A cross-scale trophic cascade from large predatory fish to algae in coastal ecosystems

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APPENDIX A

List of all fish species collected with gillnets (total 129) in 32 bays along the Swedish central Baltic Sea coast (see Methods). Total weight (Kg) is the sum of fish individual biomass estimated using species-specific length:weight conversion factors (in the Swedish national database for coastal fish, http://www.slu.se/kul). When we could not retrieve conversion factors, NA is reported for total weight. Total abundance (number of individuals) is given for all species.

Scientific name	**Common name**	**Total weight (Kg)**	**Total abundance (n)**
Abramis brama	Bream	32.33	57
Alburnus alburnus	Bleak	24.07	2946
Ammodytes tobianus	Lesser sandeel	NA	4
Blicca bjoerkna	White bream	10.86	283
Carassius carassius	Crucian carp	1.25	1
Clupea harengus	Baltic herring	7.17	233
Coregonus lavaretus	Whitefish	1.04	1
Esox lucius	Pike	70.86	40
Gasterosteus aculeatus	Three-spined stickleback	29.73	13854
Gobius niger	Black goby	0.05	7
Gymnocephalus cernuus	Ruffe	18.91	910
Hyperoplus lanceolatus	Great sandeel	0.12	9
Leuciscus idus	Ide	7.65	16
Myoxocephalus scorpius	Shorthorn sculpin	1.71	10
Nerophis ophidion	Straightnose pipefish	0.01	34
Osmerus eperlanus	Smelt	1.77	121
Perca fluviatilis	Perch	209.16	1847
Phoxinus phoxinus	Minnow	NA	46

Platichthys flesus	Flounder	0.03	2
Pomatoschistus minutus, P. microps	Sand goby, common goby	0.04	55
Pungitius pungitius	Ninespined stickleback	0.32	447
Rutilus rutilus	Roach	117.96	3498
Salmo trutta	Trout	1.86	2
Sander lucioperca	Pike-perch	0.20	1
Scardinius erythrophthalmus	Rudd	2.28	25
Spinachia spinachia	Fifteen-spined stickleback	0.01	1
Sprattus sprattus	Sprat	0.27	27
Syngnathus typhle	Broadnosed pipefish	0.01	3
Tinca tinca	Tench	17.00	15
Zoarces viviparus	Eelpout	0.31	9

APPENDIX B

Predation intensity assay - Methods

To complement our correlative survey data with measurements of a key ecological process that links the mobile fish communities with the more sessile benthic community, we used a tethering assay [1] in 17 of the bays to estimate predation intensity on gammarids; one of the most efficient grazers on epiphytic macroalgae [2,3]. Tethering is a standard ecological method that can be successfully used to estimate relative differences in predation intensity across space and/or time [4]. Gammarids (2-9 mm long) collected in the field were individually glued to the tip of a 12 cm long transparent monofilament line (0.04 mm) attached to the end of a 30 cm-long acrylic transparent rod. Laboratory tests showed that gluing did not affect gammarid survival over 24h (unpublished data). In each bay, 10 to 14 rods were vertically inserted into the sediment 1-2 m apart, along a transect at 0.5-1.8 m depth. The tethered gammarids were deployed at 4-7 pm, and retrieved and scored for predation at 7-10 am the following morning. We estimated predation intensity per bay (PI) as:

$$PI = 100 * (N_E + N_{PE}) / (N_{TOT} - N_M - N_D)$$

where N_E and N_{PE} are the numbers of prey eaten and partially eaten, respectively, N_{TOT} is the total number of prey deployed in the bay and N_M and N_D are the numbers of prey moulted and dead.

Previous studies show that not only three-spined stickleback but also small perch feed on gammarids [5]. Furthermore, predation intensity may be influenced by vegetation density, which affects predator and prey abundances as well as predator-prey encounter rate [6,7]. To test effects of different predators, vegetation cover and their interaction on predation intensity across bays, we fitted multiple linear regressions with square-root transformed values of predation intensity as the response variable. As explanatory factors we included bay averages of total vegetation cover, biomass of either sticklebacks or perch (which were negatively collinear and could not be included in the same model), and their interaction with vegetation cover.

Predation intensity assay - Results

Bay-level stickleback biomass explained 41% of predation intensity on tethered gammarids (*r* = -0.68, *n* = 17, *P* = 0.003, adjusted R^2 = 0.41), strongly supporting the idea that stickleback predation contributes to control grazer densities in shallow coastal bays. Bay-level perch biomass and vegetation cover did not explain predation intensity, nor did the interaction between vegetation cover and either perch or stickleback biomass.

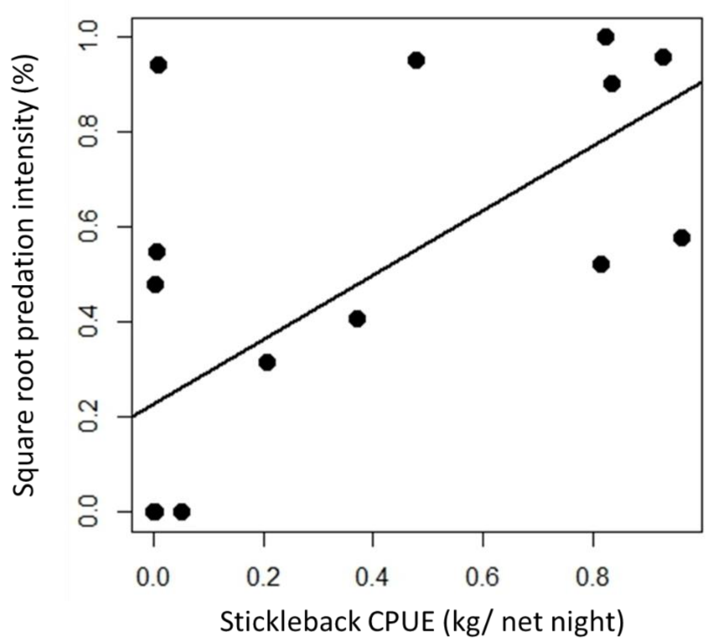

Fig. B1. Scatter plot of bay-level stickleback biomass and predation intensity on tethered gammarids and regression line (*r* = 0.68, *P* = 0.003, *n* = 17, adjusted R^2 = 0.41).

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APPENDIX C

List of species included as epiphytic algae in the analyses.

Chlorophyta
Cladophora spp.[a]
Mougeotia
Unidentified uniseriate spp.[b]
Cyanophycae
Unidentified uniseriate spp.[c]
Phaeophyceae
Dictyosiphon foeniculaceus
Ectocarpus siliculosus
Elachista fucicola
Pylaiella littoralis
Rhodophyta

Ceramium tenuicorne
Polysiphonia fucoides

[a] *Cladophora glomerata*, *C. rupestris* and *C. fracta*, [b] *Ulothrix* spp., *Urospora* spp. and *Spirogyra* spp., [c] *Lyngbya* spp., *Tolypothrix* spp. and *Rivularia* spp. previously observed in the system [1,2].

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APPENDIX D

List of species identified as macroalgal grazers, i.e. shredders and gatherers whose diet includes large proportion of plant material.

Crustacea
Asellus aquaticus
Gammarus spp.
Gammarus duebeni
Gammarus locusta
Gammarus oceanicus
Gammarus salinus
Gammarus zaddachi
Idotea spp.
Idotea balthica
Idotea chelipes
Hexapoda

Agraylea multipunctata (larvae)
Cataclysta lemnata (larvae)
Chironomidae (larvae, pupae)
Chrysomelidae (adults, larvae)[a]
Curculionidae (larvae)[b]
Hydroptila sp. (larvae)
Haliplus sp. (larvae)
Limnephilidae (larvae)
Pyralidae (larvae)

[a] Donaciinae spp. and [b] *Bagous* sp. previously observed in the system [1].

1. Hansen, J. P., Wikström, S. A. & Kautsky, L. 2008 Effects of water exchange and vegetation on the macroinvertebrate fauna composition of shallow land-uplift bays in the Baltic Sea. Estuar. Coast. Shelf Sci. 77, 535–547. (doi:10.1016/j.ecss.2007.10.013)

APPENDIX E

Effects of piscivores on grazer assemblage composition

Methods

To test whether piscivores biomass influenced the composition of the grazer assemblage across the 32 bays, we first calculated the community-weighted biomass of each of 12 grazer taxa found (i.e. their relative contribution to total biomass) at the bay scale. Second, we used a permutational multivariate analysis of variance (PERMANOVA, 9999 permutations) to test whether piscivores biomass affected grazer composition (based on Bray-Curtis dissimilarities), and included salinity, plant cover and bay openness as covariates, using the *adonis* function in the vegan R package, version 2.4-1 [1]. Finally, we visualized changes in the grazer community composition along gradients of piscivores biomass and plant cover (which were significant predictors in the PERMANOVA analysis, see below) using contour plots on a non-metric multidimensional scaling ordination model (nMDS) [2].

Results

The bay-level grazer composition was influenced by piscivores biomass ($F = 4.66$, $P = 0.007$) and plant cover ($F = 4.81$, $P = 0.007$), while salinity and bay openness had no effects ($P >> 0.05$). In bays with low piscivores biomass, the grazer assemblage was dominated by *Idotea* spp. and *Gammarus* spp., while in bays with high piscivores biomass, the assemblages were dominated by a mix of freshwater taxa including *Asellus aquaticus*, *Hydroptila* sp. and Chironomidae (Fig. E1). In bays with low plant cover, a mix of *Hydroptila*, *Asellus aquaticus* and Chironomidae dominated, while in bays with high plant cover, *Idotea* spp. and *Gammarus* spp. were prevalent (Fig. E2).

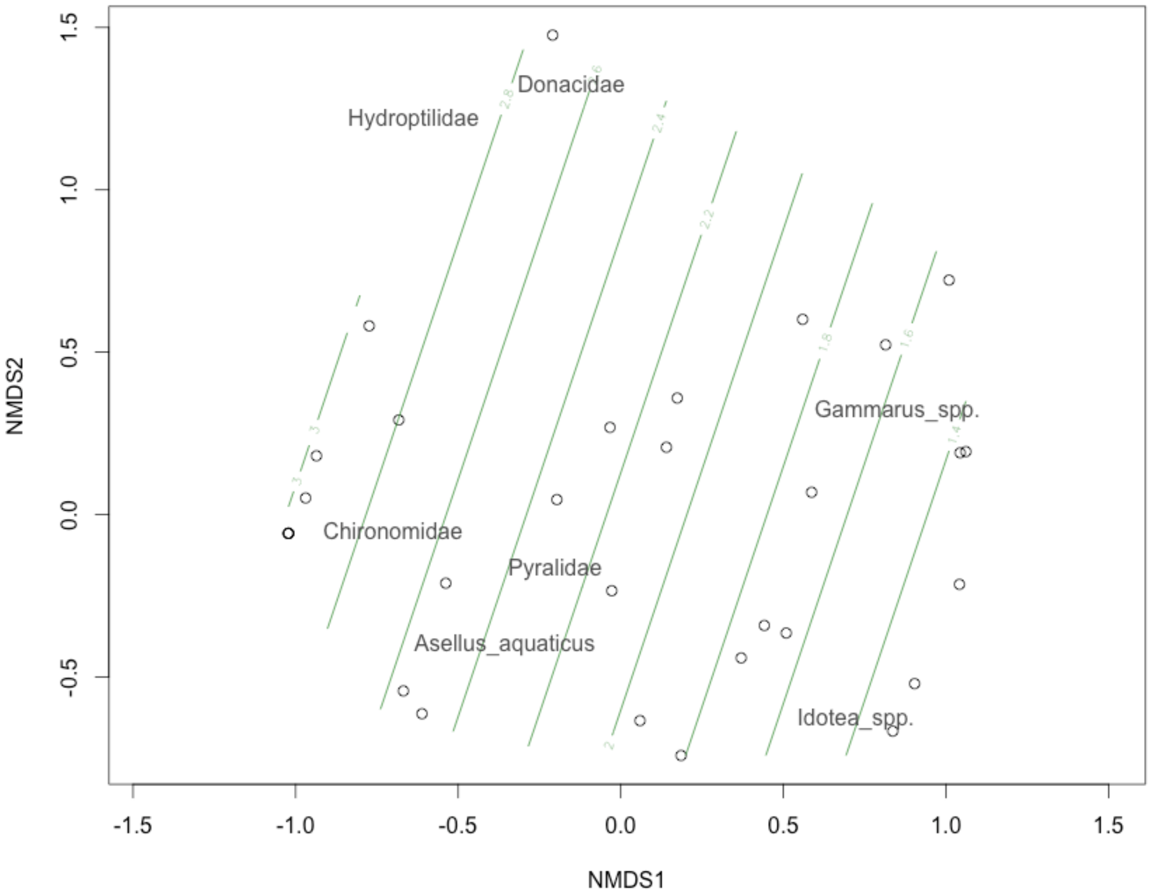

Fig. E1. NMDS plot of the grazer community composition with contours showing piscivores biomass modelled as a function of the ordination scores. Stress = 0.12. A stress value below 0.20 indicates a reliable ordination.

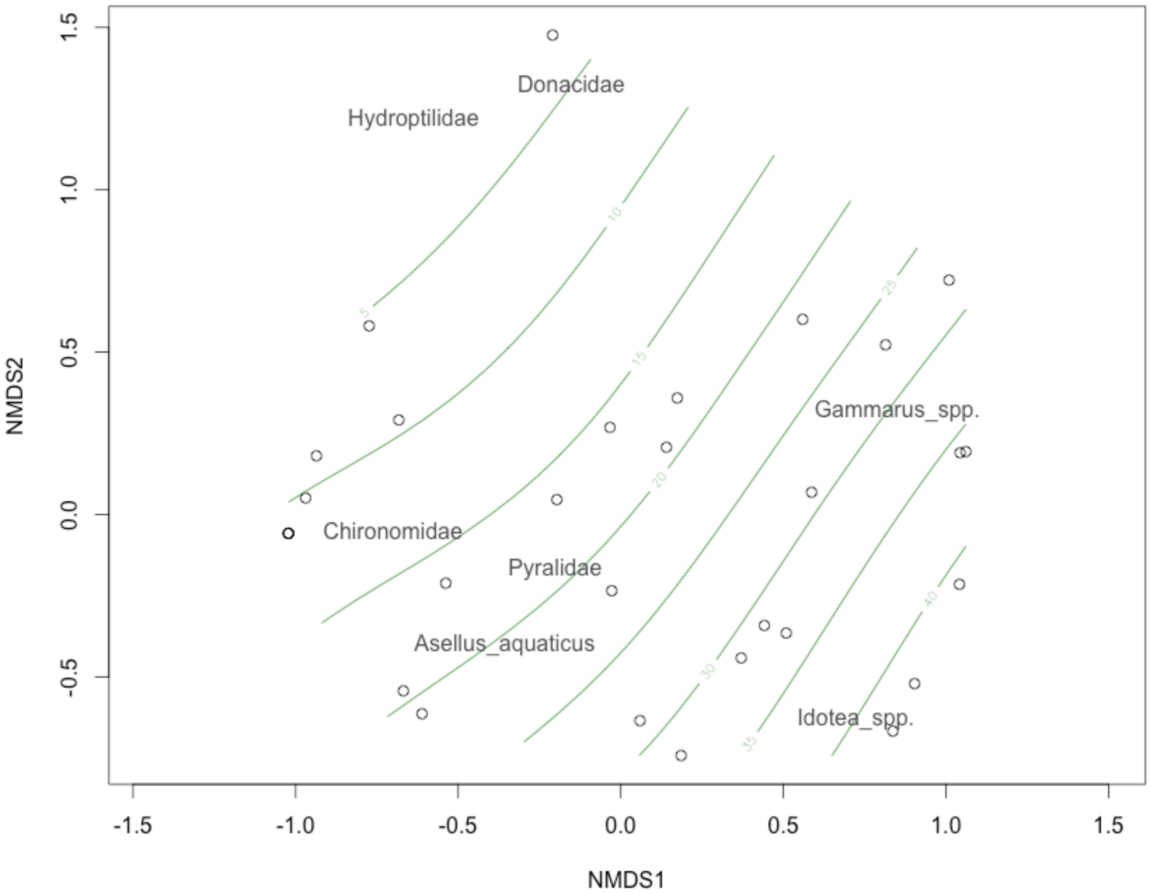

Fig. E2. NMDS plot of the grazer community composition with contours showing plant cover modelled as a function of the ordination scores. Stress = 0.12. A stress value below 0.20 indicates a reliable ordination.

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APPENDIX F

Three-spined stickleback in stomachs of perch and pike

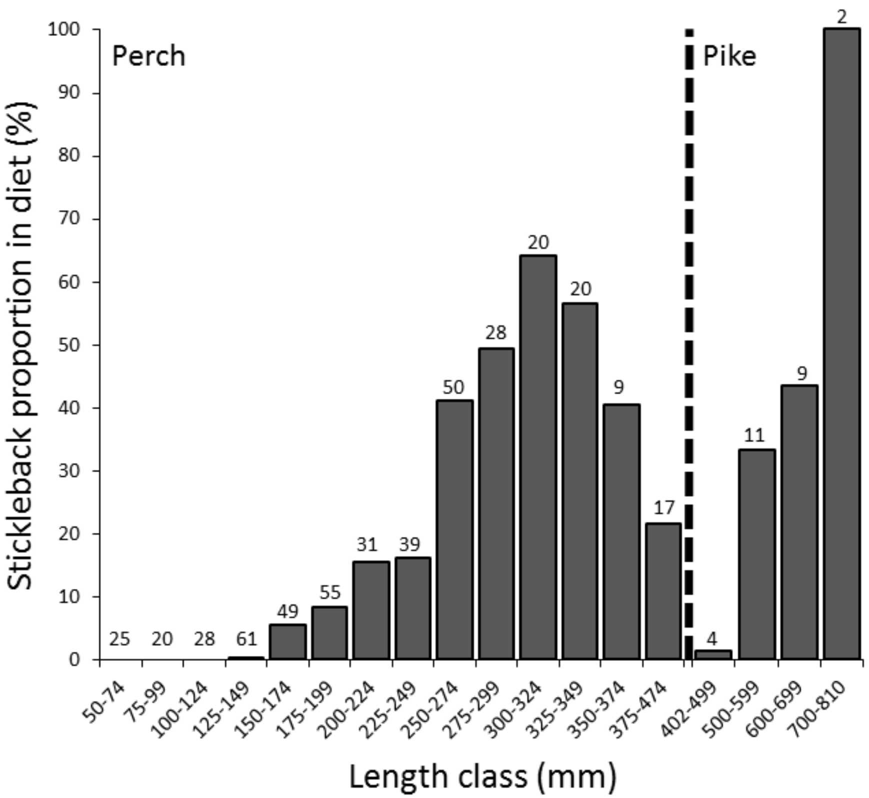

Fig. D1. Three-spined sticklebacks in stomachs of perch (left) and pike (right) expressed as percentage of total stomach content volume (following [1]). Data are shown for perch total length classes of 25 mm and pike total length classes of 100 mm. Numbers of individuals dissected for each length class are shown above bars.

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