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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 mul- let	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	Vessel ITA9	21.5%	28.0%	
Tyrrnenian seas	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)

% of landings in total landings during 1995-2015	Vessel ID	Hake	Red mul- let	Deep water rose shrimp
	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%
Aegean Sea & Crete	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 pespele- cani	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 rhomboi- des	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 liv- idus	Cassidaria spp.
Parastichopus re- galis	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
	Fish	139	24181	123	46138
	Crustaceans	13	6948	20	33519
Aegean Sea	Cepaholopods	23	2107	16	13078
and Crete	Invertebrates (other than crustaceans & cephalopods)	15	6272	1	1
	Fish	151	7771	136	17490
N. Tyrrhenian & Ligurian Sea	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:

 $DCPUEW + 0.1 \sim as.factor(year) + as.factor(season) + s(depth) +$

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

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

GSA9 Ligurian and north Tyrrhenian seas



Fig. S1a: Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **inverte-brate** 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. S3c: GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top- by season, bottom-by depth stratum).







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. 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).



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).





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. 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)