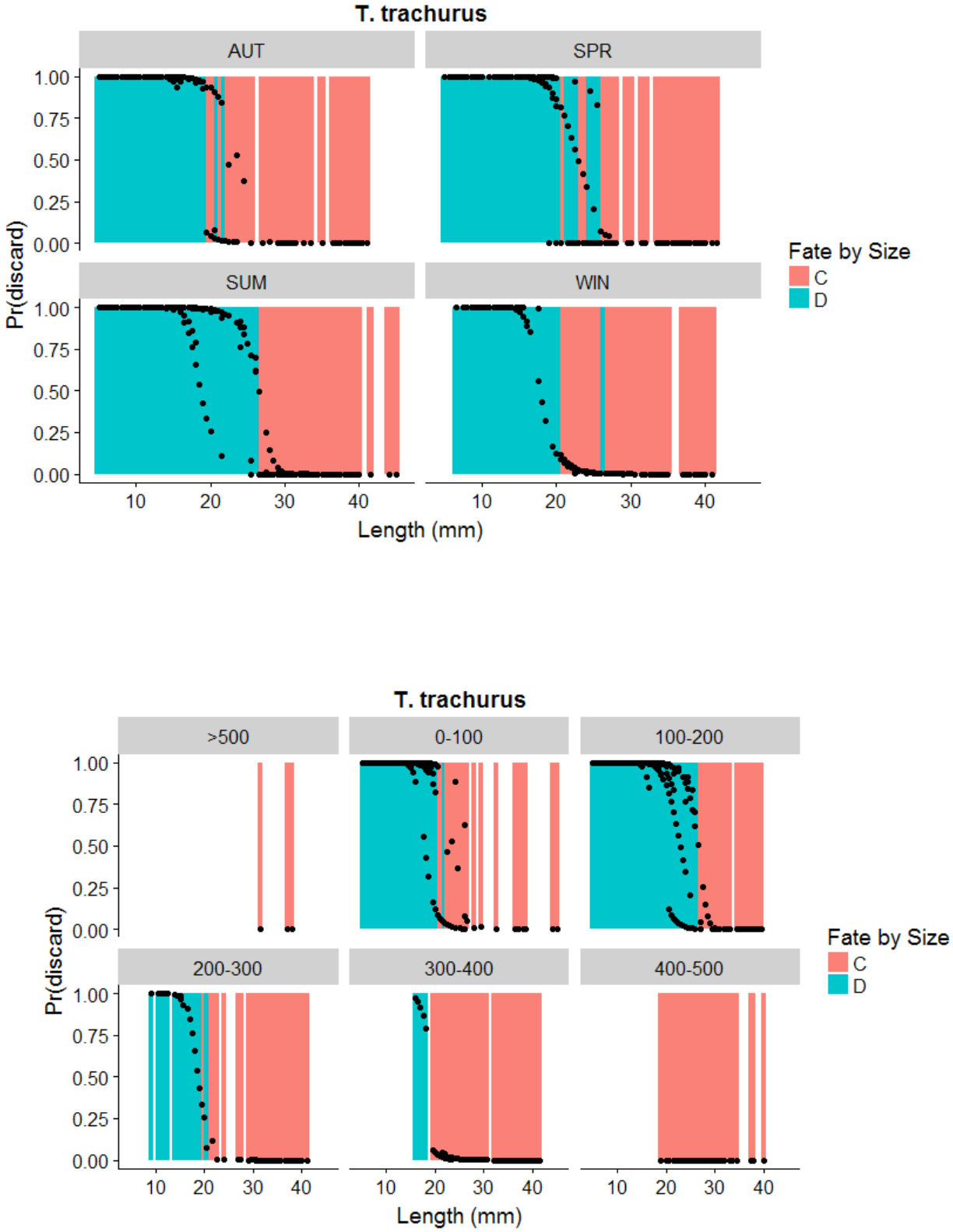


Fig. S4d: GAM derived discard probability by total length with super-imposed discard ogive for horse mackerel (top-by season, bottom-by depth stratum).

***Mullus barbatus* (MCRS = 11cm)**

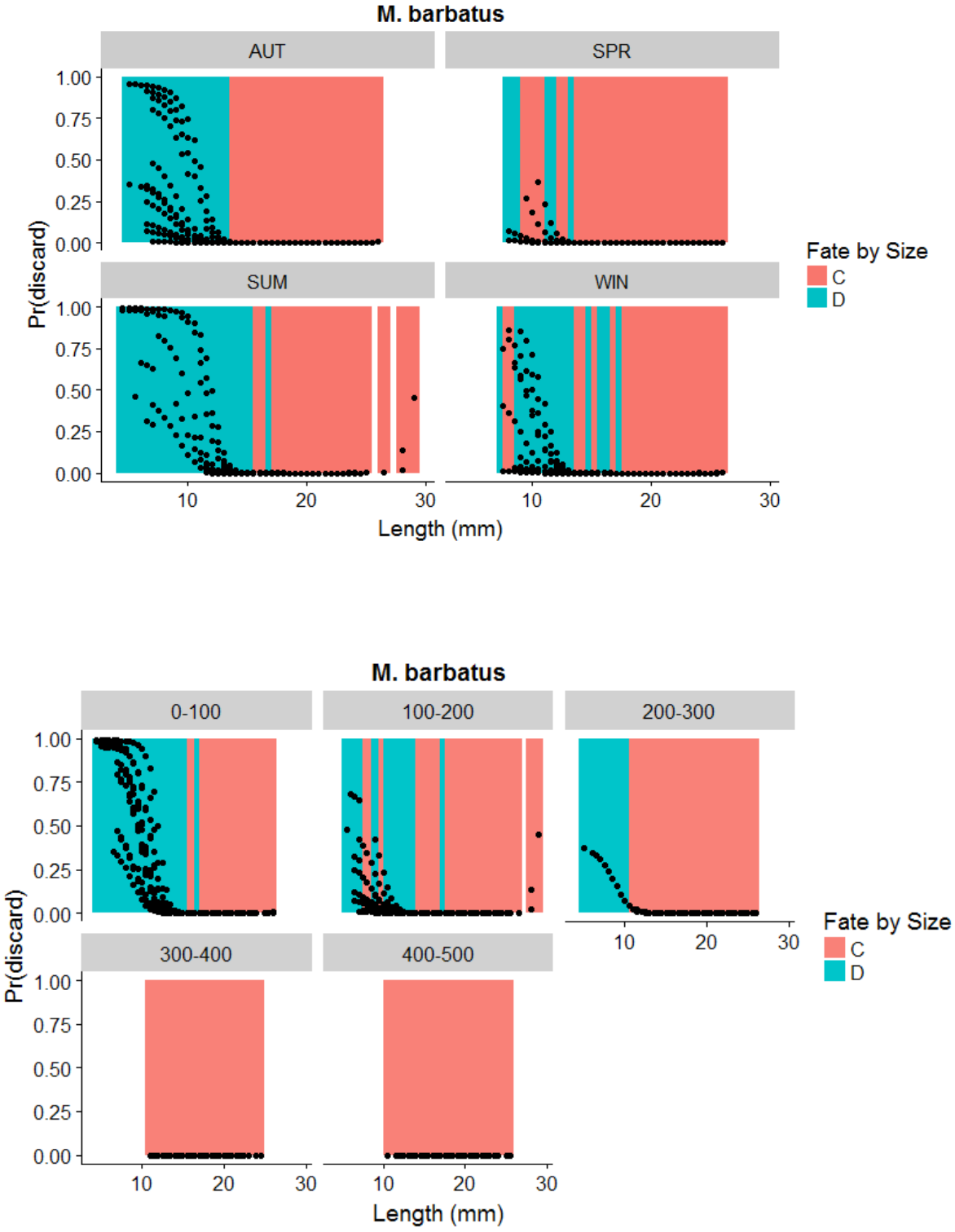


Fig. S4e: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top-by season, bottom-by depth stratum).

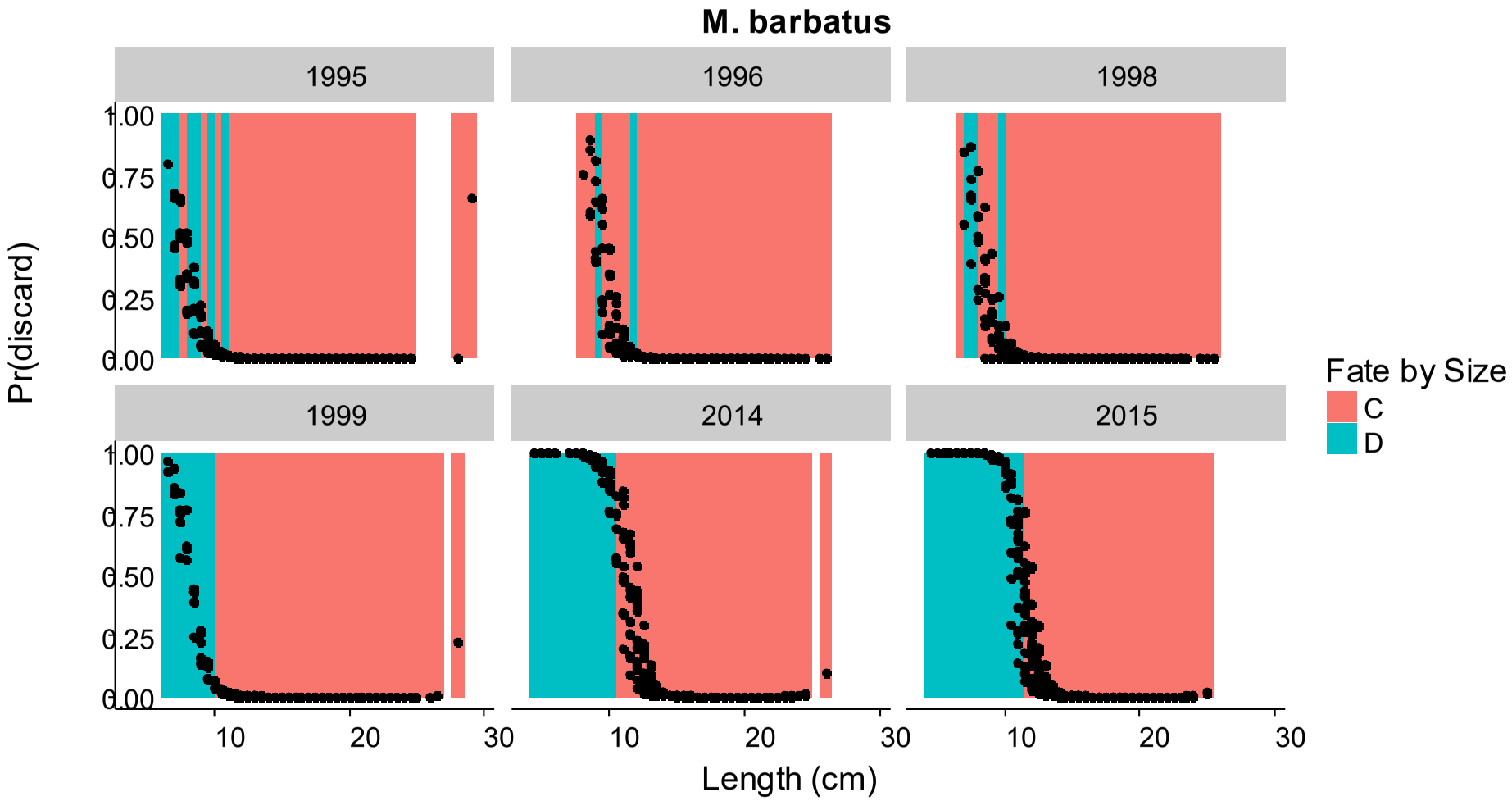


Fig. S4f: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (by year).

***Mullus surmuletus*(MCRS = 11cm)**

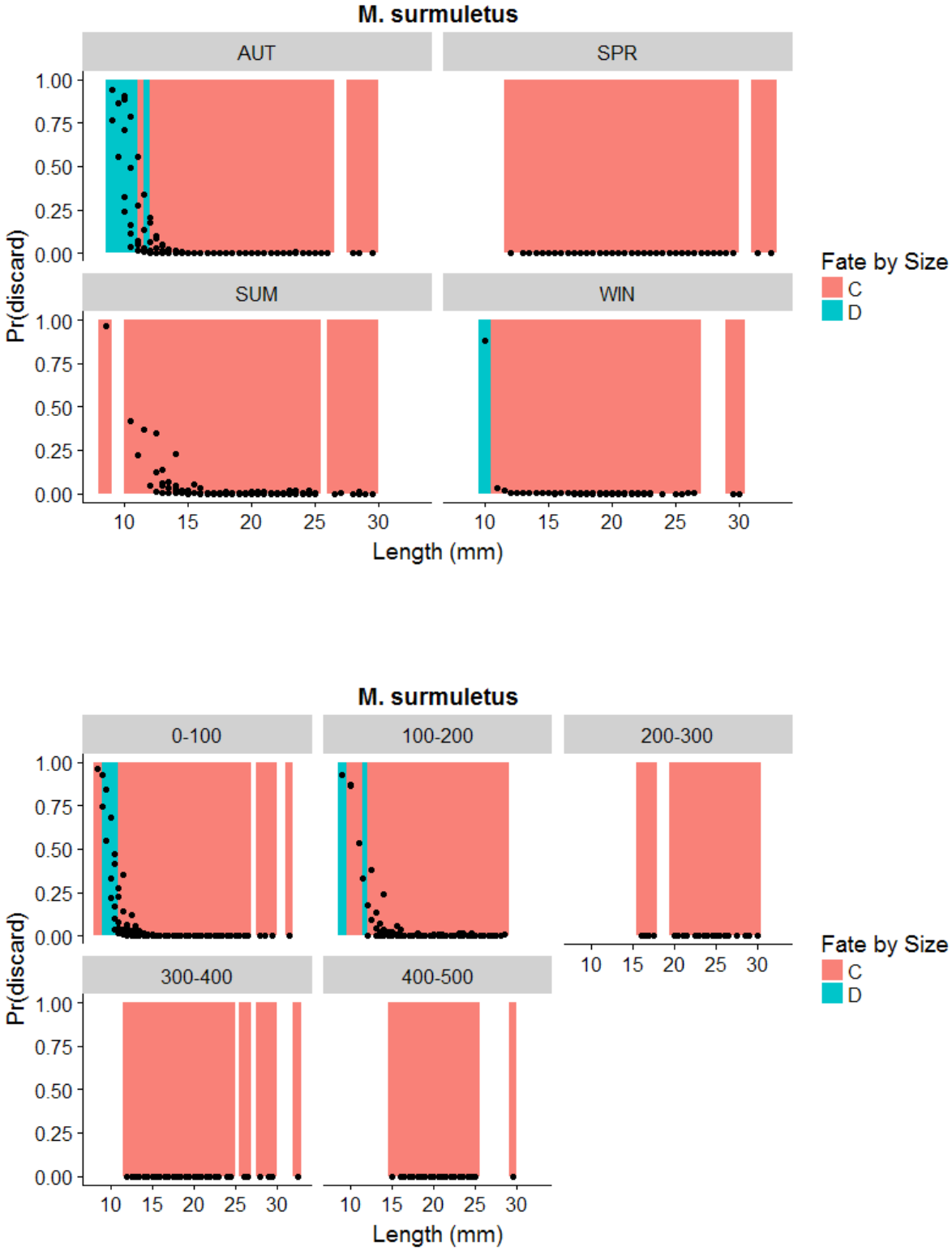


Fig. S4g: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top-by season, bottom-by depth stratum).

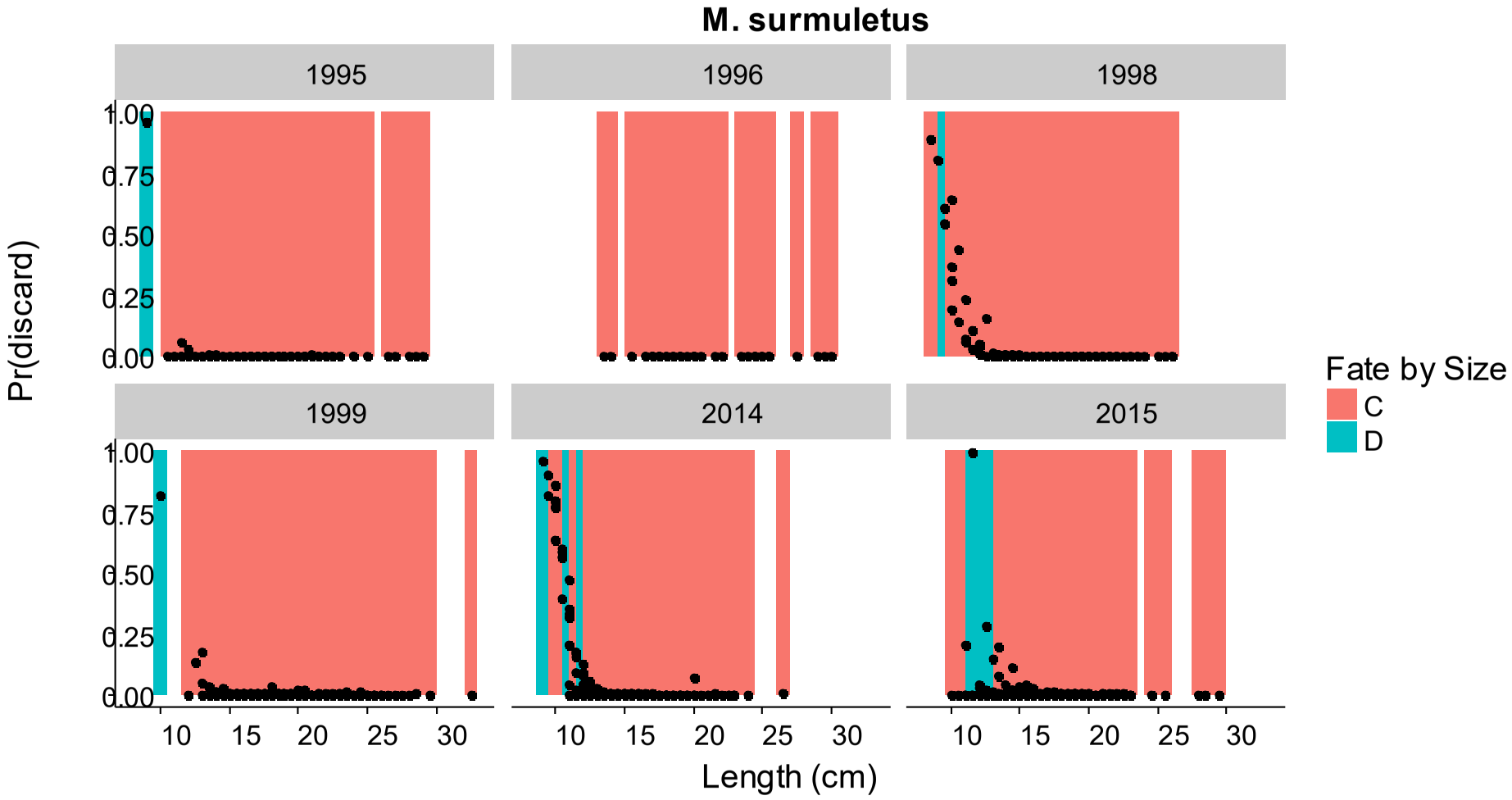


Fig. S4h: GAM derived discard probability by total length with super-imposed discard ogive for striped red mullet (by year).

Boops boops

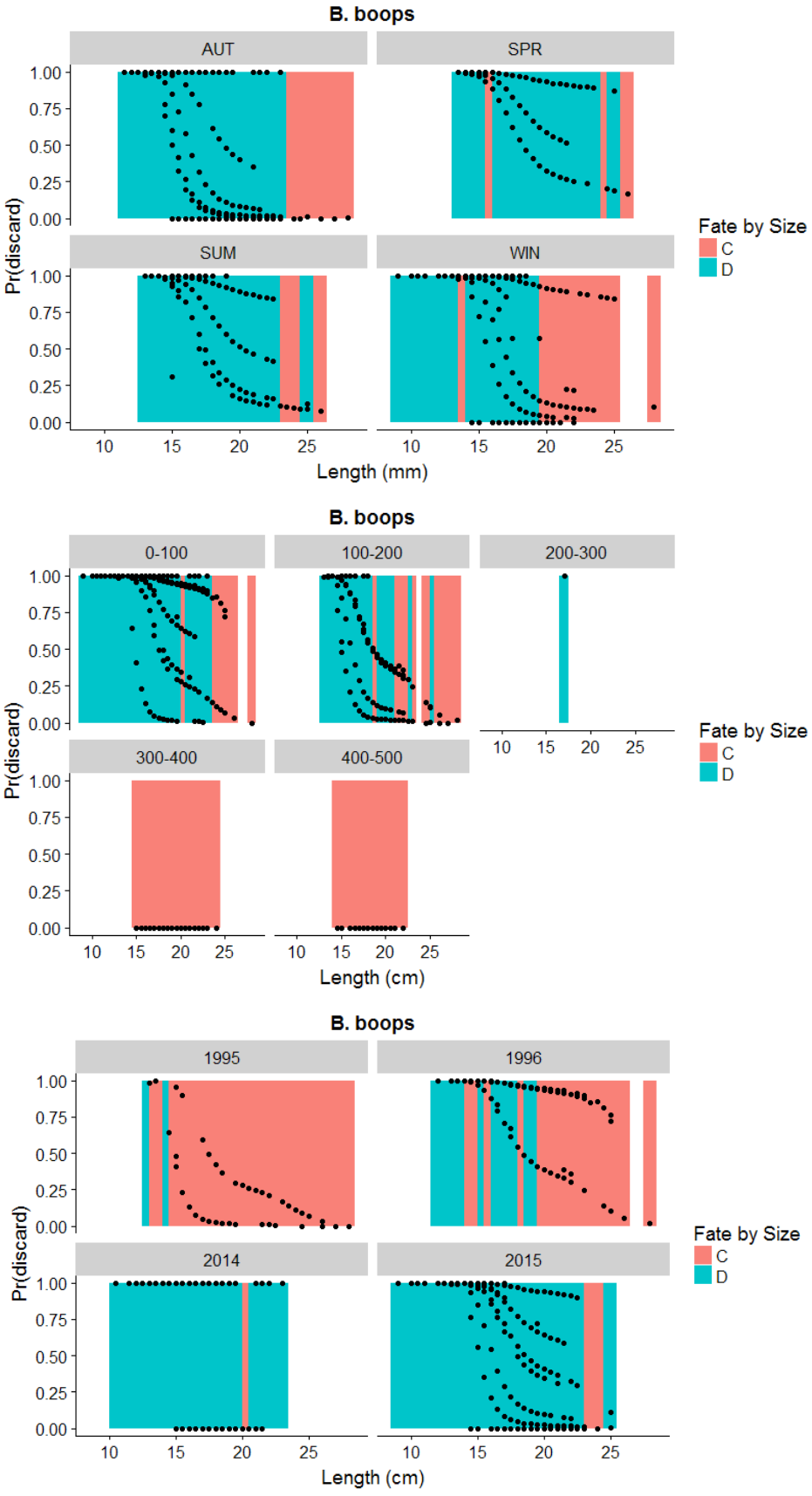


Fig. S4i: GAM derived discard probability by total length with super-imposed discard ogive for bogue (top-by season, mid-by depth stratum, bottom-by Year)