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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

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 |

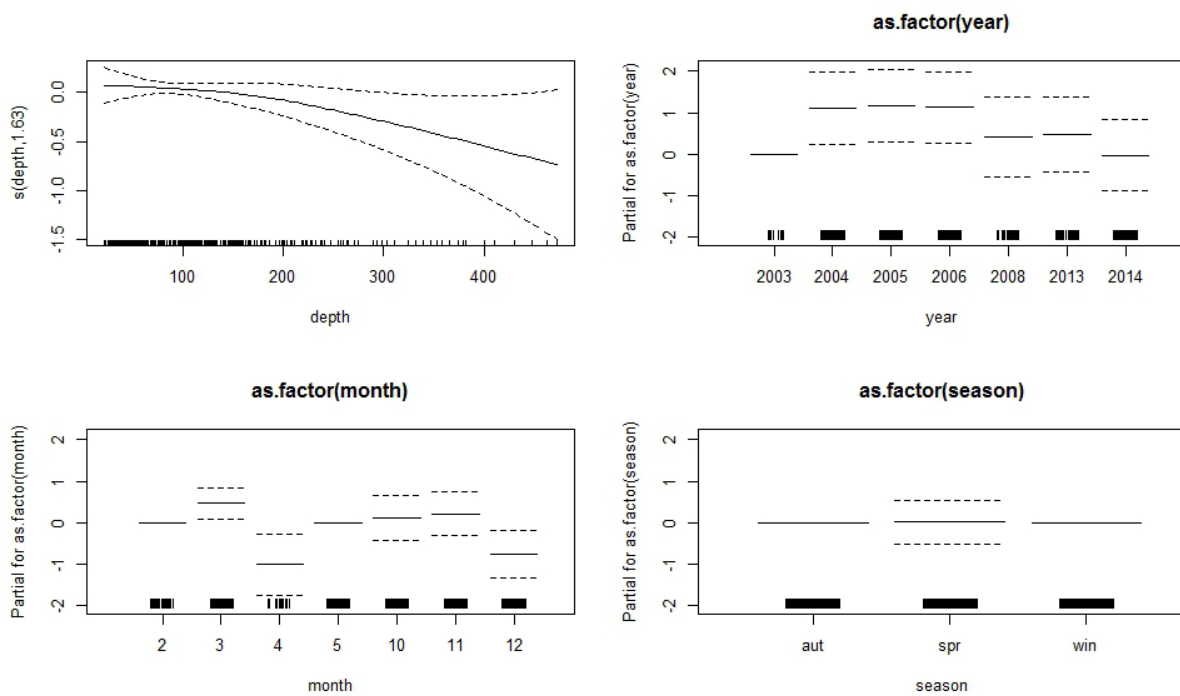


Fig. S1a: Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **invertebrate** catch in the bottom trawl fishery of the Aegean Sea and Crete. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points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

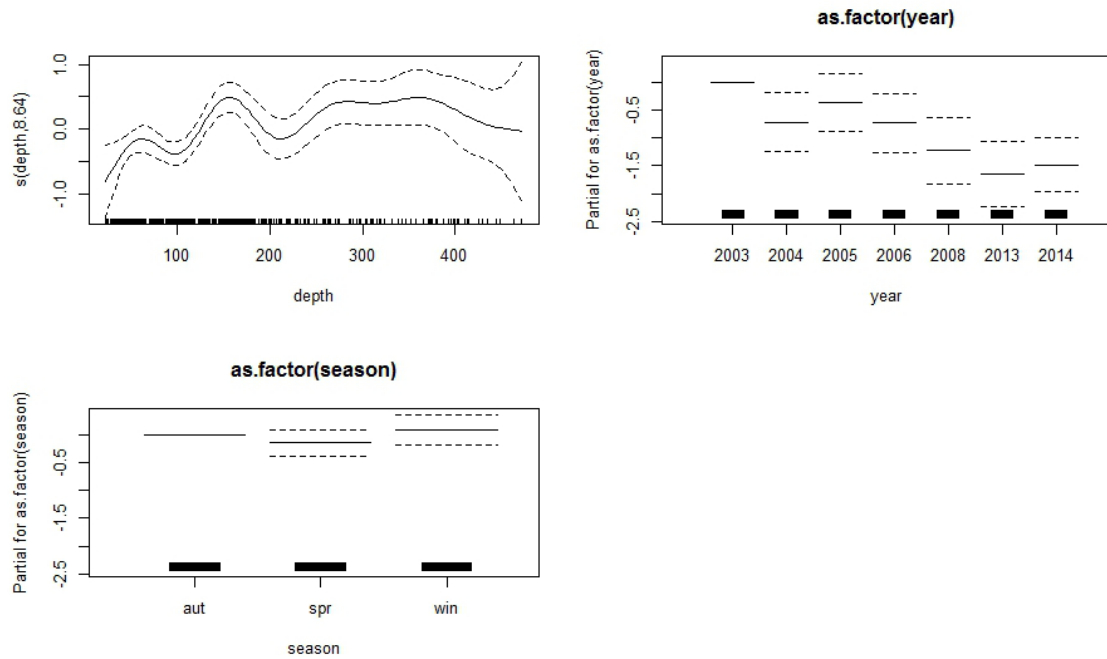


Fig. S1b: Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **elasmobranch** catch in the bottom trawl fishery of the Aegean Sea and Crete. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points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

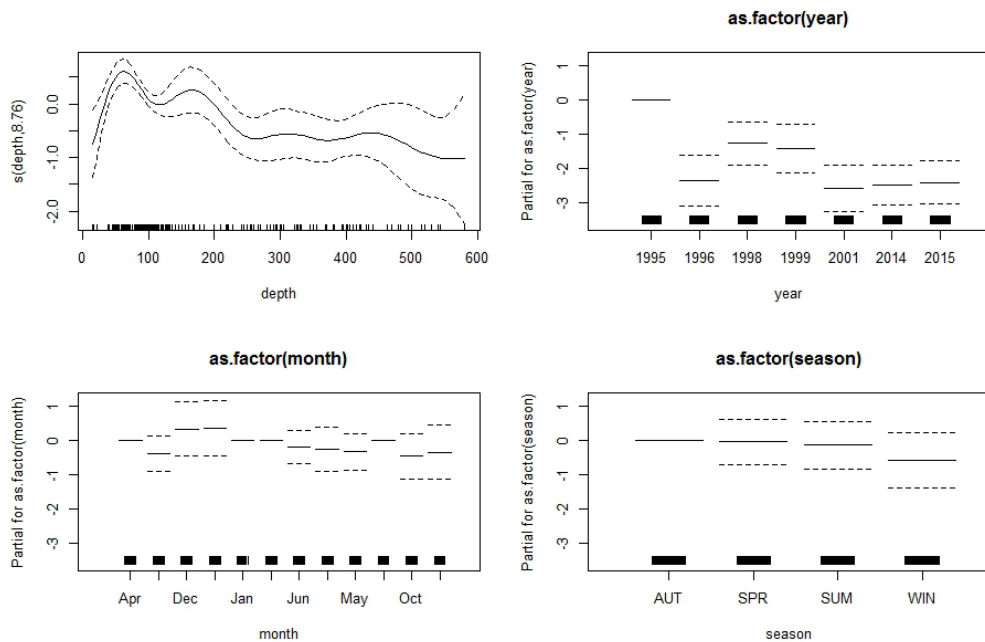


Fig. S2a: Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **invertebrate** catch in the bottom trawl of the Ligurian and north Tyrrhenian Sea. Dashed lines indicate two standard errors above and below the estimates. Relative density of data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

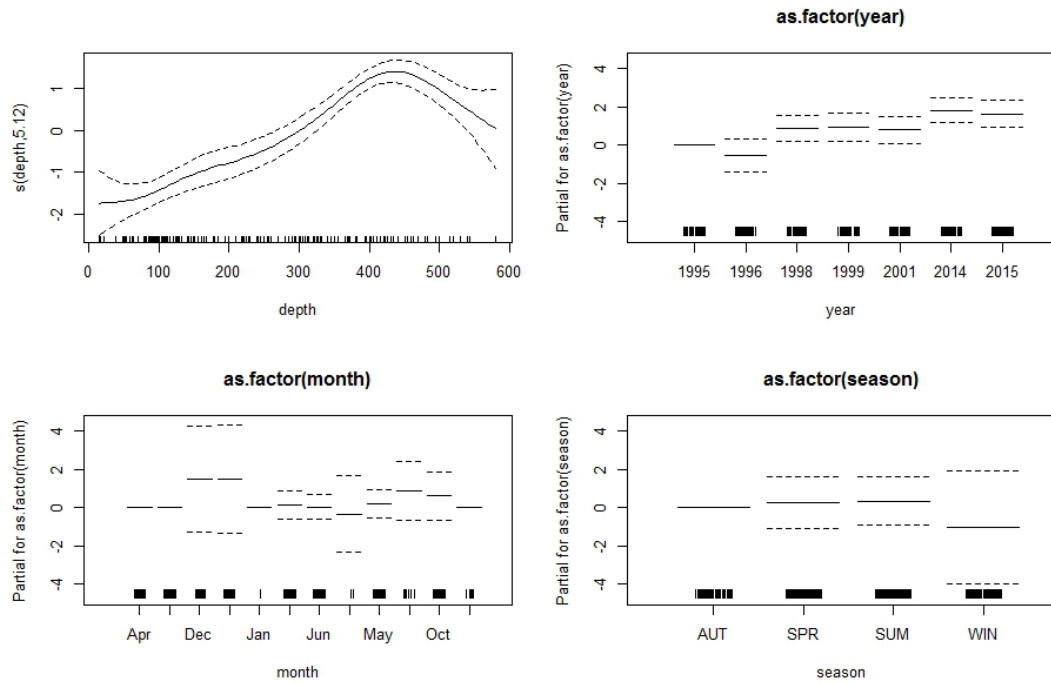
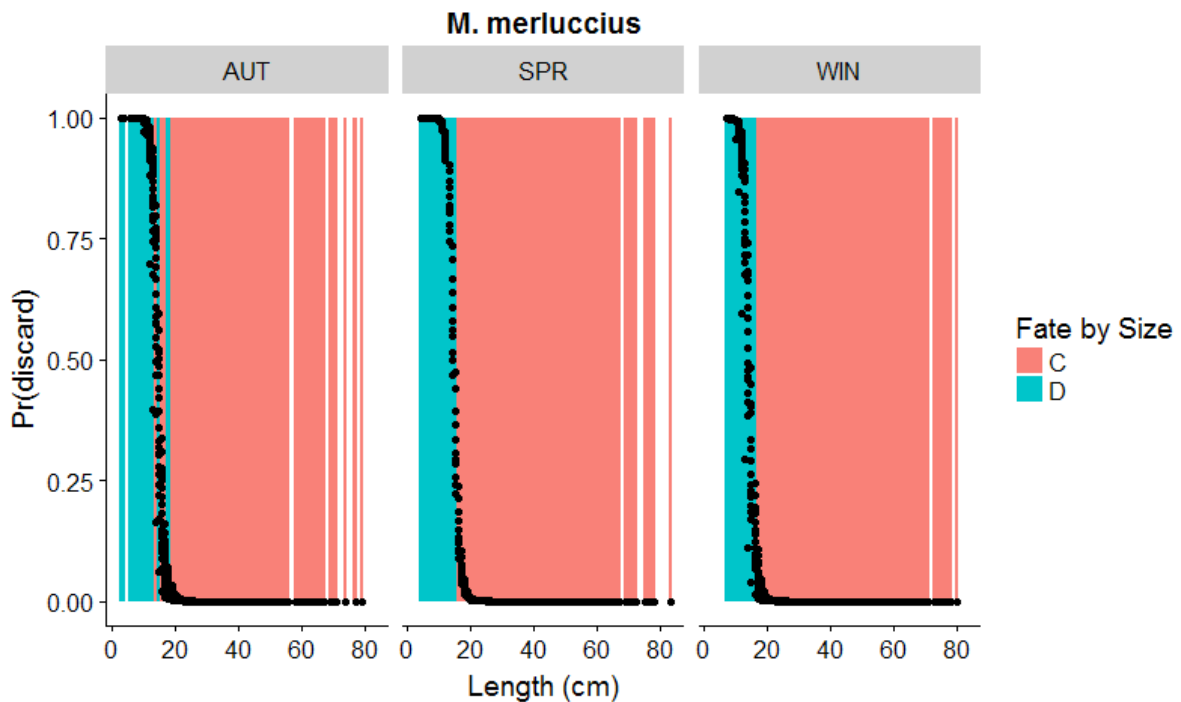


Fig. S2b: Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **elasmobranch** catch in the bottom trawl fishery of the Ligurian and north Tyrrhenian Sea. Dashed lines indicate two standard errors above and below the estimates. Relative density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

AEGEAN SEA and CRETE

Merluccius merluccius (MCRS = 20 cm)



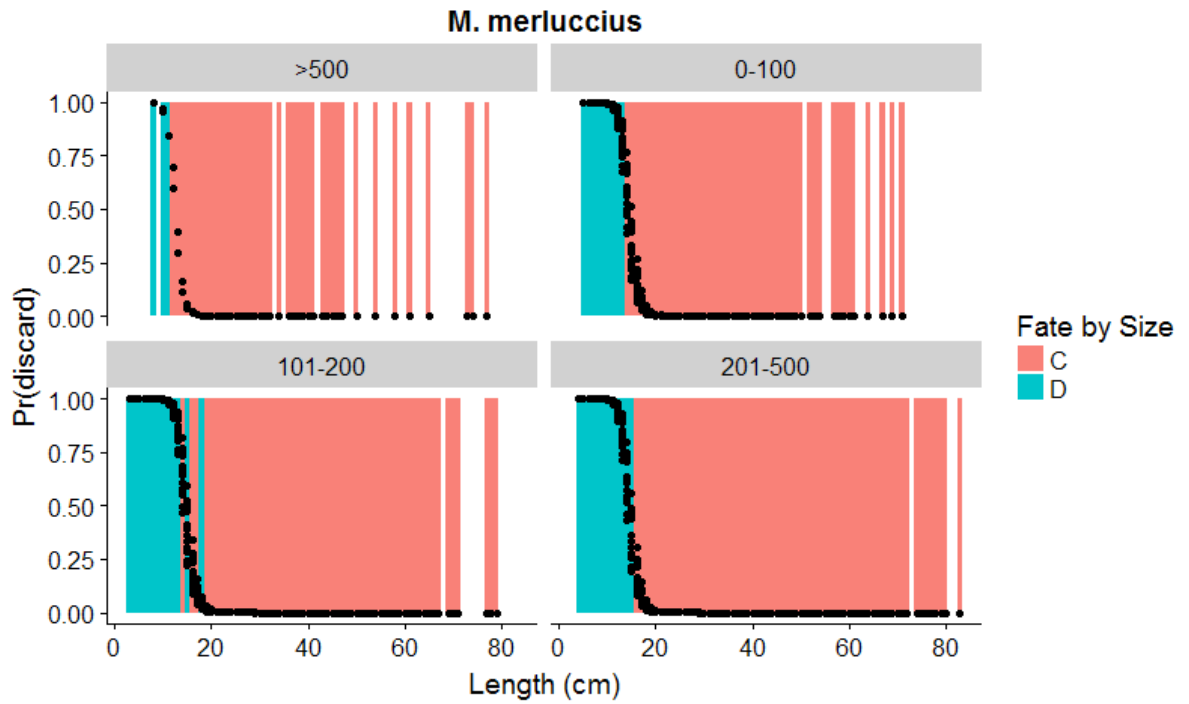


Fig. S3a: GAM derived discard probability by total length with super-imposed discard ogive for hake (top-by season, bottom-by depth stratum).

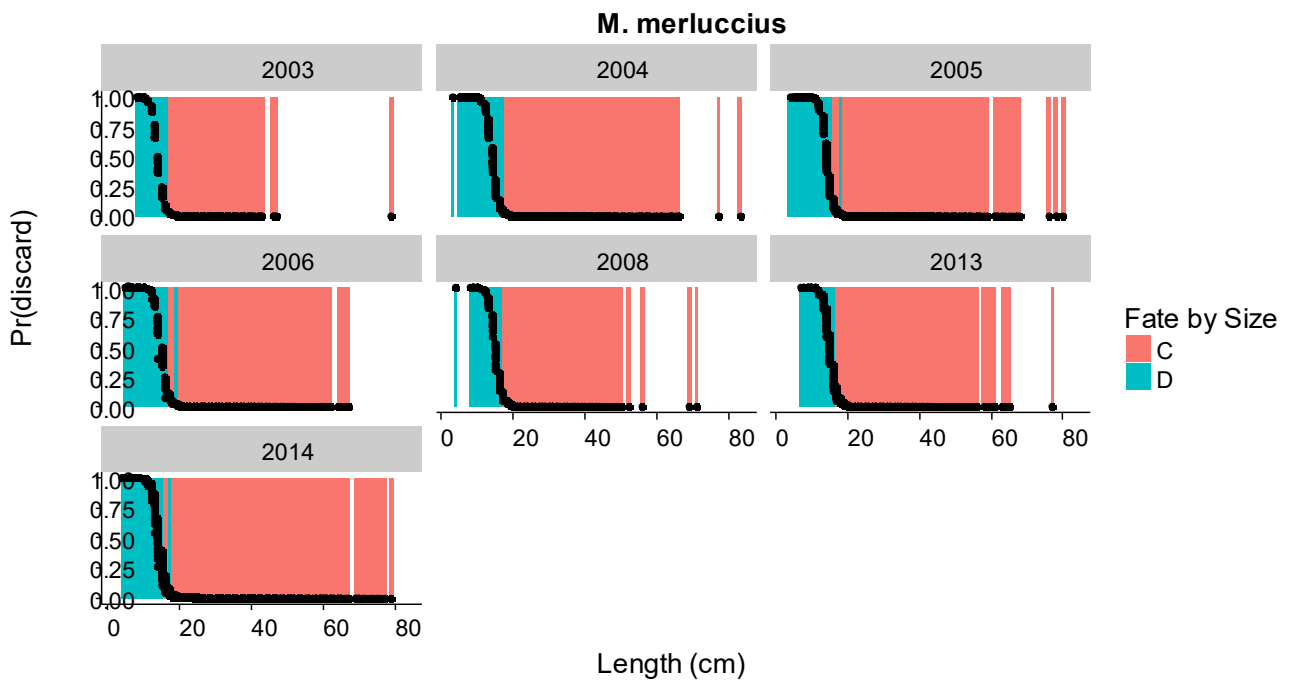


Fig. S3b: GAM derived discard probability by total length with super-imposed discard ogive for hake (by year).

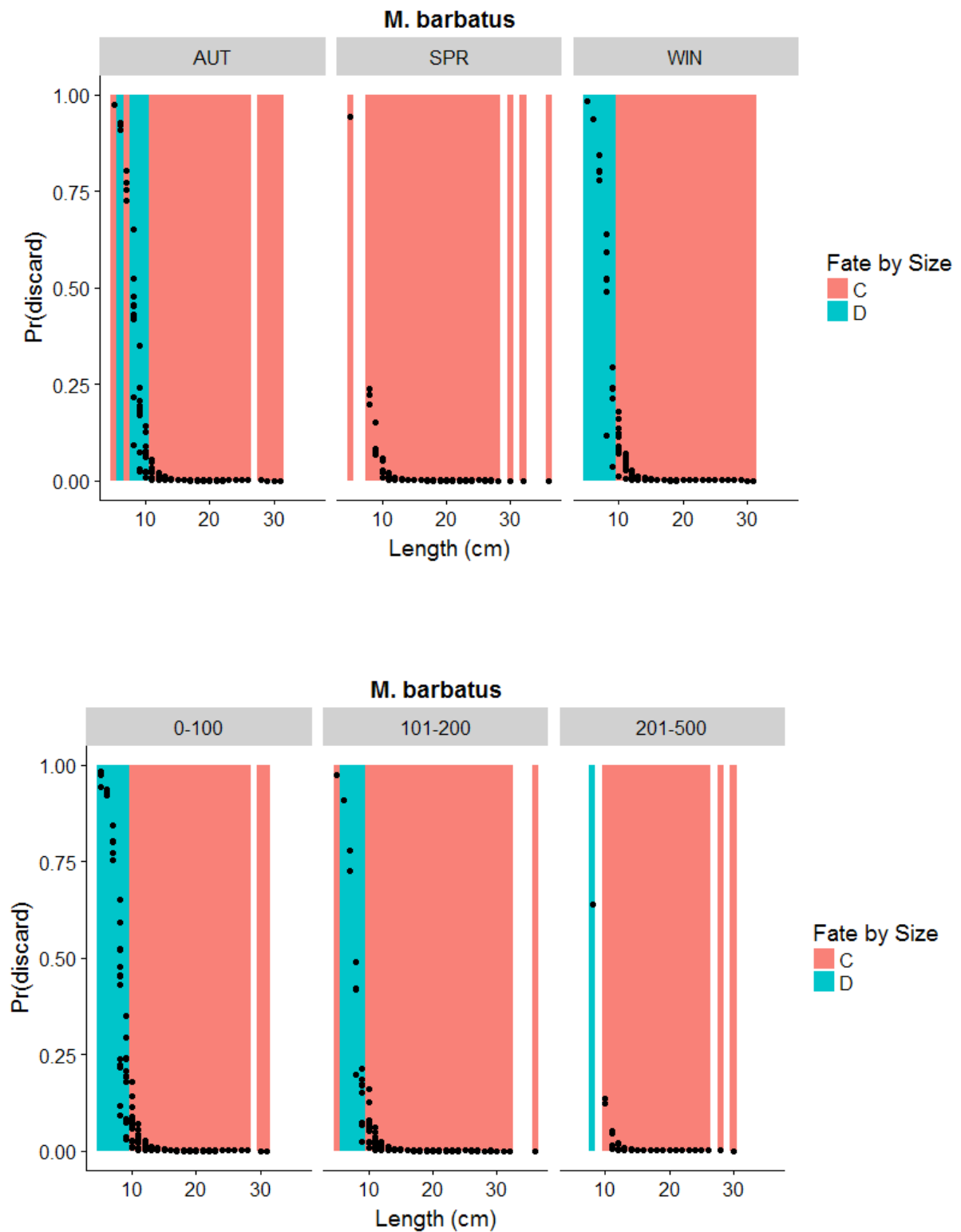


Fig. S3c: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top- by season, bottom-by depth stratum).

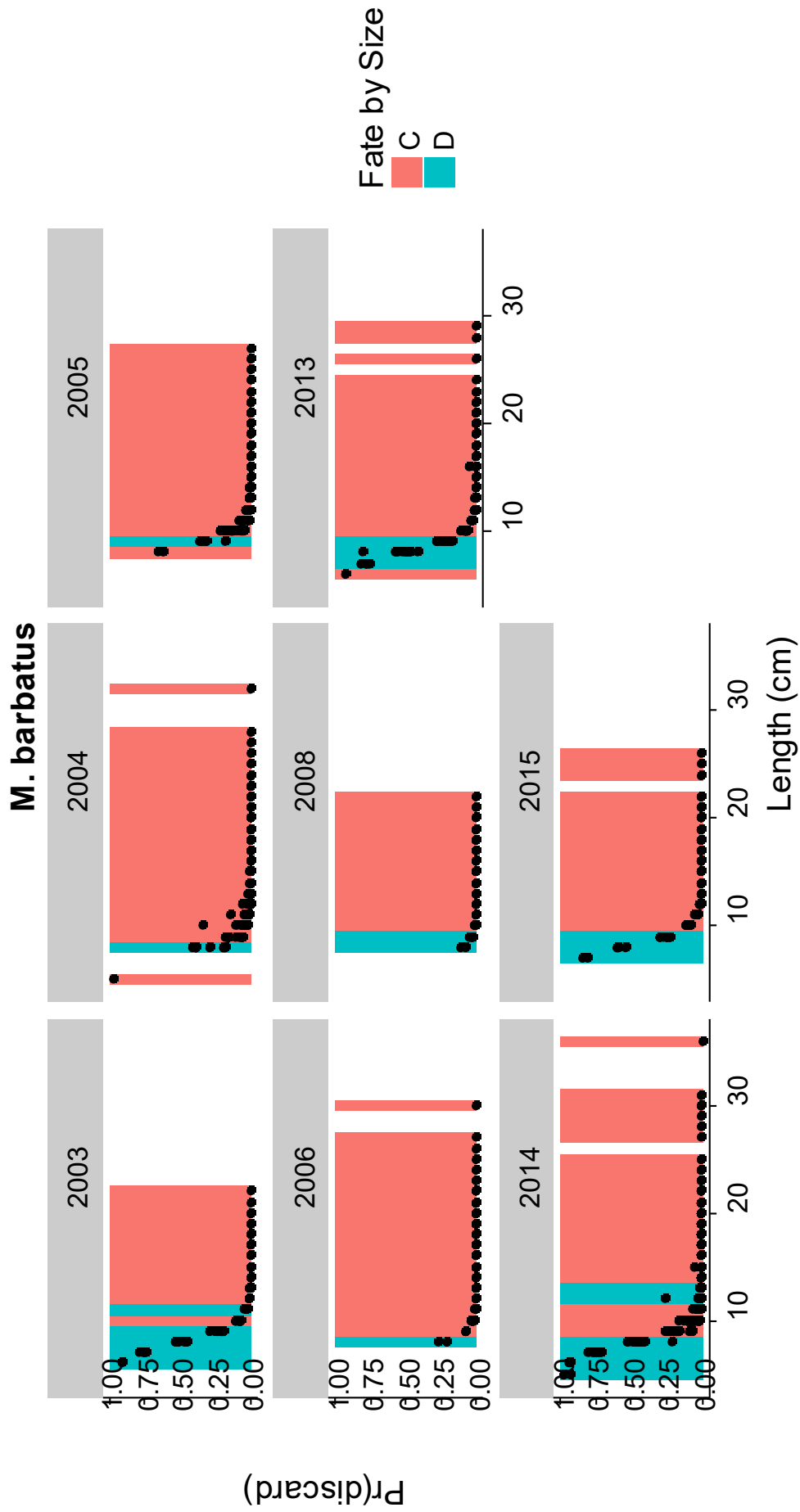


Fig. S3d: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (by year).

Trachurus trachurus (MCRS=15 cm)

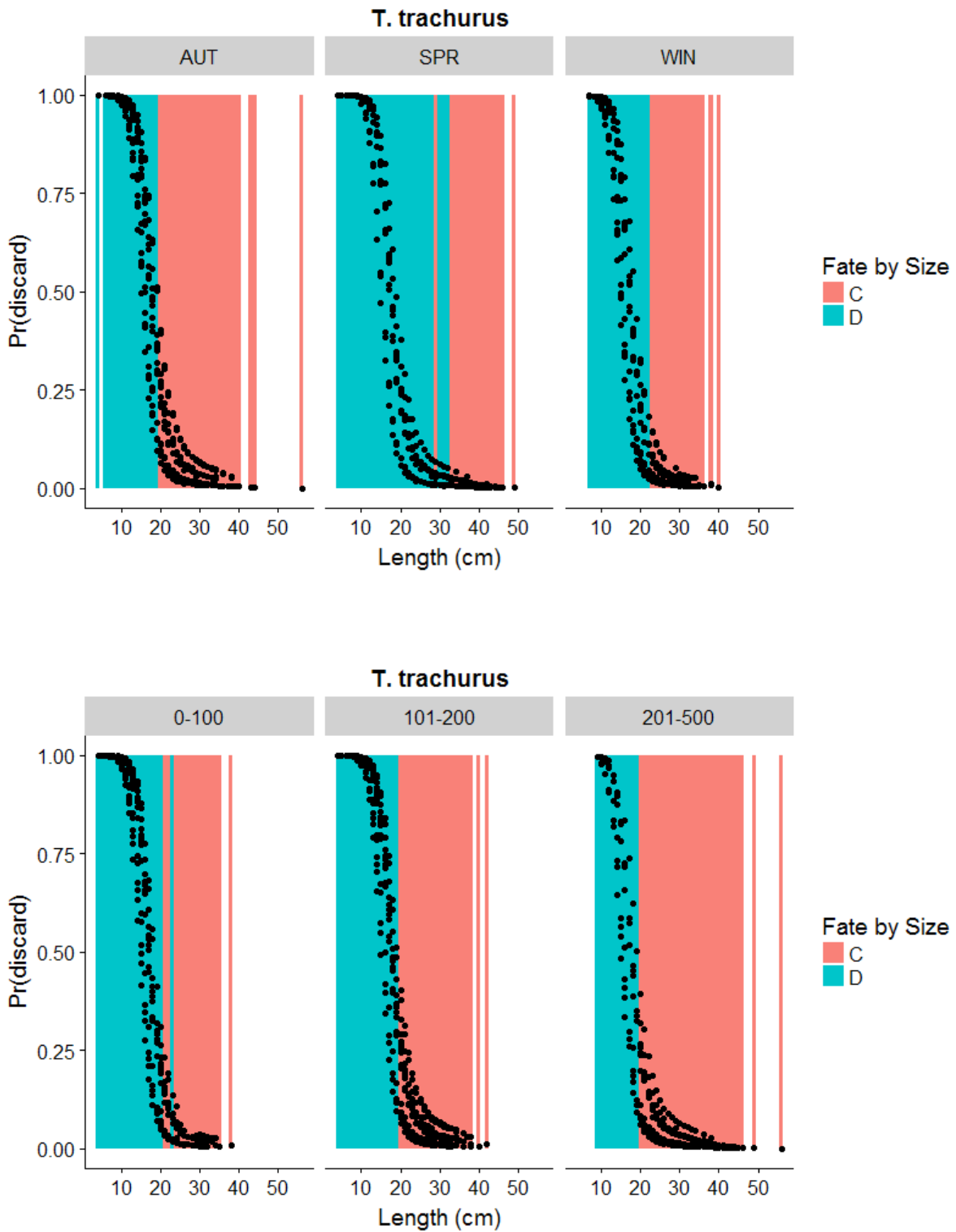


Fig. S3e: GAM derived discard probability by total length with super-imposed discard ogive for horse mackerel (top-global, mid-by season, bottom-by depth stratum).

Parapenaeus longirostris (MCRS = 20mm)

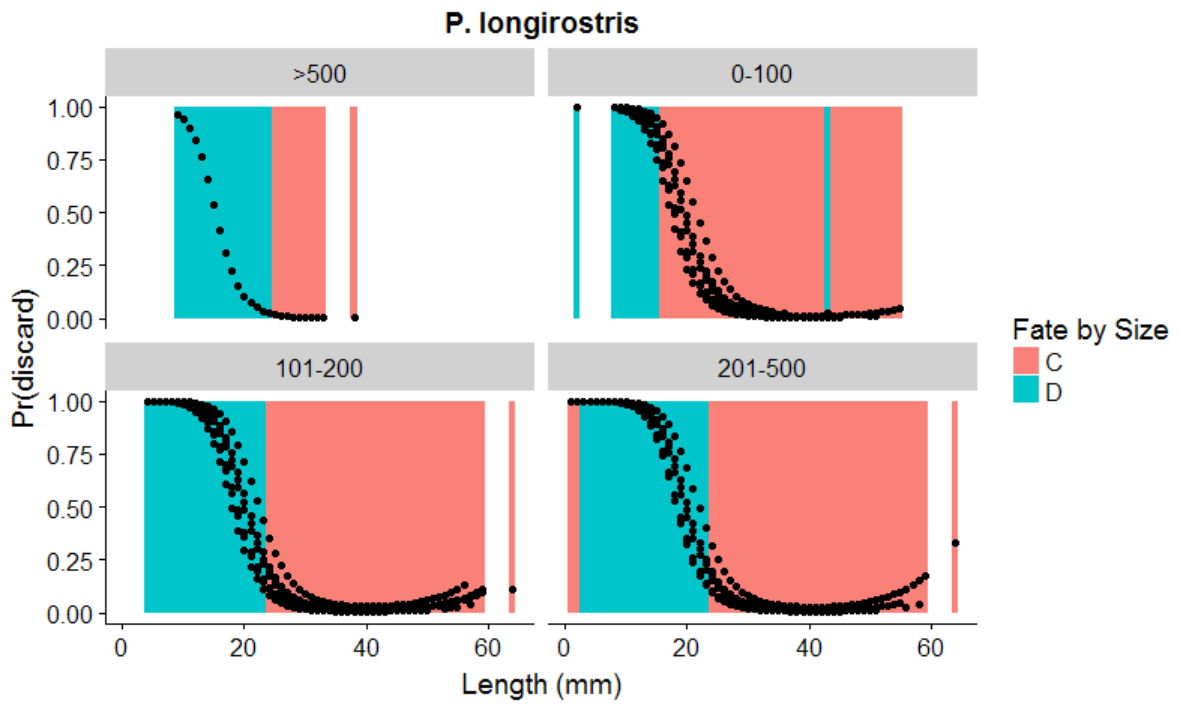


Fig. S3f: GAM derived discard probability by total length with super-imposed discard ogive for deep-water rose shrimp (by depth stratum).

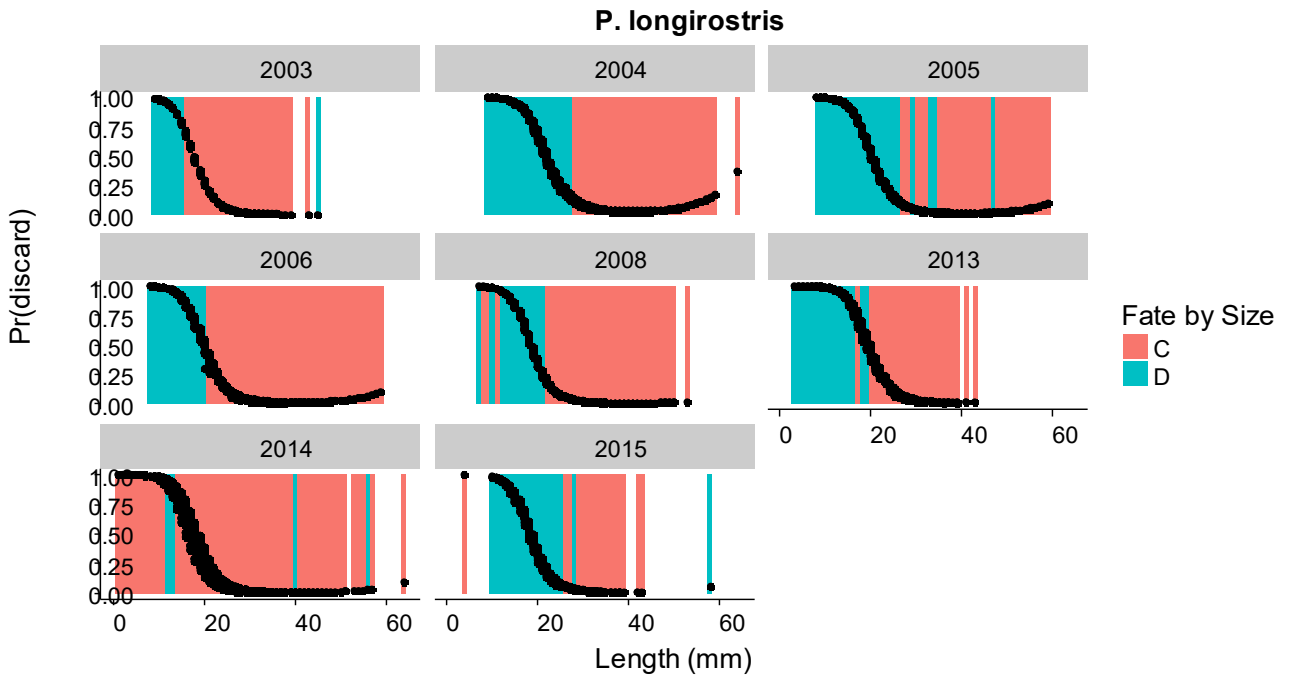


Fig.S3g: GAM derived discard probability by total length with super-imposed discard ogive for deep water rose shrimp (by year).

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

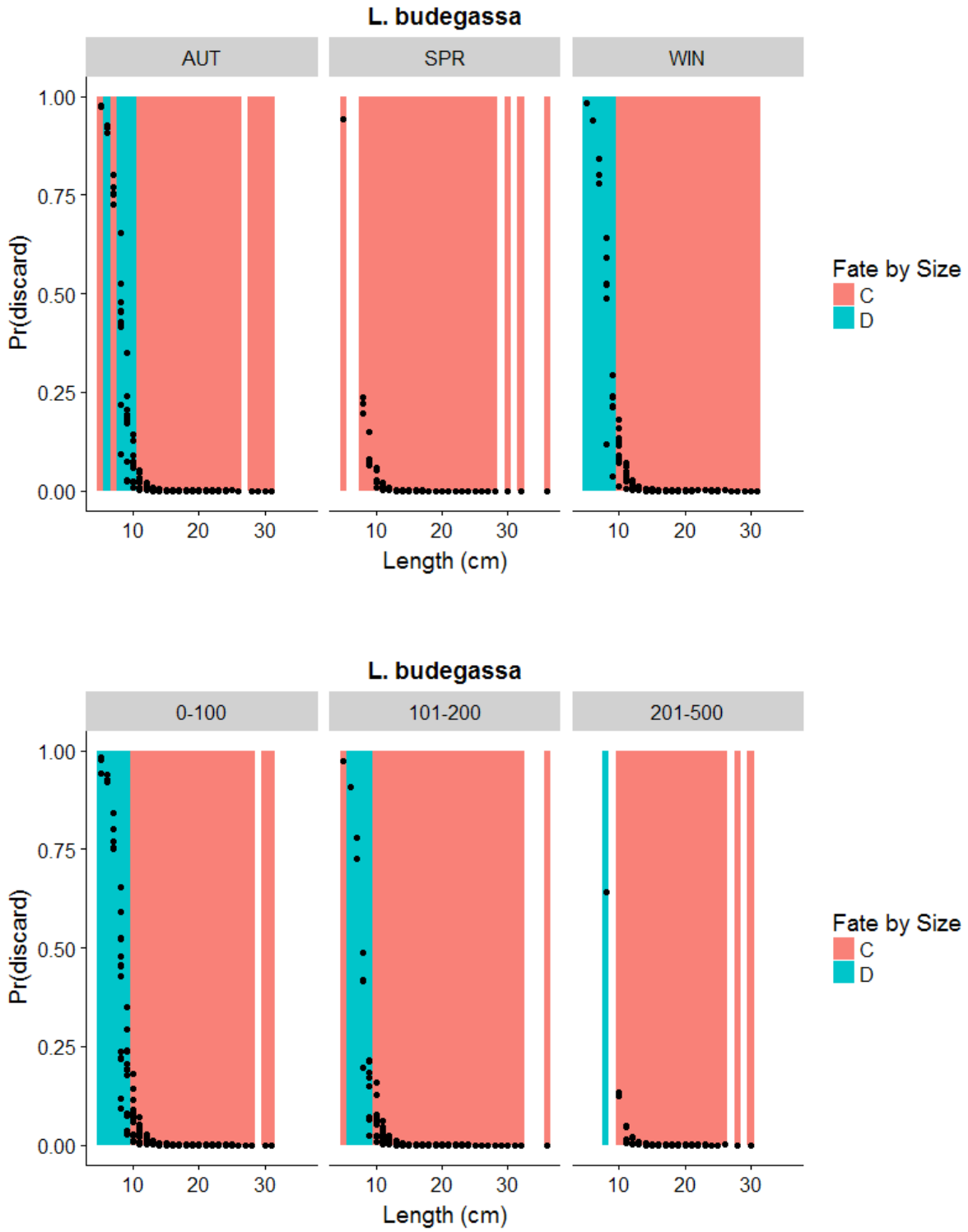


Fig. S3h: GAM derived discard probability by total length with super-imposed discard ogive for anglerfish (top- by season, bottom-by depth stratum).

L. budegassa

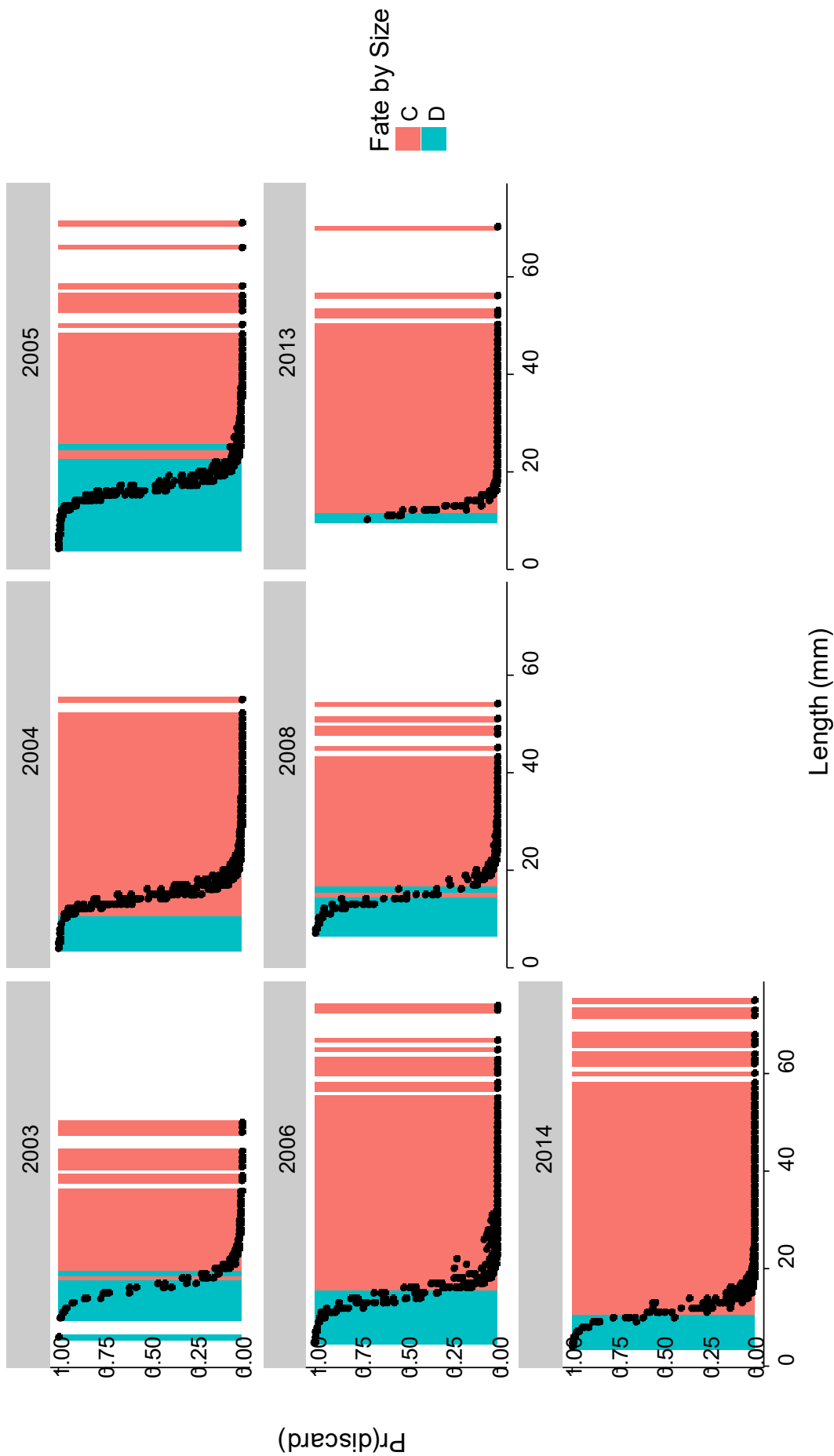


Fig. S3i: GAM derived discard probability by total length with super-imposed discard ogive for anglerfish (by year).

Boops boops (MCRS= 10 cm)

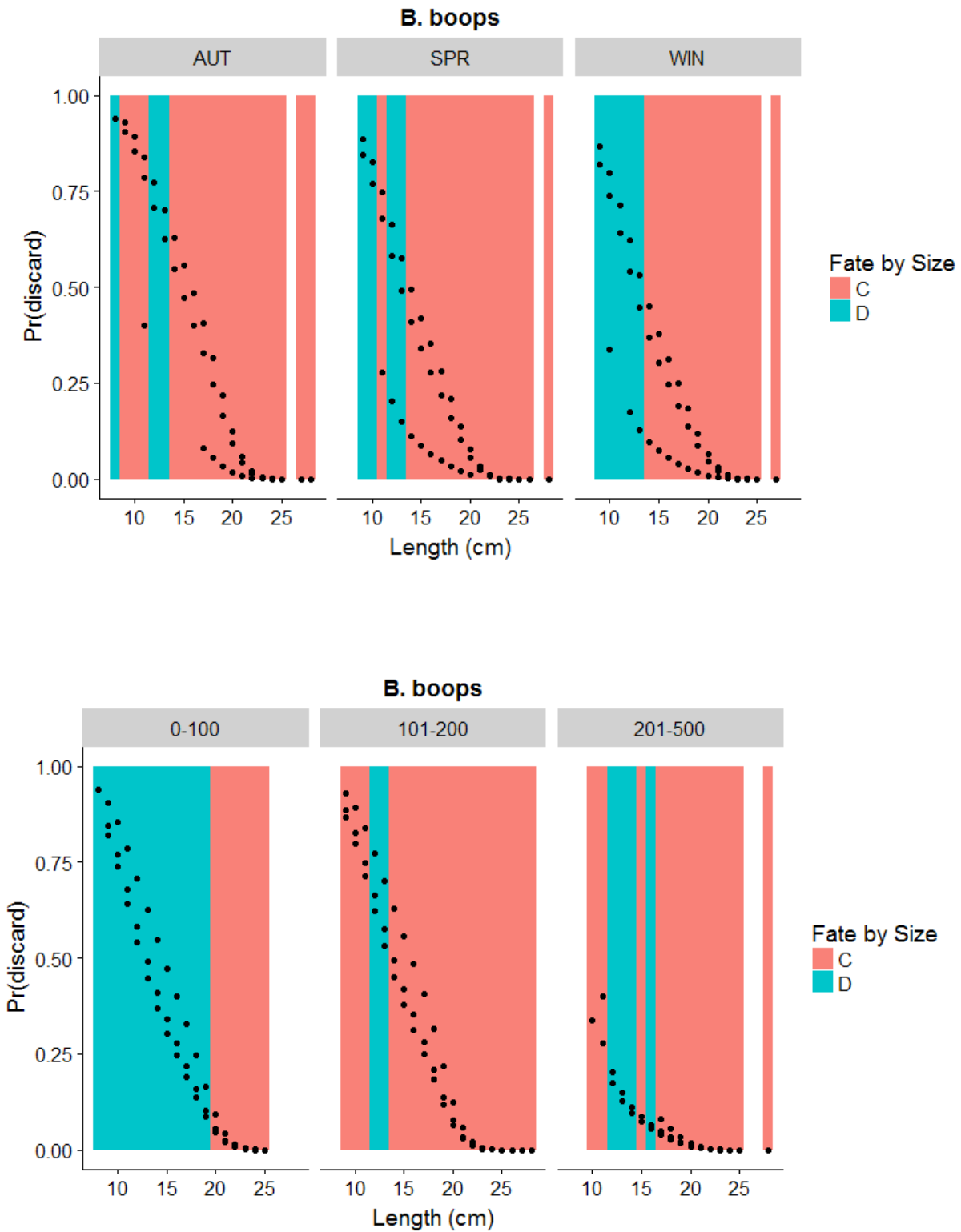


Fig. S3j: GAM derived discard probability by total length with super-imposed discard ogive for bogue (top-global, mid-by season, bottom-by depth stratum).

LIGURIAN & NORTH TYRRHENIAN SEA

Merluccius merluccius (MCRS=20cm)

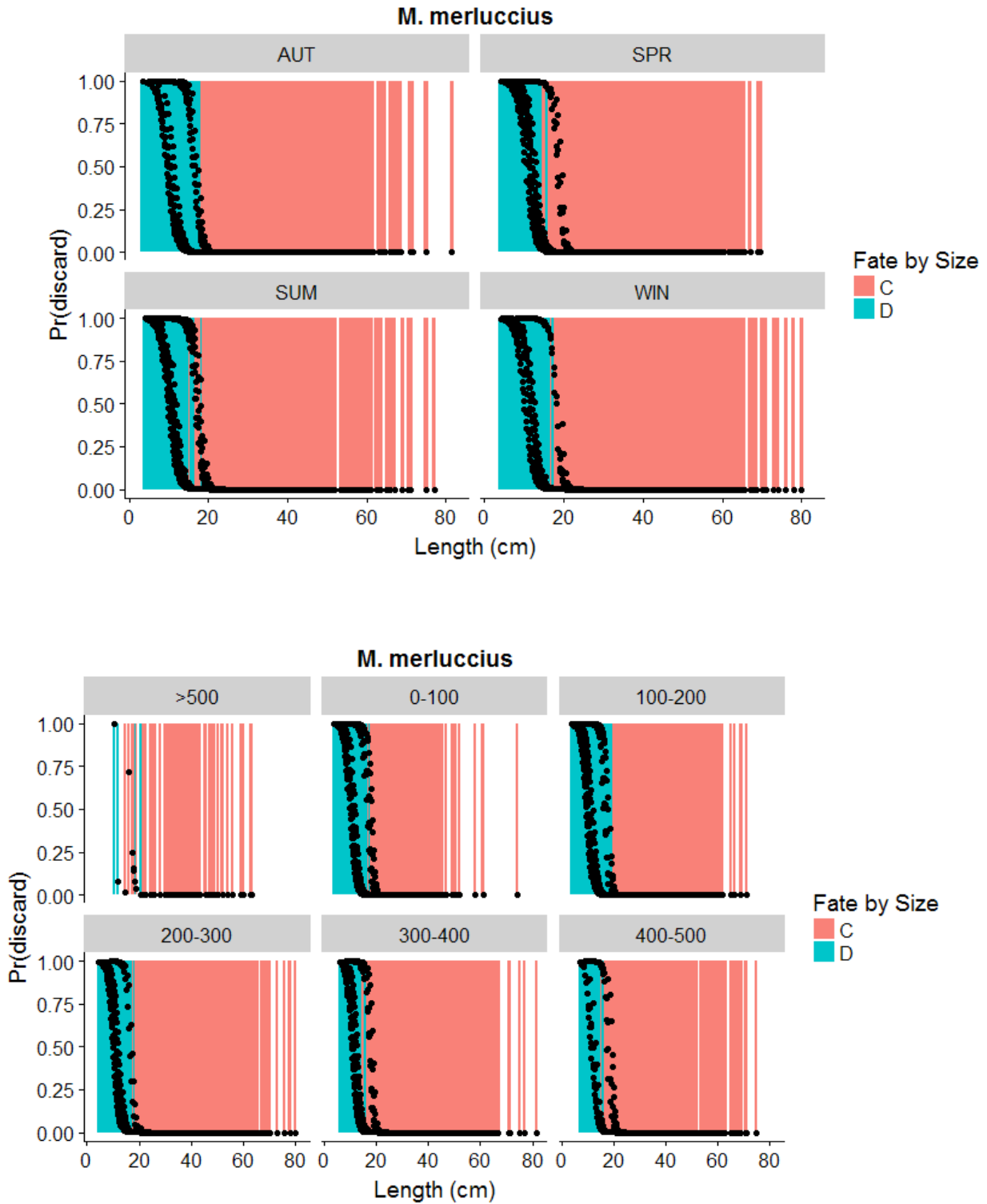


Fig. S4a: GAM derived discard probability by total length with super-imposed discard ogive for hake (top - by season, bottom - by depth stratum).

M. merluccius

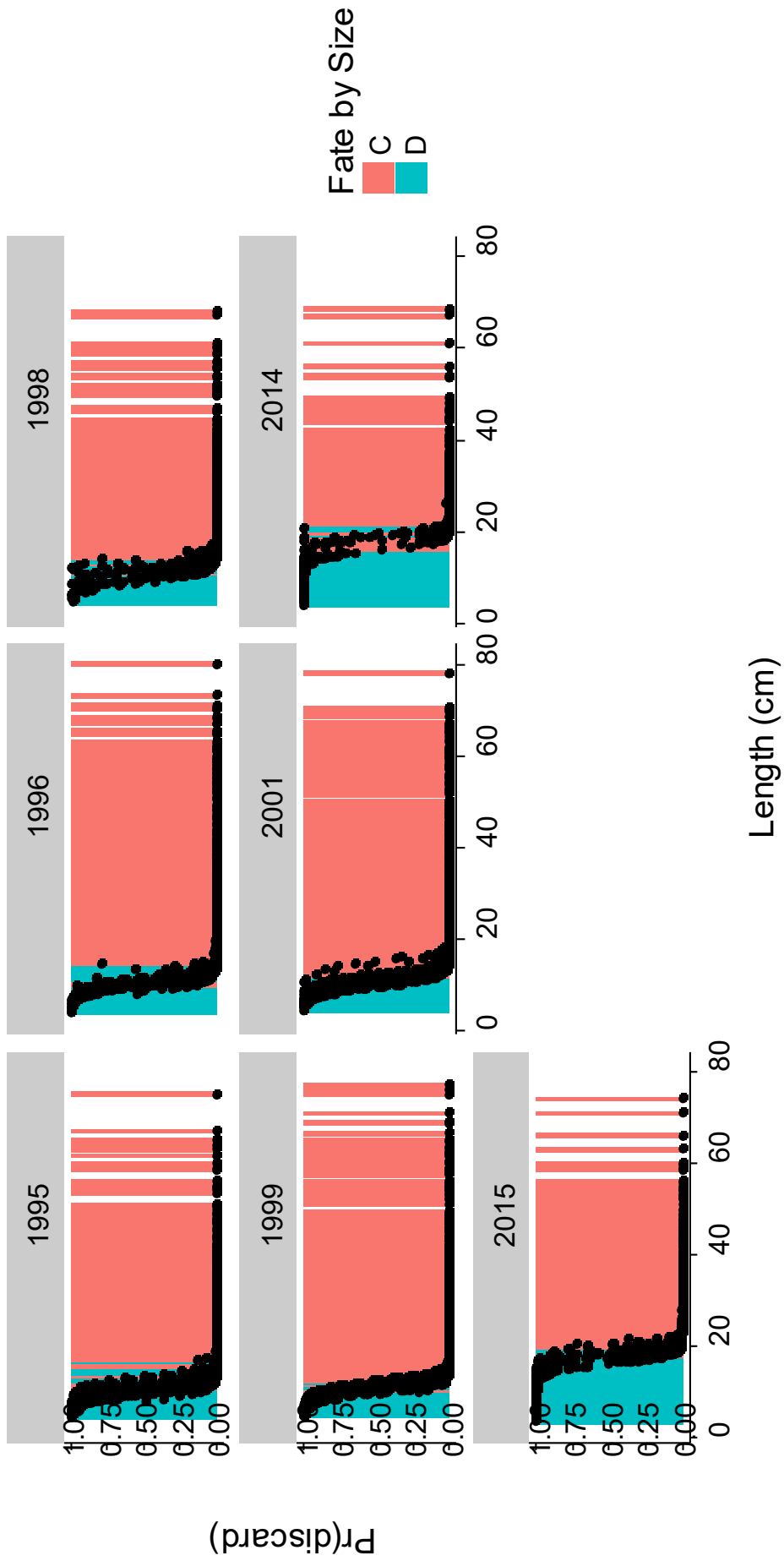


Fig. S4b: GAM derived discard probability by total length with super-imposed discard ogive for hake (by year).

Parapenaeus longirostris (MCRS=20mm)

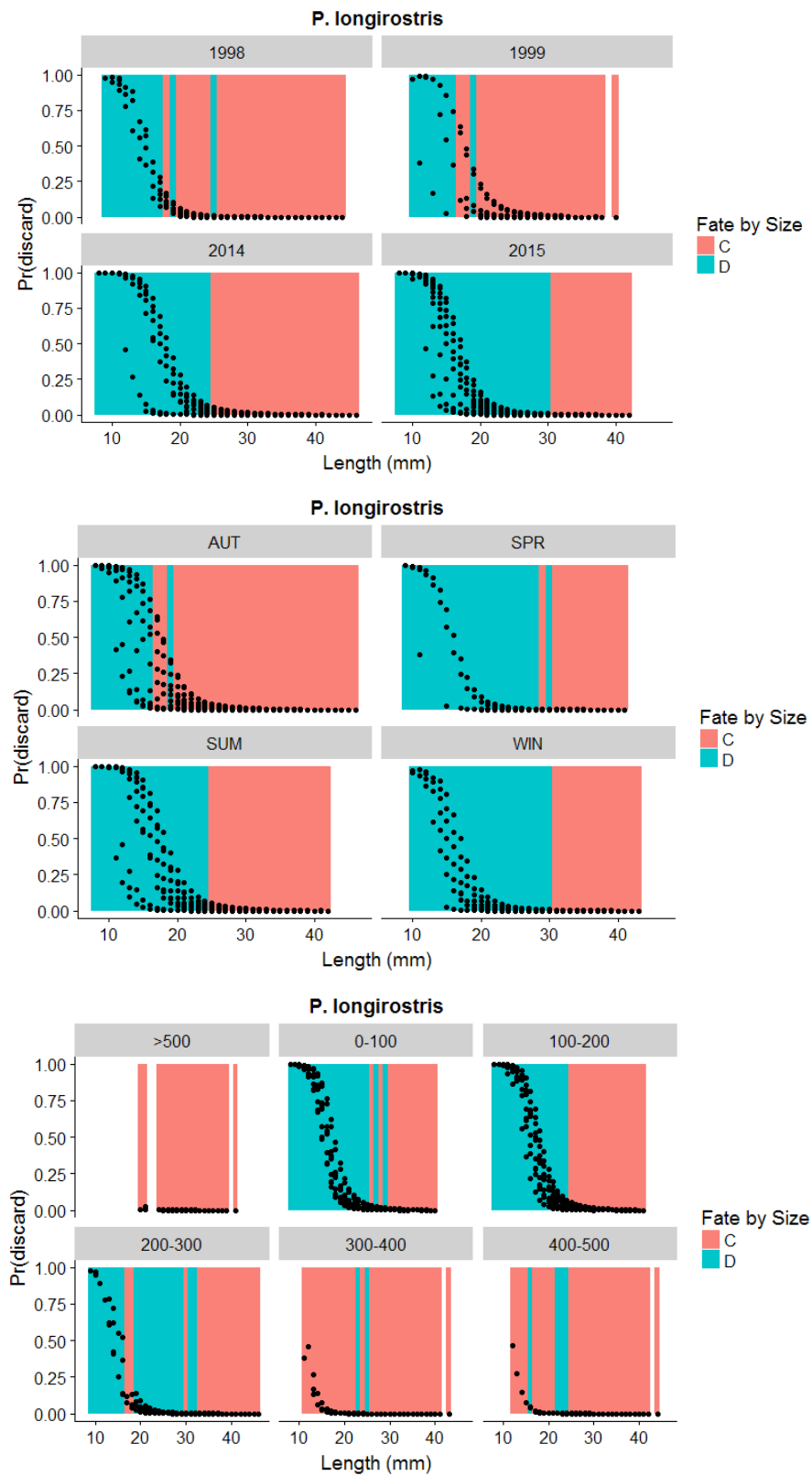


Fig. S4c: GAM derived discard probability by total length with super-imposed discard ogive for deep-water rose shrimp (top-by year, mid-by season and bottom-by depth stratum).

Trachurus trachurus (MCRS=15cm)

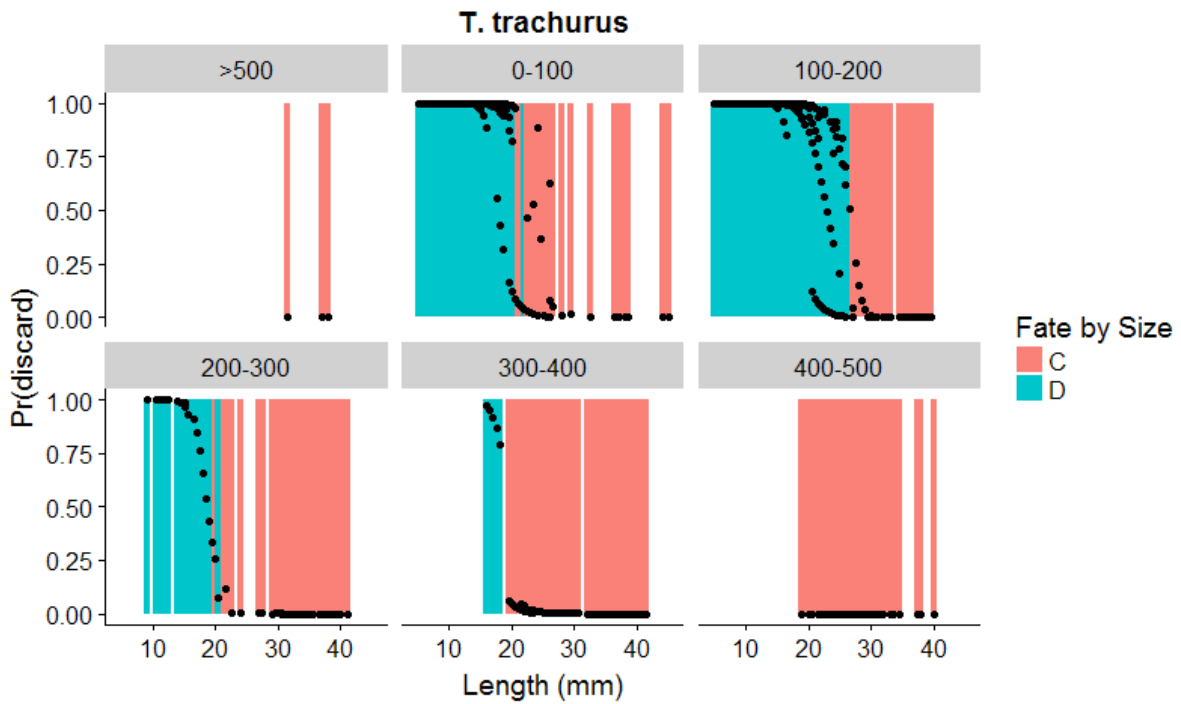
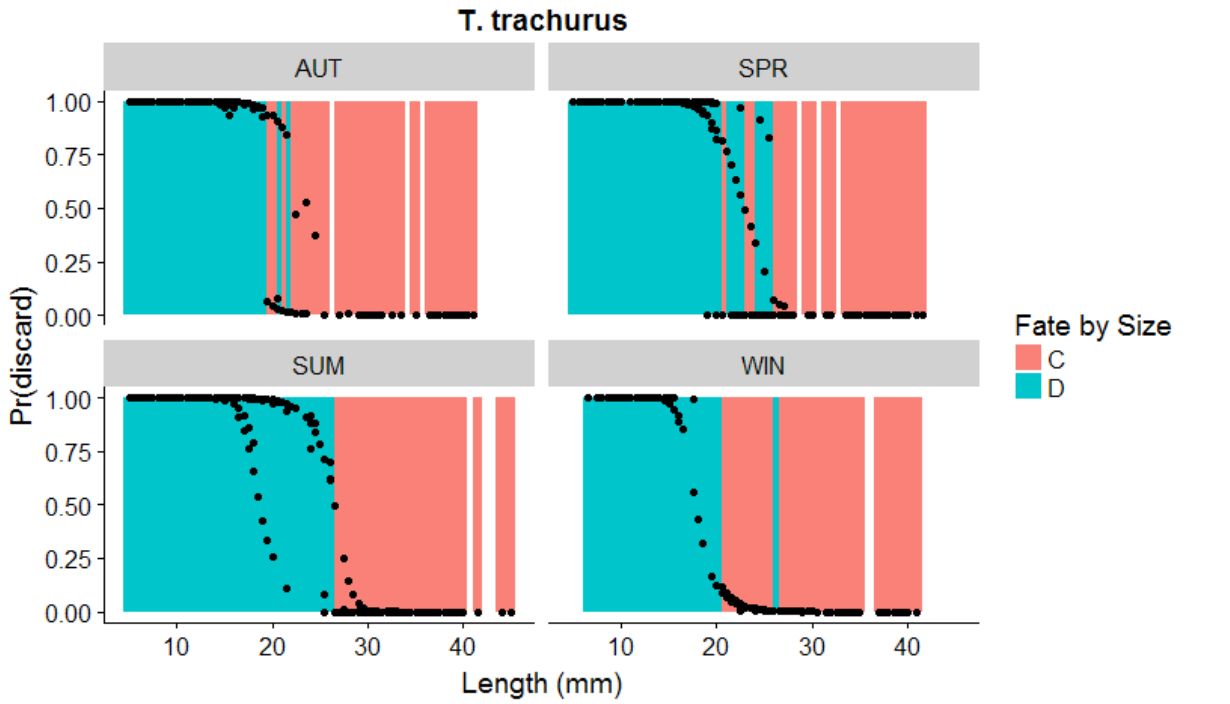


Fig. S4d: GAM derived discard probability by total length with super-imposed discard ogive for horse mackerel (top-by season, bottom-by depth stratum).

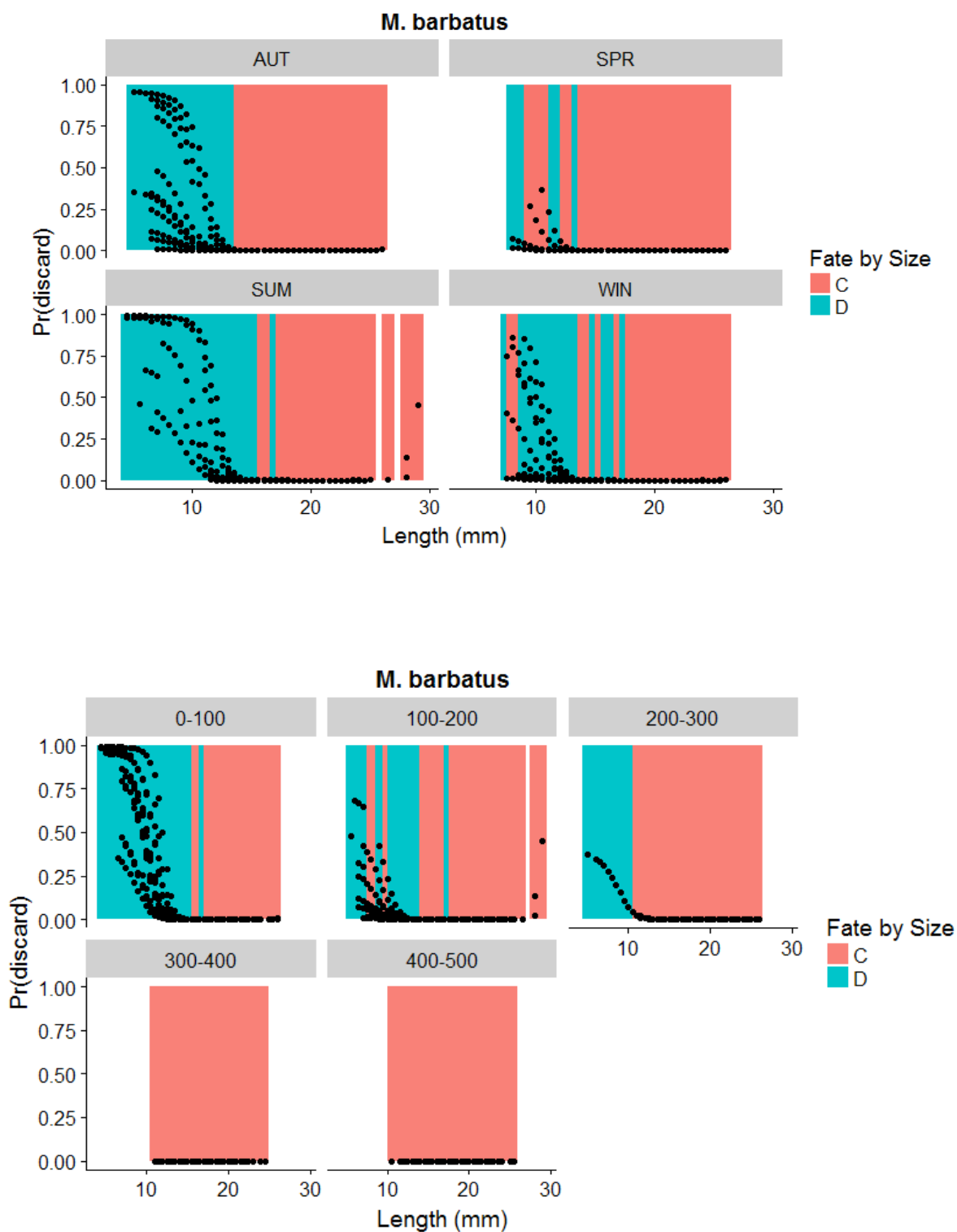


Fig. S4e: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top-by season, bottom-by depth stratum).

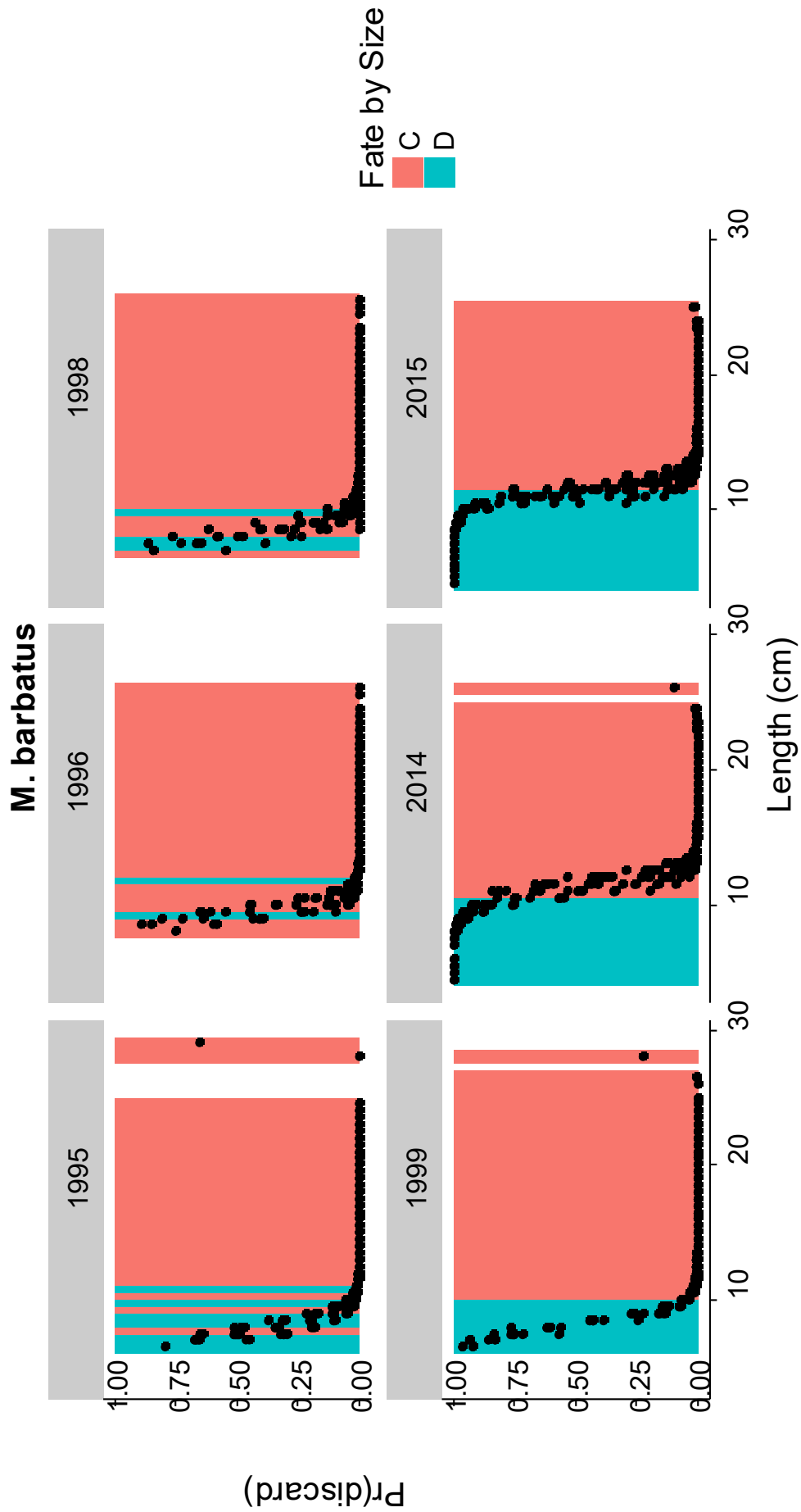


Fig. S4f: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (by year).

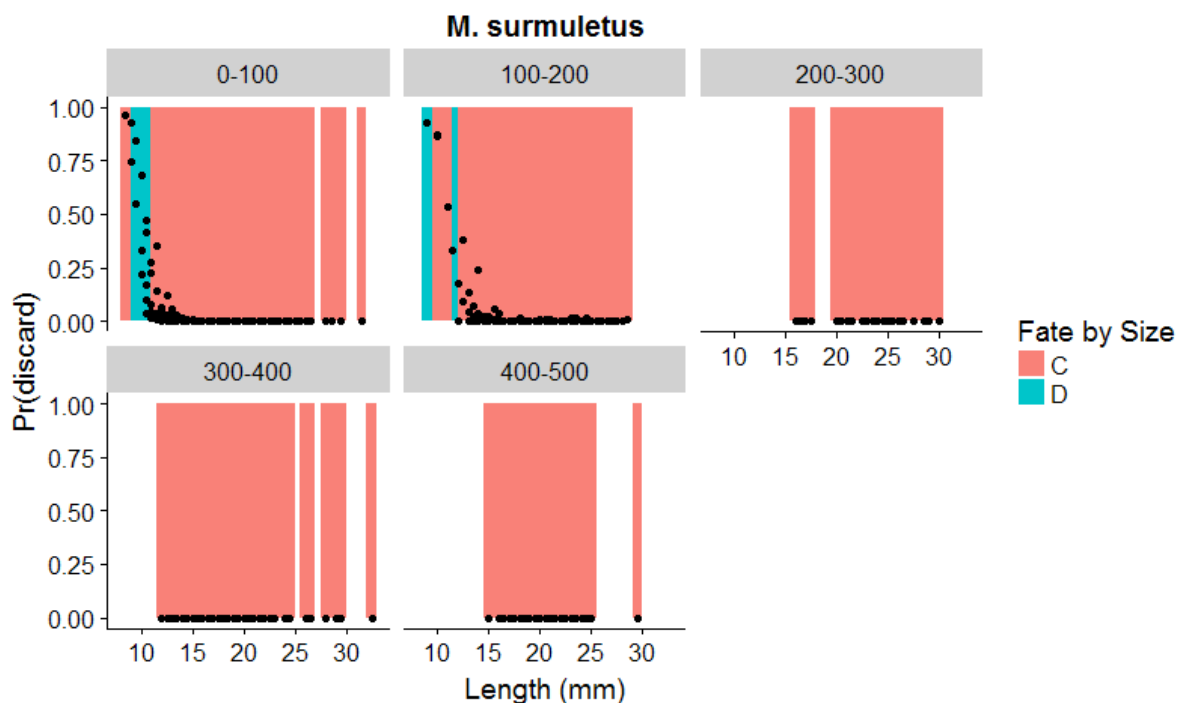
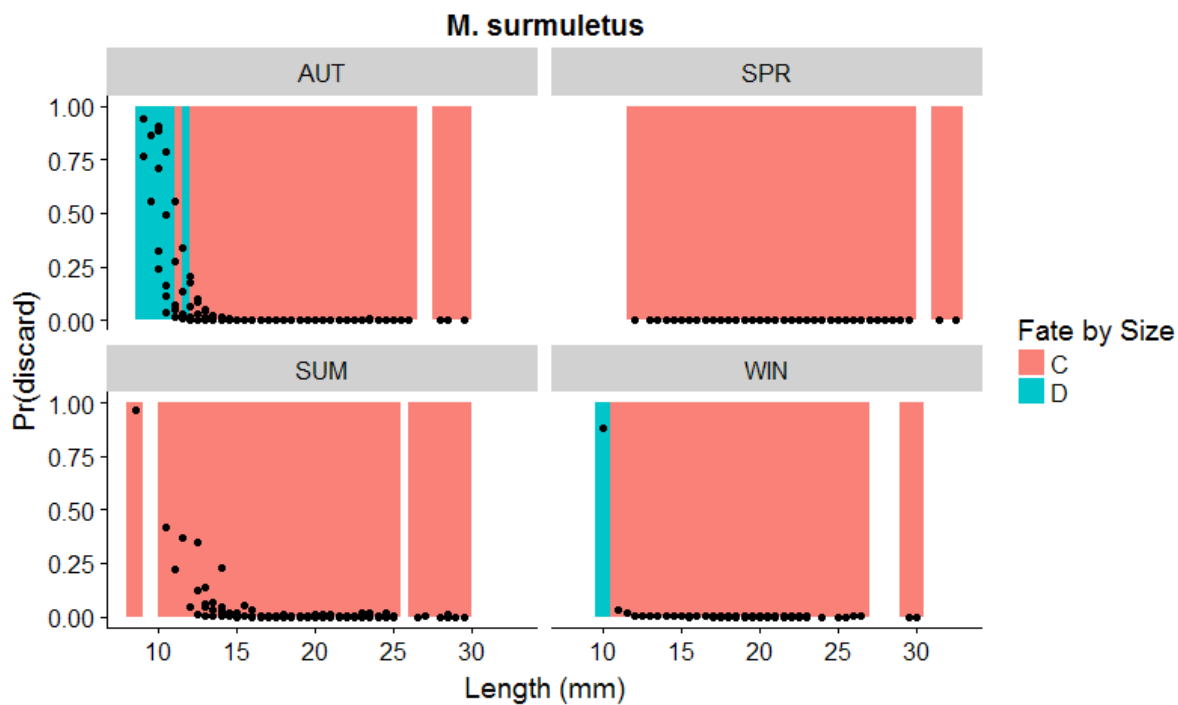


Fig. S4g: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top-by season, bottom-by depth stratum).

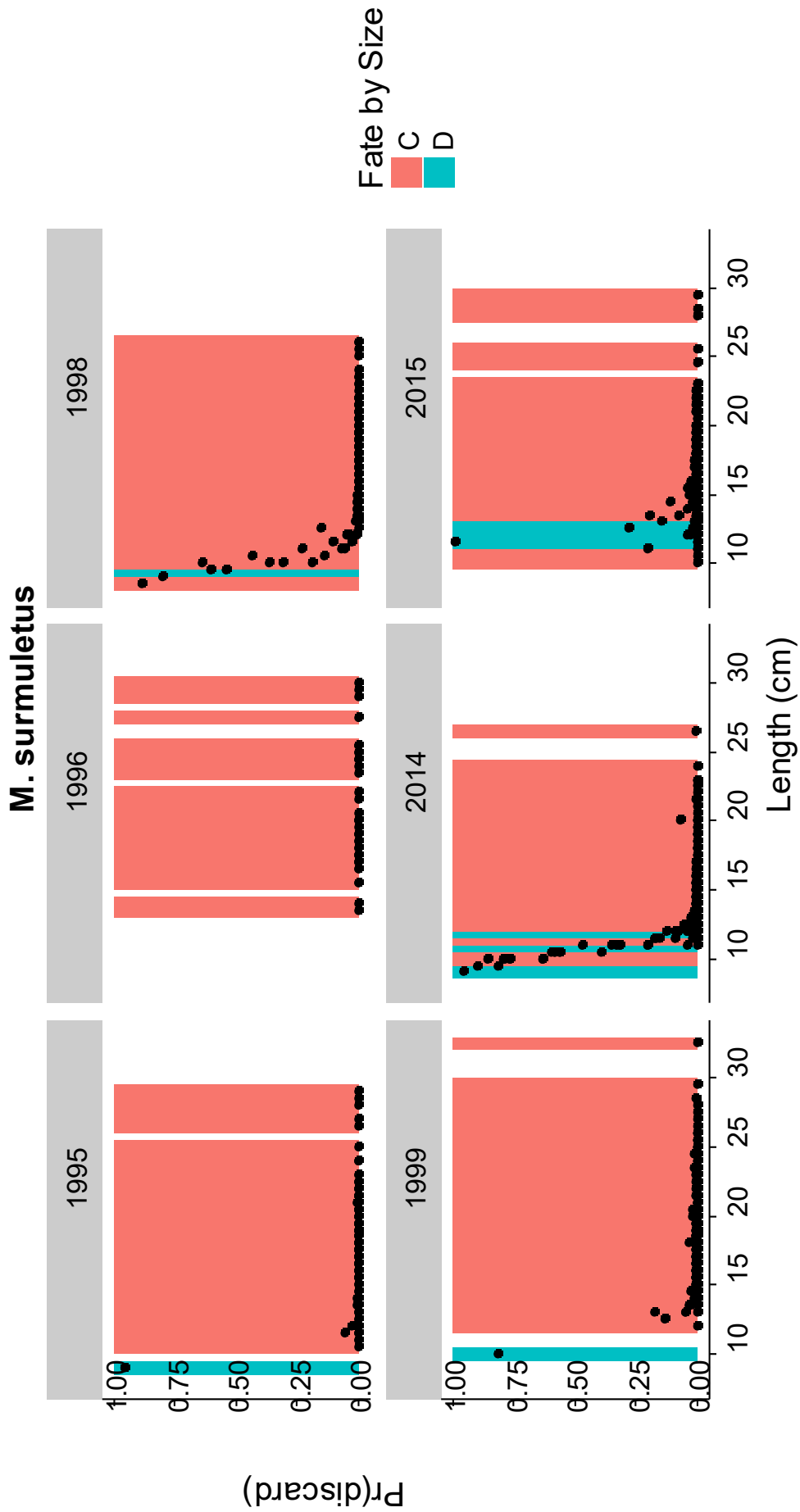


Fig. S4h: GAM derived discard probability by total length with super-imposed discard ogive for striped red mullet (by year).

Boops boops

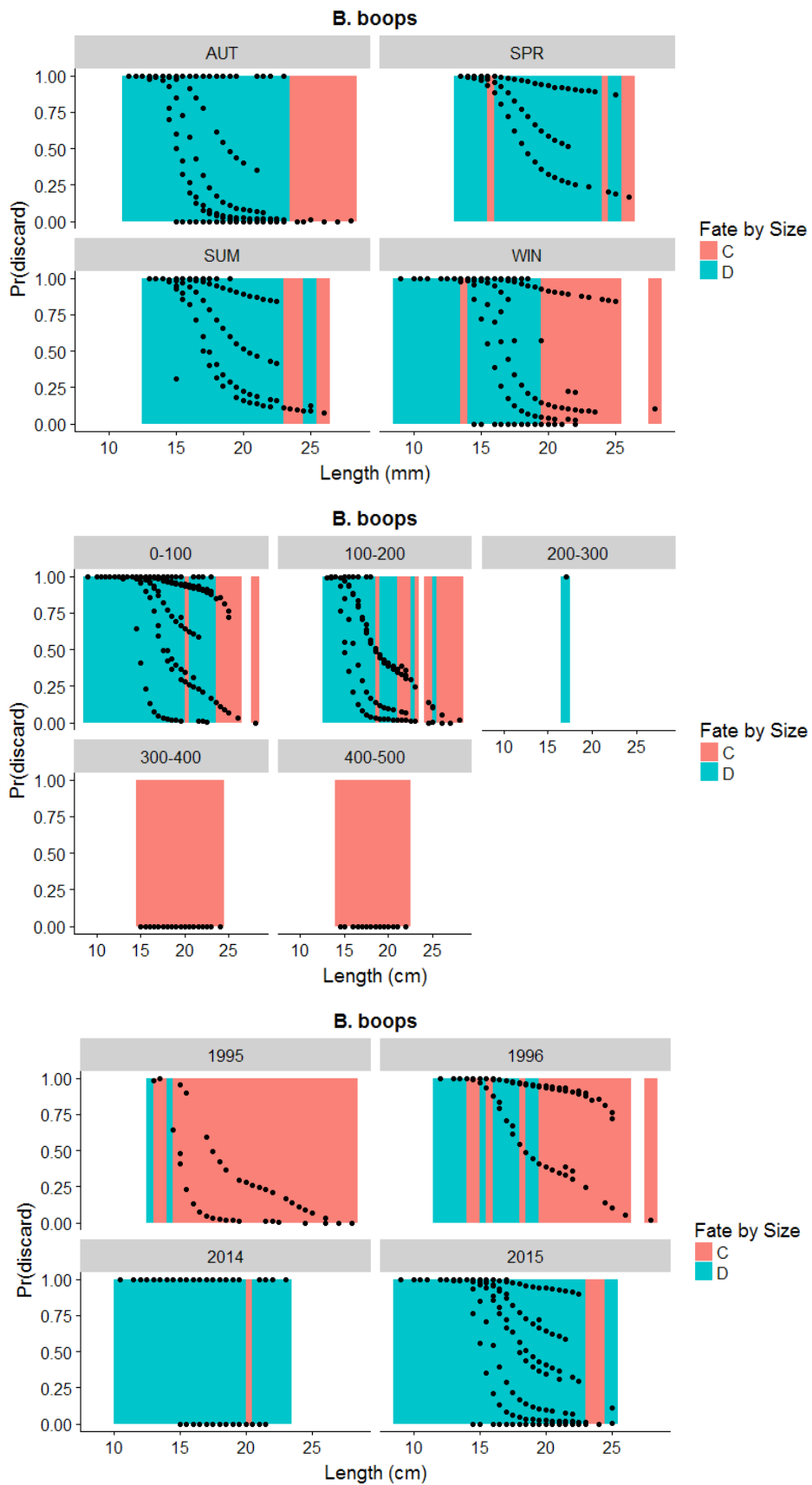


Fig. S4i: GAM derived discard probability by total length with super-imposed discard ogive for bogue (top-by season, mid-by depth stratum, bottom-by Year)