Ecosphere

Quantifying the direct and indirect relationships linking the environment, seagrass, and their associated fauna

Jade Millot, Jacques Grall, Chirine Toumi, Marion Maguer, Aurélien Boyé

Appendix S2

Literature supporting the theoretical relationships between the environment, the seagrass bed, and the associated infauna described in Figure 2.A.

1- **Higher seagrass shoot density:**
   a. If a higher current (Orth et al., 1984)
   b. If lower water temperature (Ehlers et al., 2008; Nejrup and Pedersen, 2008)
   c. If higher grain size (Folmer et al., 2012)

2- **Higher aboveground biomass:**
   a. If lower current (Boyé et al., 2022)
   b. If lower water temperature (Nejrup and Pedersen, 2008)
   c. Depends on shoot density (Vieira et al, 2018)

3- **Higher belowground biomass:**
   a. If a higher current (Fonseca and Bell, 1998)
   b. If lower water temperature (Nejrup and Pedersen, 2008)

4- **Higher drifting algae biomass:**
   a. If a higher current (Boström and Bonsdorff, 2000) or lower (Biber, 2007)
   b. If higher water temperature (Rasmussen et al., 2013)
   c. If higher seagrass shoot density (Boström and Bonsdorff, 2000)

5- **Higher organic matter rate in sediment:**
   a. If higher seagrass shoot density (Herkül and Kotta, 2009)
   b. If higher aboveground biomass (Herkül and Kotta, 2009)
   c. If higher belowground biomass (Kenworthy and Thayer, 1984)
   d. If higher drifting algae biomass (Harrold et al., 1998)
   e. If a lower current (Fonseca and Bell, 1998)

6- **Higher grain size:**
   a. If a higher current (Fonseca and Bell, 1998)

7- **Higher infauna abundance and alpha diversity:**
    a. Depends on sedimentary composition (Gray and Elliott, 2009; Sanders, 1958)
    b. If higher organic matter rate in sediment (Pearson, 1978)
    c. If higher seagrass shoot density (Rodil et al., 2021) or lower (Cimon et al., 2021)
    d. Depends on aboveground biomass (Attrill et al., 2000)
    e. If higher belowground biomass (Orth et al., 1984)
    f. Depends on drifting algae biomass (Norkko et al., 2000) or if lower drifting algae biomass (Heery, 2018)
8- **Infauna beta diversity:**
    a. Depends on seagrass shoot density (Boström et al., 2006)
    b. Depends on aboveground biomass (Rodil et al., 2021)
    c. Depends on belowground biomass (Rodil et al., 2021)
    b. Depends on drifting algae biomass (Holmquist, 1994; Rodil et al., 2021; Quillien et al., 2015)

Literature supporting the theoretical relationships between the environment, the seagrass bed, and the associated epifauna described in Figure 2.B.

1- **Higher shoot density:**
    a. If higher current (Boyé et al., 2022)
    b. If lower water temperature (Ehlers et al., 2008; Nejrup and Pedersen, 2008)
2- **Higher aboveground biomass:**
    a. If lower current (Boyé et al., 2022)
    b. If lower water temperature (Nejrup and Pedersen, 2008)
    c. Depends on shoot density (Vieira et al, 2018)
3- **Higher epiphytic biomass:**
    a. If lower water temperature (Penhale, 1977)
    b. If higher seagrass shoot density (Whalen et al., 2013)
    c. If higher aboveground biomass (Whalen et al., 2013)
4- **Higher drifting algae biomass:**
    a. If higher current (Boström and Bonsdorff, 2000) or lower (Biber, 2007)
    b. If higher water temperature (Rasmussen et al., 2013)
    c. If higher seagrass shoot density (Boström and Bonsdorff, 2000)

5- **Higher epifauna abundance and alpha diversity:**
    a. If higher seagrass shoot density (Rodil et al., 2021) or lower (Cimon et al., 2021)
    b. Depends on aboveground biomass (Attrill et al., 2000)
    c. If higher epiphytic biomass (Bologna and Heck, 1999; Edgar and Robertson, 1992; Gartner et al., 2013)
    d. If higher drifting algae biomass (Harrold et al., 1998)
6- **Epifauna beta diversity:**
    a. Depends on shoot density (Whippo et al., 2018; Rodil et al., 2021)
    b. Depends on aboveground biomass (Rodil et al., 2021)
    c. Depends on epiphytic ratio (Whippo et al., 2018)
    d. Depends on drifting algae biomass (Salovius et al., 2005)

References:

Attrill, M.J., Strong, J.A., Rowden, A.A., 2000. Are macroinvertebrate communities influenced by seagrass structural complexity? Ecography 23, 114–121. https://doi.org/10.1111/j.1600-0587.2000.tb00266.x

Biber, P.D., 2007. Transport and persistence of drifting macroalgae (Rhodophyta) are strongly influenced by flow velocity and substratum complexity in tropical seagrass habitats. Mar. Ecol. Prog. Ser. 343, 115–122. https://doi.org/10.3354/meps06893

Bologna, P.A.X., Heck, K.L., 1999. Macrofaunal associations with seagrass epiphytes: Relative importance of trophic and structural characteristics. J. Exp. Mar. Biol. Ecol. 242, 21–39. https://doi.org/10.1016/S0022-0981(99)00092-1

Boström, C., Bonsdorff, E., 2000. Zoobenthic community establishment and habitat complexity the importance of seagrass shoot-density, morphology and physical disturbance for faunal recruitment. Mar. Ecol. Prog. Ser. 205, 123–138. https://doi.org/10.3354/meps205123

Boström, C., O'Brien, K., Roos, C., Ekebom, J., 2006. Environmental variables explaining structural and functional diversity of seagrass macrofauna in an archipelago landscape. J. Exp. Mar. Biol. Ecol. 335, 52–73. https://doi.org/10.1016/j.jembe.2006.02.015

Boyé, A., Gauthier, O., Becheler, R., Le Garrec, V., Hily, C., Maguer, M., Grall, J., 2022. Drivers and limits of phenotypic responses in vulnerable seagrass populations: *Zostera marina* in the intertidal. J. Ecol. 110, 144–161. https://doi.org/10.1111/1365-2745.13791

Cimon, S., Deslauriers, A., Cusson, M., 2021. Multiple stressors and disturbance effects on eelgrass and epifaunal macroinvertebrate assemblage structure. Mar. Ecol. Prog. Ser. 657, 93–108. https://doi.org/10.3354/meps13546

Edgar, G.J., Robertson, A.I., 1992. The influence of seagrass structure on the distribution and abundance of mobile epifauna: pattern and process in a Western Australian *Amphibolis* bed. J. Exp. Mar. Biol. Ecol. 160, 13–31. https://doi.org/10.1016/0022-0981(92)90107-L

Ehlers, A., Worm, B., Reusch, T.B.H., 2008. Importance of genetic diversity in eelgrass *Zostera marina* for its resilience to global warming. Mar. Ecol. Prog. Ser. 355, 1–7. https://doi.org/10.3354/meps07369

Folmer, E.O., van der Geest, M., Jansen, E., Olff, H., Michael Anderson, T., Piersma, T., van Gils, J.A., 2012. Seagrass–Sediment Feedback: An Exploration Using a Non-recursive Structural Equation Model. Ecosystems 15, 1380–1393. https://doi.org/10.1007/s10021-012-9591-6

Fonseca, M.S., Bell, S.S., 1998. Influence of physical setting on seagrass landscapes near Beaufort, North Carolina, USA. Mar. Ecol. Prog. Ser. 171, 109–121. https://doi.org/10.3354/meps171109

Gartner, A., Tuya, F., Lavery, P.S., McMahon, K., 2013. Habitat preferences of macroinvertebrate fauna among seagrasses with varying structural forms. J. Exp. Mar. Biol. Ecol. 439, 143–151. https://doi.org/10.1016/j.jembe.2012.11.009

Gray, J.S., Elliott, M., 2009. Ecology of Marine Sediments: From Science to Management. Oxford University Press.

Harrold, C., Light, K., Lisin, S., 1998. Organic enrichment of submarine-canyon and continental-shelf benthic communities by macroalgal drift imported from nearshore kelp forests. Limnol. Oceanogr. 43, 669–678. https://doi.org/10.4319/lo.1998.43.4.0669

Heery, E.C., 2018. Reduced macrofauna diversity and abundance in response to red macroalgal detritus. J. Exp. Mar. Biol. Ecol. 505, 1–8. https://doi.org/10.1016/j.jembe.2018.04.004

Herkül, K., Kotta, J., 2009. Effects of eelgrass (*Zostera marina*) canopy removal and sediment addition on sediment characteristics and benthic communities in the Northern Baltic Sea. Mar. Ecol. 30, 74–82. https://doi.org/10.1111/j.1439-0485.2009.00307.x

Holmquist, J.G., 1994. Benthic macroalgae as a dispersal mechanism for fauna: influence of a marine tumbleweed. J. Exp. Mar. Biol. Ecol. 180, 235–251. https://doi.org/10.1016/0022-0981(94)90069-8

Kenworthy, J.W., Thayer, G.W., 1984. Production and Decomposition of the Roots and Rhizomes of Seagrasses, *Zostera Marina* and *Thalassia Testudinum*, in Temperate and Subtropical Marine Ecosystems. Bull. Mar. Sci. 35, 364–379.

Nejrup, L.B., Pedersen, M.F., 2008. Effects of salinity and water temperature on the ecological performance of *Zostera marina*. Aquat. Bot. 88, 239–246. https://doi.org/10.1016/j.aquabot.2007.10.006

Norkko, J., Bonsdorff, E., Norkko, A., 2000. Drifting algal mats as an alternative habitat for benthic invertebrates: Species specific responses to a transient resource. J. Exp. Mar. Biol. Ecol. 248, 79–104. https://doi.org/10.1016/S0022-0981(00)00155-6

Orth, R.J., Heck, K.L., van Montfrans, J., 1984. Faunal communities in seagrass beds: A review of the influence of plant structure and prey characteristics on predator-prey relationships. Estuaries 7, 339–350. https://doi.org/10.2307/1351618

Pearson, T.H., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Ocean. Mar Biol Ann Rev 16, 229–311.

Penhale, P.A., 1977. Macrophyte-epiphyte biomass and productivity in an eelgrass (*Zostera marina*) community. J. Exp. Mar. Biol. Ecol. 26, 211–224. https://doi.org/10.1016/0022-0981(77)90109-5

Quillien, N., Nordström, M.C., Gauthier, O., Bonsdorff, E., Paulet, Y.-M., Grall, J., 2015. Effects of macroalgal accumulations on the variability in zoobenthos of high-energy macrotidal sandy beaches. Mar. Ecol. Prog. Ser. 522, 97–114. https://doi.org/10.3354/meps11151

Rasmussen, J.R., Pedersen, M.F., Olesen, B., Nielsen, S.L., Pedersen, T.M., 2013. Temporal and spatial dynamics of ephemeral drift-algae in eelgrass, *Zostera marina*, beds. Estuar. Coast. Shelf Sci. 119, 167–175. https://doi.org/10.1016/j.ecss.2013.01.006

Rodil, I.F., Lohrer, A.M., Attard, K.M., Hewitt, J.E., Thrush, S.F., Norkko, A., 2021. Macrofauna communities across a seascape of seagrass meadows: environmental drivers, biodiversity patterns and conservation implications. Biodivers. Conserv. 30, 3023–3043. https://doi.org/10.1007/s10531-021-02234-3

Sanders, H.L., 1958. Benthic Studies in Buzzards Bay. I. Animal-Sediment Relationships1. Limnol. Oceanogr. 3, 245–258. https://doi.org/10.4319/lo.1958.3.3.0245

Salovius, S., Nyqvist, M., Bonsdorff, E., 2005. Life in the fast lane: macrobenthos use temporary drifting algal habitats. Journal of Sea Research 53, 169–180. https://doi.org/10.1016/j.seares.2004.05.001

Vieira, V.M.N.C.S., Lopes, I.E., Creed, J.C., 2018. The biomass–density relationship in seagrasses and its use as an ecological indicator. BMC Ecol. 18, 44. https://doi.org/10.1186/s12898-018-0200-1

Whalen, M.A., Duffy, J.E., Grace, J.B., 2013. Temporal shifts in top-down vs. bottom-up control of epiphytic algae in a seagrass ecosystem. Ecology 94, 510–520. https://doi.org/10.1890/12-0156.1

Whippo, R., Knight, N.S., Prentice, C., Cristiani, J., Siegle, M.R., O'Connor, M.I., 2018. Epifaunal diversity patterns within and among seagrass meadows suggest landscape-scale biodiversity processes. Ecosphere 9, e02490. https://doi.org/10.1002/ecs2.2490