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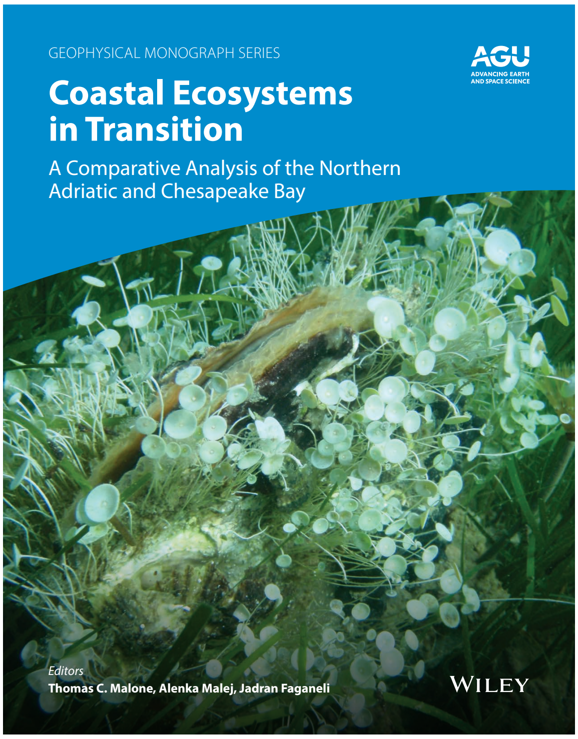

BOOK VIEW

by Alenka MALEJ, Davor LUČIĆ, Jadran FAGANELI and Jakov DULČIĆ

Coastal Ecosystems in Transition: A Comparative Analysis of the Northern Adriatic and Chesapeake Bay

A new book, entitled Coastal Ecosystems in Transition: A Comparative Analysis of the Northern Adriatic and Chesapeake Bay (AGU Wiley, New Jersey) edited by T.C. Malone, A. Malej and J. Faganeli, reports the comparison of ecosystems of the northern Adriatic and the Chesapeake Bay. It enlarges our knowledge of anthropogenic pressures on coastal ecosystems where is concentrated the majority of the population and the exploitation of natural resources. The topics are focused on demonstration and evaluation of changes over the last twenty years in the context of global climate change, an assessment of the success of management efforts, and the reduction of anthropogenic pressures on coastal ecosystems. The book builds on our knowledge of the effects of human activities on coastal ecosystems in which natural resources have been overexploited.

The book covers 11 chapters, participated by reputable American, Croatian, Slovenian and Italian scientists: 1. Introduction-Coastal Ecosystem Services (T. Malone, A. Malej, J. Faganeli); 2. Recent Status and, Long-Term Trends in Freshwater Discharge and Nutrient Inputs (Q. Zhang, S. Cozzi, C. Palinkas, M. Giani); 3. Sea State: Recent Progress in the Context of Climate Change (W.V. Boicurt, M. Ličer, M. Li, M. Vodopivec, V. Malačič); 4. Phytoplankton Dynamics in a Changing Environment (M.J. Brush, P. Mozetič, J. France', F. Bernardi Aubry, T. Djakovac, J. Faganeli, L. Harris, M. Niesen); 5. Eutrophication, Harmful Algae, Oxygen Depletion, and Acidification (M. Brush, M. Giani, C. Totti, J. Testa, J. Faganeli, N. Ogrinc, M. Kemp, S. Fonda Umani); 6. Mesozooplankton and Gelatinous Zooplankton in the Face of Environmental Stressors (J. Pierson, E. Camatti, R. Hood, T. Kogovšek, D. Lučić, V. Tirelli, A. Malej); 7. Ecological Role of Microbes: Current Knowledge and Future Prospects (V. Turk, S. Malkin, M. Celussi, T. Tinta, J. Cram, F. Malfatti, F. Chen); 8. Advances in Our Understanding of Pelagic–Benthic Coupling ((J.M. Testa, J. Faganeli, M. Giani, M.J. Brush, C. de Vittor, S. Covelli, W.R. Boynton, W.M. Kemp, N. Kovač, R. Woodland); 9. Status of Critical Habitats and Invasive Species (C. Palinkas, M. Mistri, L. Staver, L. Lipej, P. Kružić, J. Court Stevenson, M. Tamburri, C. Munari, M. Orlando Bonaca); 10. Status of Fish and Shellfish Stocks (V.S. Kenneddy, L. Bolognini, J. Dulčić, R.J. Woodland, M.J. Wilberg, L.A. Harris); 11. Ecosystem-Based Management of Multiple Pressures: Summary and Conclusions (A. Malej, J. Faganeli, T. Malone). Comprehensively, the processed contents included descriptions of ecological features, anthropogenic impact, monitoring and modeling of ecosystems.

1. KEY ECOLOGICAL FEATURES OF THE NORTHERN ADRIATIC SEA (NA) AND CHESAPEAKE BAY (CB)

1.1 Riverine inputs

Large inputs of freshwater, nutrients and suspended sediments are important drivers of ecosystem functioning of both, the Chesapeake Bay (CB) and the northern Adriatic Sea (NA). These two coastal systems are characterized by similar annual inputs of freshwater from rivers and precipitation, although their morphology differs with a shallower and more extended basin for the CB and a larger and deeper marine area for NA. The annual cycle of river flow into CB is unimodal with a spring peak while that for the NA Po River discharge is bimodal with peaks during winter-spring and autumn. Both systems are currently impacted by large overloads of N compared to P.

In the NA, sediments transported by rivers accumulate in a zone of active sedimentation parallel to the west coast. The most important depositional location is found around the Po River delta where accumulation rates are 2-6 cm y^{-1}, compared to ~0.4 and ~1 mm y^{-1} in the eastern part of the NA and central part of the Gulf of Trieste, respectively. Fine sands accumulate in a near-shore strip, paralleled by an offshore mud belt and by a further offshore zone of relict sands. Most of the deeper regions of the NA receive little or no sediment at present, and Holocene coastal sands constitute the majority of sediments. In the eastern part of the NA, recent sedimentation of terrestrial sediments and autochthonous skeletal material is significant only along the W Istrian coast. Suspended sediments are distributed within the CB estuary as a function of sediment size and type. Average deposition rates to CB sediments approach 1.3 cm y^{-1}, but large flood events associated with tropical storms can deposit much larger amounts (~4 cm) within weeks. The sand component of sediment inputs is typically deposited in the shallow oligohaline Bay while deeper parts of the oligohaline and of the mesohaline are characterized by pelite. Shoreline erosion is also a significant source of sediments.

1.2 Physical environment

During the absence of wind forcing in NA, basin wide, cyclonic coastal flow is established under the influence of buoyancy and Earth rotation, promoting the southward advection of Po River water via the Western Adriatic boundary Current (WAC). Wind stress modifies this pattern. Winds that are downwelling-favorable in the western NA (e.g., winter boras) confine the plume to the narrow western Adriatic shelf and enhance the southward flow of the WAC. Conversely, upwelling-favorable winds (e.g., summer sciroccos) spread low-salinity Po waters to the north and east, causing longer residence time of nutrients which promotes eutrophication and can, in exceptional situations, reverse the WAC. Global warming is projected to increase the intensity of sciroccos, and, therefore, the susceptibility of the NA to eutrophication.

In the absence of wind forcing in CB, circulation is buoyance driven resulting in a partially stratified estuary with a net seaward flow of surface water and landward flow of bottom water. Tropical storms (e.g., hurricanes) perturb this circulation by initially pushing salt water into the Bay from the continental shelf increasing sea level within the Bay. After hurricanes make landfall, the Bay's local winds (either up-estuary or down-estuary depending on the storm) modulate the salinity and velocity fields through vertical mixing and longitudinal salt transport. Up-estuary wind stress penetrates deeper into the water column reducing vertical stratification by reversing the gravitation circulation while down-estuary wind stress initially enhances stratification and then decreases stratification as wind stress increases. In both cases, increases in rainfall over the Bay's watershed may result in increases in land-based inputs of anthropogenic nutrients and the degree of eutrophication. Thus, projected increases in the intensity of tropical storms may mitigate management efforts to reduce nutrient loading resulting in a more eutrophic CB.

1.4 Phytoplankton

The annual cycle of Chl-a concentration exhibits a seasonal spring peak in both systems while a second seasonal peak occurs in the NA. Most Chl-a concentrations are <5 mg m^{-3} in the NA compared to 5-15 mg m^{-3} in CB. While Chl-a is negatively correlated with salinity in NA, being highest in the coastal plume of the Po River, Chl-a is generally the highest in the mesohaline reach of CB. Primary production in the NA ranges between 80 (offshore) and 150 (coastal areas) g C m^{-2} y^{-1} while that in the CB is about 4-times higher ranging between 350 and 660 g C m^{-2} y^{-1}. The seasonal cycles of phytoplankton productivity (peaks during summer in both systems) and biomass (which peaks during spring in both systems and during autumn in the NA) are out of phase in both ecosystems. N is generally considered to be the primary limiting nutrient in the CB while P appears to be limiting in the NA. In the NA, the P limitation is particularly expressed during spring in river plumes.

1.5 Microbial food web

Picophytoplankton, heterotrophic bacteria and Archaea, nanoflagellates and microzooplankton constitute the microbial food web that accounts for most nutrient cycling in oceanic and coastal waters. The annual cycles of picophytoplankton (dominated by *Synechococcus*) are characterized by summer maxima and winter minima in both systems, but abundance varied over a broader range in CB (10^2 to 10^6 cells ml^{-1}) than in the NA (10^3 to 10^5 cells ml^{-1}). Rates of heterotrophic bacterial activity in both systems are driven primarily by temperature during autumn, winter and spring, and by the availability of higher concentrations of dissolved organic matter during summer when bacteriophages limit bacterial abundance. The abundance of heterotrophic bacterioplankton and viral like particles (VLPs) tracked the abundance of picophytoplankton. Although bacterial productivity exhibited similar ranges in both systems (0.2 – 200 mg C m^{-3} d^{-1} in the NA, 7 – 240 mg C m^{-3} d^{-1} in CB), bacterial abundance has been an order of magnitude higher in CB (10^6-10^7 cells ml^{-1}) than in the NA (10^5 to 10^6 cells ml^{-1}). This suggests that the turnover rate of bacterioplankton is higher in the NA, a difference that may reflect the high ratio of viral like particles to bacteria in the NA compared to CB.

1.6 Mesozooplankton and gelatinous zooplankton

The species richness of mesozooplankton and gelatinous zooplankton is higher in the NA than in CB and tends to increase with increasing salinity in both systems. Copepods and meroplanktonic crustaceans dominate the mesozooplankton in CB while copepods and cladocerans dominate in the NA. The copepod *Acartia tonsa* is the most abundant copepod in the mesohaline and polyhaline reaches of CB while *Eurytemora carolleeae* is more abundant in the oligohaline reach. Given this, CB has experienced a long-term decline in the abundance of copepod taxa, a trend that has been attributed to increases in predation by ctenophores and/or increases in the spatial and temporal extent of seasonal bottom water hypoxia.

In the NA, the dominant copepod species (*Calanus helgolandicus, Ctenocalanus vanus, Pseudocalanus elongatus, Temora longicornis* and *Centropages typicus*) peak during winter-spring while the dominant species of cladocera (*Penilia avirostris* and *Evadne* spp.) peak during summer-autumn. As the Adriatic Sea warmed during 1970-2005, the abundance of small, warm water species of copepods (*Paracalanus parvus, Oncaea* spp. and *Euterpina acutifrons*) increased at the expense of larger cold water species (*Pseudocalanus elongatus, Clausocalanus* spp. and *Ctenocalanus vanus*).

The abundance of gelatinous zooplankton has increased in both systems over the past few decades (ctenophores in CB and scyphomedusae in the NA). In terms of species richness, the most striking difference is the number of hydromedusae in the NA (29) compared to CB (6). Both CB and NA have experienced large, episodic blooms of scyphozoan medusa, and both systems are home to the ctenophore *Mnemiopsis leidyi*, which is endemic to CB but invasive in the NA. Three endemic species of scyphomedusae are abundant in CB: *Chrysaora chesapeakei, Aurelia aurita*, and *Cyanea capillata*. Five scyphomedusae (*Aurelia aurita, Chrysaora hysoscella, Cotylorhiza tuberculata, Pelagia noctiluca, Rhizostoma pulmo*) form blooms and were observed regularly in the NA, and three ctenophore species (*Bolinopsis vitrea, Leucothea multicornis, M. leidyi*) form blooms in the NA.

The dominant copepods in both systems are omnivorous and graze on phytoplankton, microzooplankton, and organic detritus. Major predators on copepods in CB are gelatinous zooplankton (scyphozoans and ctenophores), forage fish and fish larvae. Major predators in the NA are hydrozoans, scyphozoans, ctenophores, chaetognaths, forage fish and fish larvae. The fate of higher trophic level consumption of copepods in both systems is very different when predation is due primarily to mesozooplankton than when gelatinous species are the dominant predators. The former supports commercially and recreationally valuable fish species via metazoan food webs while the latter supports the formation of gelatinous biomass that is, for the most part, not consumed by fish but by bacteria.

1.7 Fisheries and phytoplankton production

Both systems support economically important fisheries (finfish and shellfish species) that are heavily fished with some stocks being overfished. Just as species richness as a whole is higher in the NA, the species richness of fisheries is also higher. Fisheries in both systems exploit small, pelagic forage fish (*Engraulis encrasicolus, Sardina pilchardus*, and *Sprattus sprattus* in the NA and *Brevoortia tyrannus* in CB). Both regions harvest a variety of demersal species (*Merluccius merluccius, Mullus barbatus, Solea solea,* and *Sparus aurata* in the NA; *Micropogonias undulates, Leiostomus xanthurus*, and *Paralichthys dentatus* in CB), but only the Adriatic supports an elasmobranch fishery. Invertebrate fisheries in the Adriatic target a variety of crustaceans (*Nephrops norvegicus, Parapenaeus longirostris*, and *Penaeus kerathurus*) and mollusks (*Anadara inaequivalvis, Mytilus edulis, Chamelea gallina, Pecten jacobaeus, Tapes semidecussatus*). In contrast, invertebrate fisheries in CB target one species of crustacean (*Callinectes sapidus*) and one species of mollusk (*Crassostrea virginica*).

Total fish landings in the NA fluctuated around 140,000 tonnes yr^{-1} from 1992 to 2002 and increased to 180,000 tonnes yr^{-1} in 2016. Over the same period, landings in CB trended downward from ~350,000 tonnes yr^{-1} to < 200,000 tonnes yr^{-1}, so that landings in 2016 were roughly equivalent in the two systems. In this context it should be noted that landings in per unit surface area for CB were 3-times higher than for the NA while landings per unit phytoplankton production was 1.5x higher in the NA than in CB. Although the effect of fish migrations from adjacent waters on fish landings may be a factor, the former probably reflects the higher phytoplankton production of CB while the latter may reflect differences in pelagic-benthic coupling.

1.8 Pelagic-benthic coupling

A much lower fraction of particulate organic matter inputs (autochthonous net phytoplankton production + allochthonous river born inputs) are deposited to the benthos in the NA (19%) compared to CB (83%) indicating that most phytoplankton production in the NA is assimilated and recycled in the water column. This contrast may explain why fish landings per unit phytoplankton production is higher in the NA and is consistent with the high rate of benthic respiration in CB relative to the NA. At the same time, benthic communities respire a similar percentage of organic matter that reaches the bottom (86% in the NA, 92% in CB) including the oxidation of reduced chemical species (Mn^{2+}, Fe^{2+}, S^{2-}) produced in the anaerobic degradation of organic matter. Small DIC production by carbonate dissolution in the NA sediments occurs in the summertime. Sediment release of regenerated N is also similar in both systems, with the release of 0.3 mol N m^{-2} y^{-1} in CB and of 0.2 mol N m^{-2} y^{-1} in the NA.

Released nutrients are mostly utilized by microphytobenthos in the NA where benthic primary production accounts for about 25% of microbial primary production. Rates of denitrification are somewhat higher in CB (0.53 mol N m^{-2} y^{-1}) than in the NA (0.30 mol N m^{-2} y^{-1}) and larger fractions of deposited N and P are buried in CB than in the NA (N – 23% in NA, 45% in CB; P – 50% in NA, CB – 91%). Denitrification and burial of P in sediments, together with P depleted inflows, helps to explain why phytoplankton productivity is P limited in the NA.

2. ANTHROPOGENIC IMPACTS ON THE ECOLOGY AND ECOSYSTEM SERVICES IN THE NA AND CB

The NA and CB are both subjected to anthropogenic pressures that impact the condition of ecosystems and their capacity to support ecosystem services. Of these pressures, anthropogenic nutrient loading and climate-driven warming directly impact the broadest range of ecosystem conditions and services.

2.1 Eutrophication

For both CB and the NA, eutrophication (as indicated by loss of seagrass habitat, temporal and spatial extent of bottom water hypoxia/anoxia and frequency of toxic algal events) has a major impact on ecosystem services (Table 1). Riverine inputs of anthropogenic nitrogen (N) and phosphorus (P) are the primary drivers of eutrophication (N in CB, P in the NA) and associated ecological degradation of coastal ecosystems, e.g., habitat loss, oxygen depletion, increases in the frequency of toxic algal events, and decreases in the depth of the euphotic zone. Although both systems have long histories of nutrient-driven cultural eutrophication that accelerated during the four decades following WWII, CB is more eutrophic system-wide than is the NA where eutrophication is confined to low salinity river plumes along the north and west coasts. This being said, while both systems harbor a large number of potentially toxic phytoplankton genera including four that are common to both (*Lingulodinium*, *Prorocentrum*, *Dinophysis*, and *Alexandrium*), it appears that the NA has experienced more toxic events during recent decades. The NA also experiences unique seasonal, aperiodic mucilage events, sedimentation of which locally fuels the development of hypoxia and leads to mass benthic mortalities.

As a consequence of managed decreases in anthropogenic nutrient inputs over the last three decades, levels of eutrophication have begun to decline in both systems, but achieving the goals of the Chesapeake Bay Program (HERRMANN *et al.*, 2018) and EU-Water Framework Directive (VOULVOULIS *et al.,* 2017) remains a challenge. Since 1985, management efforts have reduced anthropogenic nutrient loading with total N loading trending downward in CB and total P trending downward in the NA. However, it is noteworthy that total P trended upward in CB and total N trended upward in the NA. As the processes of restoration proceed, it will be critically important to document recovery trajectories and to understand how these trajectories are affected by other anthropogenic stressors (and synergies among them) including climate-change, fishing pressure, and coastal development.

2.2 Climate change

Climate-driven increases in sea surface temperature (and increases in vertical stratification), the intensity of extreme wind events (increase intensity of sciroccos in the NA and tropical storms in CB), changes in annual rainfall (projected to increase in the CB watershed and decrease in the NA watershed), and sea level rise (increasing at about the same rate in both systems) are changing current fields, mixing regimes, and wave environments in both systems. These changes portend of profound impacts on the ecology of the NA and CB and on their capacity to support ecosystem services. For example:

- In the NA and its watersheds, projected decreases in annual rainfall may promote oligotrophication (APPIOTTI *et al.*, 2014) while projected increases in the CB watershed (combined with increases in water temperature) may increase the spatial and temporal extent of bottom water hypoxia despite managed reductions in anthropogenic nutrient inputs (PYKE *et al.*, 2008).
- Increases in water temperature in both systems will favor the growth of warm water species at the expense of colder water species, e.g.,
- The seagrass *Zostera marina* occurs near the southern limit of its range in both systems,

and summer warm water outbreaks have been associated with declines in their abundance. Thus, increasing temperatures associated with climate change are likely to result in the significant regression of *Z. marina*in the NA and CB.

- Increases in water temperature and/or extreme heating events may continue to increase coral reef bleaching events in the NA.
- Increasing temperatures will likely impact the success of cold-water versus warm water associated species by expanding the summer time period over which warm water species (e.g., predators such as *Chrysaora* spp.and *Mnemiopsis leidyi*) are abundant.
- In CB, it appears that the cold water adapted copepod species *Acartia hudsonica* is no longer present in CB as a consequence of increasing water temperature.
- Increases may enhance the flow of energy via microbial food webs relative to metazoan food webs.
- As sea level rises and the intensity of extreme weather (tropical storms in the CB and scirocco in the NA) increases,
- The vulnerability to coastal flooding and erosion will increase in both systems.
- Tidal marshes will be submerged reducing their spatial extent in both systems.
- Given the high buffer capacity (carbonate input from Alpine rivers) and the limited spatial and temporal extent of hypoxia in the NA relative to CB, calcareous species (e.g., shellfish) may be more vulnerable to acidification in CB than the NA. However, while the NA will remain supersaturated with respect to calcite and aragonite, an impact of acidification cannot be ruled out since calcareous organisms require a high saturation index.

2.3 Synergies

On an annual time-scale, both CB and the NA are autotrophic systems in which gross primary production exceeds respiration. However, while CB exports particulate organic carbon to the continental shelf, the combination of phytoplankton production and dense water formation (ADW) on the continental shelf of the NA enhances the transport of carbon to the Mediterranean Sea contributing to the sequestration of atmospheric CO_2 (COSSARINI *et al.*, 2015). Climate-driven increases in sea surface temperature will likely reduce dense water formation resulting in a significant decrease in atmospheric CO_2 sequestration and deep-carbon transport.

Increases in temperature, combined with increases in fishing pressure, have altered the composition of the Adriatic fish communities from large, late-maturing species with relatively low fecundity to smaller, earlier-maturing species with relatively high fecundity, and the species composition of food webs has shifted towards smaller, lower trophic-level species. Climate-driven warming of Adriatic waters may have an adverse effect on the survival of boreal fish species (e.g., *Sprattus sprattus* and *Merlangius merlangus*) that are relatively more wide-spread in the NA than elsewhere in the Mediterranean Sea. At the same time, increases in the prawn (*Penaeus kerathurus*) population in recent decades may be related to warming of the Adriatic.

Habitat loss is indicated by both the seasonal development of bottom water hypoxia/anoxia and by the degradation of biologically engineered habitats. While bottom water oxygen depletion occurs in both systems during late spring-summer-early fall, the sustained spatial and temporal extent of hypoxic/anoxic bottom occurs simultaneously and predictably over the entire mesohaline reach of the Bay while the development of hypoxic/anoxic bottom water is more localized and less predictable in time and space in the NA. Oxygen depletion eliminates habitat for benthic animals including oyster and coral reefs.

Biologically engineered habitats degraded during the period of increasing anthropogenic nutrient loading (1945-1985) include habitats that are common to both systems (seagrass beds, tidal marshes) and habitats that are unique to one or the other (CB – oyster reefs; NA – coral reefs, canopy-forming macroalgae, and coastal lagoons). Habitat loss has been exacerbated by concurrent increases in coastal development, water temperature and invasions of non-native species which number in the hundreds for both systems. However, most of these habitats (except oyster reefs in CB and coral reefs and coastal lagoons in the NA) are showing signs of recovery due to in part to reductions in anthropogenic nutrient loading.

3. MONITORING AND MODELING

Given the anthropogenic pressures described above, sustainable development requires ecosystem-based approaches (EBAs) to managing ecosystem services that consider socio-economic development (e.g., the use of ecosystem services) in the context of ecosystem dynamics (MALONE *et al.*, 2013). In this construct, economic activity occurs within a network of social interactions, both of which are constrained by the availability of ecosystem services. EBAs have the potential of providing a cost-effective means to address the multiple (often conflicting) goals of socio-economic development and environmental sustainability in a synergistic manner. Although ecosystem services are the foundation of sustainable socio-economic development, services and the ecosystem states upon which they depend are not routinely monitored, reported or analyzed on time and space scales required for proactive, effective EBAs (MALONE *et al.*, 2013).

Advances in the scientific understanding of coastal ecosystems and the predictability of changes in ecosystem states that impact the capacity of the NA and CB to support ecosystem services require sustained monitoring and modeling that informs ecosystem-based management (EBM) of ecosystem services. EBM is informed by integrated ecosystem assessments (IEAs), a process that involves and informs citizens, industry representatives, scientists, resource managers, and policy makers in the following (LEVIN *et al.*, 2009):

(1) Agree on priority ecological, social and economic goals and management targets that policy and management should address;
(2) Identify anthropogenic pressures on ecosystems and indicators of ecosystem health and use them to assess status and trends in ecosystem services relative to established management targets (e.g., sustain specified ecosystem services at agreed upon levels);
(3) Determine the natural and anthropogenic (ecological, social, and economic) causes and consequences of trends in ecosystem states and associated services;
(4) Forecast changes in ecosystem states and services under a range of policy and/or management actions;
(5) Routinely evaluate management effectiveness at regular intervals in the context of goals and management targets; and
(6) Identify crucial knowledge and data gaps in monitoring and modeling that need to be addressed to improve IEAs.

At present, the skill of model-based forecasts of circulation and mixing regimes is limited by the uncertainty of regional-scale forecasts of changes in precipitation, river runoff, and wind stress. Improving forecasts of physically driven changes in ecosystem states will require sustained, high resolution, synoptic monitoring and modeling of changes in regional scale patterns of atmospheric pressure gradients, air-sea fluxes of heat and CO_2, extreme wind events (e.g., bora, scirocco, and tropical storms), environmental parameters of ecosystem dynamics (e.g., temperature, salinity, nutrient concentrations, oxygen levels, vertical mixing, the spatial extent of biologically structured habitats, the abundance of invasive species), and the abundance and distribution of key groups of organisms (e.g., phytoplankton, copepods, gelatinous zooplankton, keystone predators, and selected fish populations).

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