A Framework for Integrated Management of Burrowing Shrimp in SW Washington: An Annotated Bibliography of Most Relevant Resources

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Andrews, K., Williams, G., Samhouri, J., Marshall, K., Gertseva, V., & Levin, P. (2015) **The legacy of a crowded ocean: Indicators, status, and trends of anthropogenic pressures in the California Current ecosystem.** Environmental Conservation, 42(2), pp. 139-151. Available from: https://doi.org/10.1017/S0376892914000277

Research Article: The strain of anthropogenic commercial and recreational activities combine with varied environmental factors to yield a confluence of entangled pressure-points that overload the California Current ecosystem. The focus is disentangling and examining the relationships between these different pressures – the authors define 22 anthropogenic pressures – as well as determining their associated environmental indicators over the course of a time-series. The researchers develop a methodology designed to be a dynamic spatial and temporal model for evaluating trends in the interactions and confluent pressure of multiple anthropogenic factors.

Booth, S.R., Patten, K. and New, L. (2019) **Response of estuarine benthic invertebrates to field applications of insecticide.** Estuarine, Coastal and Shelf Science, 218, pp.86-94. https://doi.org/10.1016/j.ecss.2018.11.025

Research Article: Principle Response Curve (PRC) analysis was used to assess the impact field applications of the neonicotinoid insecticide, imidacloprid at five study sites over the course of three years. Only six of the sixty PRCs showed negative effects. The low frequency of a negative effect was likely due to imidacloprid exposures that were limited to low concentrations and short time periods, low toxicological susceptibility to imidacloprid for many taxa, and natural resilience to disturbance and extreme environmental events.

Cavallo, M., Borja, A., Elliott, M., Quintino, V., Touza, J. (2019) **Impediments to achieving integrated marine management across borders: The case of the EU Marine Strategy Framework Directive.** Marine Policy, 103, pp. 68-73. Available from: https://doi.org/10.1016/j.marpol.2019.02.033.

Research Article: This is a 4-year analysis of reports related to the implementation of the EU Marine Strategy Framework Directive (MSFD) to define a spectrum of obstacles in realizing international integrated marine management. The terms 'bottlenecks, show-stoppers, and train-wrecks' are coined by the authors as a means to describe the minor, immediate, and major blockades in establishing integrated marine management across borders, such as 'excessive and redundant advice documents,' 'lack of experts with multidisciplinary backgrounds,' and 'resistance to collaboration,' respectively. Although multiple factors are defined and explored by the authors in each one of these categories, the key limitations remain countries' unwillingness to work jointly and inability to adapt current (or past/traditional) marine management activities/policies into the new, international MSFD system.

Cranford, P.J., Kamermans, P., Krause, G., Mazurié, J. Buck, B.H., Dolmer, P., Fraser, D., Nieuwenhove, K.V., O'Beirn, F.X., Sanchez-Mata, A., Thorarinsdóttir, G., Strand, Ø. (2012) **An ecosystem-based approach and management framework for the integrated evaluation of bivalve aquaculture impacts**, Aquaculture Environment Interactions, 2, pp. 193-213. Available from: https://doi.org/10.3354/aei00040.

Research Article: This article asserts that realizing the goal of sustainable and resilient bivalve aquaculture necessitates an ecosystem-based management framework (EBM) in order to effectively incorporate the competing foci of social and ecological needs. The authors expand upon the Drivers-Pressures-State Change-Impact-Response (DPSIR) management framework by determining 'performance indicators' that describe the ecosystem-carrying capacity (ECC), even as it relates to socioeconomic needs, in a hierarchical range. Additionally, multiple thresholds per indicator are used by the authors to account for the spectrum of severity as they pertain to ECC. The combination of the 'tiered indicator toolbox' and the multiple thresholds serve to provide a flexible framework that focuses on facilitating improved communication between key stakeholders.

Dara, S.K. (2019) **The New Integrated Pest Management Paradigm for the Modern Age**. Journal of Integrated Pest Management, 10(1), pp. 1-9. Available from: https://doi.org/10.1093/jipm/pmz010.

Research Article: This article describes how to enhance and reform IPM frameworks to better incorporate the modern tools of agrotechnology and new communication interfaces in order to buffer the emergent modern pressures of globalization and fluctuating consumer trends. Merging research and community outreach into IPM frameworks' goals supports this fresh focus on sustainability: social, economic, and environmental. The author's main goal encapsulates the importance for interagency cooperation and specific delineation of humans' needs in order to make IPM a lasting solution for sustainable agriculture. Pest management tactics are viewed solely with relevance to terrestrial agriculture.

Dumbauld, B.R., Booth, S., Cheney, D., Suhrbier, A. and Beltran, H. (2006) **An integrated pest management program for burrowing shrimp control in oyster aquaculture**. Aquaculture, 261(3), pp. 976-992.

Research Article: The use of shrimp burrows as an action threshold for shrimp control was demonstrated as problematic due to subjective differences between observers. Shrimp burrow densities of 20 – 40/m^2 resulted in severe oyster loss, especially to seed oysters, but a more precise economic injury level could not be derived due to the loss of some experimental plots during the winter and difficulties establishing plots with lower burrow densities. Nevertheless, a decision tree for treatment based on both levels of juvenile shrimp recruitment and shrimp burrow densities is presented.

Dyke, J.G., Weaver, J.S. (2013) **The emergence of environmental homeostasis in complex ecosystems**. PLoS Computational Biology, 9(5), p.e1003050.

Research Article: The conceptual biotic Daisyworld model was used to demonstrate that life on a planet subject to frequent and dramatic perturbations (asteroid impacts, runaway climate change, increased sunlight) will develop a homestatic and self-regulating processes via the development of multiple feedback loos between the life and the environment.

Ehler, L.E. (2006) **Integrated pest management (IPM): definition, historical development and implementation, and the other IPM.** Pest Management Science, 62: 787-789. https://doi.org/10.1002/ps.1247.

Review Article: A divergence has occurred within IPM framework practitioners that the author describes as 'The Real IPM' and 'The Other IPM.' The prior centers around the original IPM principles and therefore requires complexity and long-term solutions. The latter could call for renaming the acronym of IPM to 'integrated pesticide management' due to the emphasis on simple, short-term chemical controls in the IPM framework. The author hypothesizes that focusing on the original IPM's values and inherent complexity as it stands yields the long-term sustainability desired for security in any region or industry where pest management is necessary.

Elliott, M. (2013) **The 10-tenets for integrated, successful and sustainable marine management.** Marine Pollution Bulletin, 74(1), pp. 1-5. Available from: https://doi.org/10.1016/j.marpolbul.2013.08.001.

Research Article: This article proposes a 10-tenet framework for analyzing marine environmental stressors, both independently and in combination with one another. The tenets are as follows: 1. Environmental and ecological sustainability, 2. Economic viability, 3. Technological feasibility, 4. Social desirability and liberality, 5. Legal permissibility, 6. Administrative achieveability, 7. Political expediency, 8. Ethical defensibility, 9. Cultural inclusivity, 10. Communication and outreach efficacy. These tenets emphasize the need for a multidisciplinary approach to IPM as well as the emergent pressure for experts and key stakeholders to move in different or even opposing spheres to accomplish the goal of sustainability via IPM.

Elliott, M., McLusky, D.S. (2002) **The Need for Definitions in Understanding Estuaries, Estuarine, Coastal and Shelf Science**. 55(6), pp. 815-827. Available from: https://doi.org/10.1006/ecss.2002.1031.

Review Article: This review outlines the parameters for defining estuarine systems while underpinning the importance of developing a distinct and detailed definition multidisciplinary approach to defining estuaries (i.e., physical comparisons of % area coverage and % tideland coverage, chemical profile, socioeconomically). The authors assert that environmental exploitation and exhaustion abound when the current ambiguities and inconsistencies in estuarine definitions leave space for misinterpretation and little cross-disciplinary communication. Due to the difficulty in defining estuarine areas, the authors suggest that practitioners use a checklist that incorporates the physical attributes, the primary products, primary consumers, vertebrate predators, and general characteristics into the final designation of a given area as an estuarine system.

Elliott, M., Quintino, V. (2007) **The estuarine quality paradox, environmental homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas**. Marine Pollution Bulletin, 54(6), 640-645.

Viewpoint Article: Estuaries are environmentally naturally stressed due to both highly variable physico-chemical characteristics such as oxygen, temperature and salinity in the water column and bed sediment dynamics and also frequent natural disturbance. However, their biota is well-adapted to cope with that stress and may be regarded as resilient. Their ability to absorb stress without adverse effects is regarded as Environmental Homeostasis and is accomplished via life-history strategies and population processes that have long been associated with early successional stages of ecosystems in general. An over-reliance on ecosystem structural features, such as diversity, in quality indicators therefore makes the detection of the anthropogenic stress more difficult. This difficulty is termed the Estuarine Quality Paradox. Because of these difficulties, the article argues that functional characteristics as well as than structural ones should be used in detecting environmental perturbations in estuaries.

Elliott, M. and O'Higgins, T.G. (2020) **From DPSIR the DAPSI (W) R (M) Emerges… a Butterfly–'protecting the natural stuff and delivering the human stuff'**. In Ecosystem-Based Management, Ecosystem Services and Aquatic Biodiversity, pp. 61-86. Available from: https://doi.org/10.1007/978-3-030-45843-0_4.

Book Chapter: The authors track the advantages and shortcomings of the DPSIR framework as it evolved into DAPSI (W)R(M) and ultimately propose a new framework that stems from its core values and disentangles environmental factors from anthropogenic needs by clarifying what human need really is. They argue that the potential sustainability and efficacy of DPSIR and DAPSI(W)R(M) are limited by the ambiguity of what constitutes 'social activities.' They draw upon Maslow's hierarchy of needs to clarify the necessity of a variety levels of humanity's use of the environment, ranging from recreational to subsistence.

Elliott, M. and Whitfield, A.K. (2011) **Challenging paradigms in estuarine ecology and management**. Estuarine, Coastal and Shelf Science, 94(4), pp.306-314.

Review Article/Essay: The authors identify and present eight paradigms of estuarine ecology and management for both the northern and southern hemispheres, six of which are "science-based" and two of which "management-based". Each paradigm is accompanied by "interpretation/meaning" and "comments/relevance/support" sections. Briefly, the paradigms are: 1) "An estuary is an ecosystem in its own right but cannot function indefinitely on its own in isolation and that it depends largely on other ecosystems, possibly more so than do other ecosystems." The paradigm is derived from the estuaries connectivity between marine and terrestrial systems, with the emphasis in the northern hemisphere on the input of freshwater and macro-tides whereas in the southern hemisphere, many estuaries receive freshwater only seasonally and tides are much smaller. 2) "As ecosystems, estuaries are more influenced by scale than any other aquatic system; their essence is in the connectivity across the various scales and within the water body they are characterized by one or more ecotones." 3) "Hydromorphology is the key to understanding estuarine functioning but these systems are always influenced by salinity (and the resulting density/buoyancy currents) as a primary environmental driver." Hydromorphology represents the links between the substrate and suspended sediments, water movements, and tidal balance, all of which influence the biota. Salinity is primary factor. 4) "Although estuaries behave as sources and sinks for nutrients and organic matter, in most systems allochthonous organic inputs dominate over autochthonous organic production. 5) "Estuaries are physico-chemically more variable than other aquatic systems but estuarine communities are less diverse taxonomically and the individuals are more physiologically adapted to environmental variability than equivalent organisms in other aquatic systems." Such variability results in a lower biological diversity compared to most other aquatic systems, and ultimately, greater resilience to disturbance. 6) "Estuaries are systems with low diversity/high biomass/high abundance and their ecological components show a diversity minimum in the oligohaline region which can be explained by the stress-subsidy concept where tolerant organisms thrive but non-tolerant organisms are absent." 7) "Estuaries have more human-induced pressures than other systems and these include both exogenic unmanaged pressures and endogenic managed pressures. Consequently, their management has to not only accommodate the causes and consequences of pressures within the system but, more than other ecosystems, they need to respond to the consequences of external natural and anthropogenic influences." An example is the need to alleviate eutrophication by managing upstream inputs. Estuaries often host ports and industrial centers which contribute outside inputs. The authors cite the DSPIR framework within the Ecosystem Approach as an important management tool (see Elliot and O'Higgins 2020). 8) "Estuaries provide a wider variety of ecosystem services and an increased delivery of societal benefits than many other ecosystems. Hence estuaries are one of the most valuable aquatic ecosystems serving human needs but for this to occur they require functional links with the adjoining terrestrial, freshwater and marine systems."

Grumbine, R.E. (1994) **What Is Ecosystem Management?.** Conservation Biology, 8, pp. 27-38. Available from: https://doi.org/10.1046/j.1523-1739.1994.08010027.x.

Essay: Grumbine asserts that a stewardship approach to ecosystem management is the key to mitigating climate change. However, ecosystem management must be clearly delineated in order to be effective and as wide-reaching as the name implies. A multidisciplinary perspective that highlights short-term deliverables developed by drawing upon the combined input of scientists, politicians, and citizens should be just the first step of an operative ecosystem management plan; an overall emphasis placed on the long-term goal of consistent interagency cooperation and adaptive modes for evaluating successes and shortcomings of ecosystem management practices. Although human interests should be considered, the main action of ecosystem management includes consistent monitoring via data collection and subsequent adaptive management practices based on those findings. Special emphasis should be placed on population maintenance, protected and viable ecosystems in all climate types, maintenance of evolutionary and ecological processes over time, and the ensured evolutionary potential of organisms within a given environment.

Felder, D.L., Nates, S.F., and Robles, R.R. (2003) **Hurricane Mitch: Impacts of bioturbating crustaceans in shrimp ponds and adjacent estuaries of coastal Nicaragua**. Open File Report 03-179, p. 47. Available from: https://doi.org/10.3133/ofr03179.

USGS Open File Report: The primary objective of this study was to evaluate agents, processes and progress of increased decompositional effects that followed Hurricane Mitch in benthic and epibenthic environments of coastal Nicaragua, particularly in penaeid shrimp culture ponds. A primary response was an increase in bioturbating burrowing shrimp (*Lepidophthalmus spp*.), which were already common to the ponds before the storm. Existing burrowing shrimp management tactics rely primarily on pesticides, which are used not only as a response to the bioturbation, but also because the burrowing shrimp were suspecting of vectoring "white spot" disease to the cultured penaeid shrimp. The primary pesticide used in trichlorfon, a broad-spectrum highly toxic pesticide which has been phased out of use in most crops in the U.S..

Fredricks, K. T., Hubert, T. D., Amberg, J. J., Cupp, A. R., & Dawson, V. K. (2021) **Chemical controls for an integrated pest management program.** North American Journal of Fisheries Management, 41(2), 289-300.

Review Article: An initial introduction of IPM concepts, aquatic needs (principally to remove or suppress invasive species) and favorable attributes for an aquatic pesticide use is followed by an overview of selected registered chemical tools. These include: 1) 3-trifluoromethyl-4-nitrophenol (TFM) and 2) niclosamid for the selective control of Sea Lamprey in the Great Lakes (see Hubert 2003), 3) antimycin for removal of invasive or foreign fish (i.e., brook trout from a tributary to Yellowstone Lake, Green Sunfish from live-haul trucks carrying fingerling catfish to production ponds), 4) rotenone for the eradication of invasive fish, 5) Zequanox and 6) Earth-tec QZ to control zebra and quagga mussels. Several aquatic herbicides are described, as well as the potential of developing tactics such as the manipulation of carbon dioxide and ozone.

Hubert, T.D., Miller, J. and Burkett, D. (2021) **A brief introduction to integrated pest management for aquatic systems**. North American Journal of Fisheries Management, 41(2), pp.264-275. Available from: https://doi.org/10.1002/nafm.10331.

Special Section on IPM Article: A brief history of IPM as it pertains to managing invasive aquatic pest species is presented, with a few examples, followed by a broad presentation the Great Lake Fishery Commission's (GLFC) Integrated Management of Sea Lamprey Control Program in the Great Lakes Basin. The program features cultural control in the promotion of carp as food, physical control in the netting of invasive carp and mechanical and electrical barriers to larval lamprey entering the Lakes from spawning streams, and selective use of pesticides, also against larval lampreys in spawning streams. The program is inter-agency and inter-national.

Kluger, L., Taylor, M., Rivera, E.B., Silva, E.T., Wolff, M. (2016) **Assessing the ecosystem impact of scallop bottom culture through a community analysis and trophic modelling approach**. Marine Ecology Progress Series, 547, 121-135. Available from: https://doi.org/10.3354/MEPS11652.

Research Article: As an example of Ecosystem Based Management, this article focuses on developing methods of trophic modeling to analyze and suggest possible mitigation tactics for the impact of increased bivalve mariculture (bottom culture) in Sechura Bay, Peru on the ecosystem carrying capacity (ECC) as it pertains to the Peruvian bay scallop (*Argopecten purpuratus*). The authors used EcoSim and Ecopath software to model an optimal ECC given a primary input of phytoplankton, as it pertains to the aquaculture of the Peruvian bay scallop (*Argopecten purpuratus*) in Sechura Bay, Peru. The model also simulated impacts of increased scallop aquaculture on several other functional groups (i.e., phytoplankton, zooplankton, polychaetes, sea urchins, herbiverous gastropods, predatory crabs, littoral fish, pelagic predatory fish, marine mammals, and seabirds).

Kogan M. (1998) **Integrated pest management: historical perspectives and contemporary developments**. Annual Review of Entomology, 43, 243–270. https://doi.org/10.1146/annurev.ento.43.1.243.

Review / Research Article: A short history of IPM development, including definitions and concepts. Kogan explores the evolution of IPM frameworks through ecology, agriculture, and the eventual fusion of the two in the development of agroecology. He presents a conceptual paradigm of IPM of hierarchical scales of the ecological, socio-economic, and agricultural complexity that, in turn, shape the complexity of the IPM program. He provides examples for several cropping systems at several levels, including national and international programs to develop and implement IPM.

Kogan, M., Bajwa, W.I. (1999) **Forum Integrated Pest Management: A Global Reality?.** Anais da Sociedade Entomológica do Brasil, 28(1), pp. 1-25. Available from: https://doi.org/10.1590/S0301-80591999000100001.

Forum Article: The goal of realizing the IPM framework as a global gold standard is still restricted by lack of a consistent definition and difficulty in adapting that consistent definition to the challenges of varied sociocultural and environmental needs. Success in implementing IPM strategies locally and regionally bears statistical significance, however even in combination with advancements in pest control technologies, the ceiling of global crop loss due to pests pre and post-harvest has yet to be scratched and remains much the same as the early 1900's. Trends in environmental health, as impacted by agriculture, demand that at the very least IPM strategies be incorporated and pesticide-reliance reduced globally. In order for IPM to be successfully implemented and sustained globally, IPM parameters and mission must be defined both locally – in contrast to a given regions' current pest-management programs – as well as in a general and objective manner in order to clarify the IPM principles as they might apply across varied borders and ecosystems.

Kogan, M., Jepson, P. (eds) (2007) **Perspectives in Ecological Theory and Integrated Pest Management.** Cambridge: Cambridge University Press. https://doi.org10.1017/CBO9780511752353.

Book: This book focuses on IPM's dependence on ecological theory. Rather than IPM frameworks existing as a reaction to a regions' ecological patterns, the authors describe how regional and spatial environmental factors might be incorporated and maneuvered to support sustainable IPM. The book's first chapter, 'Ecology, sustainable development IPM: the human factor,' centers around the elements of human impact that both detract and support ecologically sensitive IPM implementation. The authors examine the limiting confluent pressures of extreme poverty and excessive consumerism that impact a regions' ability to initiate and maintain IPM.

Levin, S.A., Lubchenco, J. (2008) **Resilience, Robustness, and Marine Ecosystem-based Management.** BioScience, 58(1), pp. 27-32. Available from: https://doi.org/10.1641/B580107.

Research Article: 'Robustness and resilience' in marine Ecosystem-based management frameworks must be the main focus in order to mitigate the sweeping influence of human activities. Due to the complex and layered nature of marine ecosystems, a small anthropogenic impact can ripple out to the detriment of the integral feedback loops that contribute to biodiversity within the system.

Lonsdale, J.A., Blake, S., Griffith, A. (2020) **A novel systematic, risk based approach to support the designation of aquatic disposal sites.** Marine pollution bulletin, 162, 111874. Available from: https://doi.org/10.1016/j.marpolbul.2020.111874.

Research Article: Cumulative Impact Assessment (CIA) (or Cumulate Effect Assessment (CEA)) is evaluated as a tool for marine management or an expansion of marine spatial planning by: 1) reviewing current principles and approach, 2) identifying gaps in CEA, and 3) developing and demonstrating a new approach. The last of the these was to identify potential sites for the deposit of dredged materials, often contaminated, during three development projects in the UK. The new approach combined GIS technologies to create a three dimensional analysis. The terminology followed the DAPSI(W)R(M) framework: Drivers (the need for space, food and security), Activities (i.e., fishing, dredging, etc) which produce Pressures (the mechanisms leading to effect (e.g., abrasion of the seabed, removal of bed material, etc); Pressures lead to State (e.g., a reduction in biodiversity, loss of populations, etc) which can lead to Impacts (on human Welfare) (e.g. loss of fish stocks, a reduction in amenity value). Finally, the Drivers, Activities and Pressures then need to be controlled by Responses (using management Measures) to prevent the State changes and Impacts (on human Welfare). "Hence a CEA is a fundamental Response and management Measure.). The review of CIA is comprehensive and included pros and cons.

Peterson, R.K.D., Higley, L.G., Pedigo, L.P. (2018) **Whatever Happened to IPM?.** American Entomologist, Volume 64, Issue 3, Fall 2018, Pages 146–150, https://doi.org/10.1093/ae/tmy049.

Forum Article: Rather than embracing multiple tactics, IPM remains focused on "the silver-bullet fetish" and still assumes to control, rather than manage pests. The authors of this article insist that to clarify the increasing widespread ambiguity in practicing and developing IPM frameworks, a rejuvenation and realignment with a core focus on ecology and evolution must be put into place. Rather than embracing multiple tactics, IPM remains focused on "the silver-bullet fetish" and still assumes to control, rather than manage pests. The authors suggest that the focus should be shifted from the pest to the host [crop] and its response to the host.

Radcliffe, E.B., Hutchinson, W.D., Cancelado, R.E. (eds.) (2009) **Integrated Pest Management Concepts**, **Tactics, Strategies and Case Studies.** Cambridge, UK: Cambridge University Press.

Book: This book represents the breadth and depth of IPM, incorporating multiple foci within the realms of social and ecological sciences. Emphasis on the inherent interdisciplinary approach that is required for successful and sustainable IPM. Chapters include coverage of: IPM concepts and strategies, economic impacts and decision making rules, biological precepts, population dynamics, sampling methods, biological control methods, crop diversification, use arthropod pathogens, biological pesticides, pesticide resistance, environmental risks of pesticides, host plant resistance and resistance management, biotechnology, use of pheromones, hormone-based pest control products, eradication strategies, physical insect management, cotton arthropod IPM, IPM in greenhouse vegetables and ornamentals, structural IPM, gypsy moth IPM, IPM for invasive species, IPM information technology, IPM in developing countries, the USA National IPM Road Map, organic and sustainable IPM, and the future of IPM.

VanBlaricom, G.R., Eccles, J.L., Olden, J.D., McDonald, P.S. (2015) **Ecological effects of the harvest phase of geoduck (*Panopea generosa* Gould, 1850) aquaculture on infaunal communities in southern Puget Sound, Washington.** Journal of Shellfish Research, 34(1), 171-187.

Research Article: A ''before–after-control-impact'' experimental design, was used to evaluate the effects of geoduck harvest on benthic infaunal communities at three study sites in southern Puget Sound. A multivariate statistical analysis showed strong seasonal and spatial signals in patterns of abundance were found, but there was "scant" evidence of effects on the community structure within cultured plots, and no indications of significant on uncultured adjacent habitat. The authors suggest that adaptation to an active natural disturbance regime, has facilitated assemblage-level infaunal resistance and resilience to harvest disturbances. (This is a complementary article to: McDonald, P.S., Galloway, A.W., McPeek, K.C. and VanBlaricom, G.R., 2015. Effects of geoduck (*Panopea generosa* Gould, 1850) aquaculture gear on resident and transient macrofauna communities of Puget Sound, Washington. Journal of Shellfish Research, 34(1), pp.189-202.)