A Framework for the Integrated Management of Burrowing Shrimp in SW Washington

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Introduction

This “Framework for the Integrated Management of Burrowing Shrimp in SW Washington” is intended to cover Willapa Bay and Grays Harbor and is an extension and update of related Integrated Pest Management (IPM) Plans (Booth 2003, Booth 2007, and Booth 2010). The 2003 plan was divided into five primary sections: 1) IPM Definitions and Concepts, 2) IPM Goals, 3) Principal Authorities (participatory stakeholders), 4) Principal Policies, 5) 5 Plan Elements[1]. The Plan Elements (Funding, Research & Development, Implementation, Evaluation / Regulatory Compliance, and Dissemination) were conceptualized as interacting through feedback loops, especially between Research & Development, Implementation, Evaluation / Regulatory Compliance. Several elemental steps also occur simultaneously. Funding was considered the primary driving force, as the resources were initially scant. Both the 2007 and 2010 IPM Plan updates focused on the Research & Development element with tables of collaborating scientists and the titles of completed and on-going studies of potential management tactics.

In this framework, we adapt the IPM concept proposed in the 2003 Plan, and its underlying paradigm, to align with a greater understanding of estuarine ecology, particularly as a resilient ecosystem in homeostatic equilibrium. The ecological scales that contribute to the level of IPM are enlarged relative to the socioeconomic and agricultural scales in the conceptual diagram of the IPM paradigm. The enhanced conceptual role of the ecosystem also aligns, partially but not wholly, with the construct of Ecosystem-Based Management (EBM), which is being implemented to the management of the coastal zones of Washington, Oregon, and California. The relatively larger ecological scales of the IPM paradigm suggests that the Plan Elements should be altered, in concept if not in practice. In particular, we suggest that Evaluation (of IPM success) and Regulatory Compliance / Policy (of specific IPM tactics) are in fact two separate elements and that the Regulatory component arises from policy. Both need to be better defined and standardized, but the requirements for compliance need greater consistency, transparency, and perhaps ultimately, revision. A Knowledge Base is also added as a sixth Element and provides a preliminary annotated bibliography of relevant literature as a start.

IPM in Terrestrial Agriculture

The legal definition of IPM as presented to Washington State agencies with pest control responsibilities is “a coordinated decision-making and action process that uses the most appropriate pest control methods and strategy in an environmentally and economically sound manner to meet agency programmatic pest management objectives...” (RCW 17.15.010, 1997).

Kogan (1998) defined IPM with less legalese as “… a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society, and the environment.” Aside from the implication that the goals of IPM serve more than the objectives of Washington state agencies, Kogan’s definition includes the key word “management”. Efforts in the

[1] An Introduction, a placeholder for Timelines as they developed, and a Reference section were also included.

1960s to curtail pesticide use by integrating biological control for some pests was termed "integrated pest control" (Kogan 1998, Ehler 2006). After some back and forth throughout the 1960s, the term "management" was used to supplant the implied goal to "control" pests, as the latter implies actions that occur without human interference[2] (Kogan 1998).

Primary indicators of IPM (Kogan and Bajwa 1999) include:

1. Use of appropriate sampling or monitoring procedures (monitoring pest and natural enemy population trends, pest phenology, to crop phenology, diseases, biodiversity, etc.).
2. Access to appropriate information to support [management] decisions (economic injury levels and economic thresholds, information on the principal natural enemies, history of pest distributions, predictive models of pest dynamics).
3. Selection of management tactics based on IPM principles (resistant cultivars, habitat management to enhance natural enemy activity, classical and augmentative biological control, biorational pesticides, selective pesticides; broad spectrum pesticides as a last resort).
4. Consideration of environmental impacts of [management] actions (non-target impacts on flora and fauna, contamination of water and ground, resistance development).
5. Consideration of the total ecosystem.

Primary performance indicators (Kogan and Bajwa 1999) are:

1. Ability of the system to maintain pest populations below established economic injury levels.
2. Measurable reduction of pest impact on crop yield and quality over a period of time, leading to greater stability in the productivity of the system.
3. Reduction in amounts of production and protection inputs of non-renewable resource origin (mainly pesticides) while maintaining stable productivity levels for the region.
4. Level of adoption of the IPM system by producers.
5. Preservation of environmental quality, as determined by measurable indicators.
6. Increase in safety and comfort of rural workers and their families.
7. Increase in the level of consumer confidence in the safety of agricultural products.

As specified in the primary and performance indicators of IPM, and as noted by Kogan (1998) and others (Higley and Pedigo 1996, Norris et al. 2003, Radcliff et al. 2009) the decision-based structure of IPM relies on thresholds to trigger management or other actions. The most typical of these is the Economic Injury Level (EIL) which is the level (density) of pests at which economic injury is incurred unless pest densities are suppressed. Other types of thresholds aside from the EIL include aesthetic (the level of pests that will damage an ornamental crop), nuisance (level of annoyance or disturbance caused by a nuisance pest such as a mosquito or fly), composite (which considers both biotic and abiotic stressors) (Norris et al. 2003).

<u>Reduced Risk Management Programs</u>

Many of the management strategies and tactics typical in terrestrial IPM programs are not available or simply cannot apply to the management of burrowing shrimp. For example, the introduction of a foreign biological control agent is likely not feasible in an estuary, where many organisms are more mobile and the potential for unknown trophic consequences are high (Booth 2003). Microbial control agents (pathogens or vectors of pathogens), which frequently exhibit a high degree of host-specificity, are mass-produced, and applied seasonally or as needed in many terrestrial crops (Kogan 1998; Anwer 2017), but the introduction of a disease in an open-system like an estuary, could be disastrous. The release of sterile male to compete with fertile males for mates has been quite effective in the

[2] Although biological control, a primary IPM strategy, retains the term, as humans play a much smaller role.

management of some insect pests (Kogan 1998, Klassen and Curtis 2005), but even if the technology was available to rear and sterilize thousands of burrowing shrimp, their release would likely impact more than on-farm populations of shrimp. Many IPM programs include the use of synthetic sex pheromones to confuse the males of pestiferous moths and prevent reproduction (Klassen and Curtis 2005). Burrowing shrimp likely release pheromones as part of their reproductive processes, but none have been isolated, let alone synthesized.

So far, successful management of burrowing shrimp in Willapa Bay has depended primarily on treatment with the carbamate insecticide carbaryl or the neonicotinoid insecticide imidacloprid. The former is somewhat selective towards the survival of some invertebrates (Dumbauld et al. 2001) while the latter allows many other invertebrates and all vertebrates to survive (Tamizawa and Casida 2003). Applications were applied to areas where shrimp burrow densities were above a “thumbnail” threshold of 10 per m^2 based on an annual survey of commercial shellfish grounds. A decision tree for shrimp management was developed based on the duration that an oyster crop will remain on the bed, treatment history, recent shrimp recruitment patterns, and a revised and adjustable minimum threshold burrow count (Dumbauld et al. 2006). The improved decision strategy has not been fully adopted due to the termination of carbaryl use and the denial of imidacloprid use.

In recognition of these and other departures from Kogan’s paradigm, the 2003 plan for burrowing shrimp management recognized the “reduced risk” and “supervised control” of pest species (Ehler and Bottrell 2000). The authors acknowledged that complex ecosystems are difficult to describe let alone manipulate, and that traditional IPM tactics do not always apply. In particular, the authors noted: a) advanced monitoring schemes are often too complicated and expensive, b) predicting population pest and natural enemy trends is difficult, c) economic thresholds and injury levels are "operationally intractable"; predetermined static thresholds are "problematic" and dynamic thresholds take years to develop. Indeed, a two-year field study of the levels of injury caused by burrowing shrimp to seed and fattening oysters yielded highly variable results and incurred substantial costs (Dumbauld et al. 2006).

Despite decades of research that involved dozens of investigators and cost millions of dollars, the two strategies to manage burrowing shrimp in Willapa Bay feature either a chemical treatment or the mechanical disruption of shrimp burrows and habitat. Both strategies impose a pulse disturbance to the habitat and to the surrounding zone.

Ehler (2006), determined that IPM had yet to be implemented to a large scale in the United States. Reasons given included: 1) IPM is often too complicated for a small farmer to implement while dealing with the myriad of other farming tasks, 2) paid consultants usually serve multiple clients and are likewise too busy to do much more than conduct basic monitoring and recommend simple management tactics, and 3) land-grant university scientist usually study a single tactic at a time and rarely assess the impacts of a complex IPM system, 4) those tactics usually included the efficacy and impacts of selective pesticides. In practice, IPM became an acronym for Integrated Pesticide Management rather than Integrated Pest Management. Other IPM experts (Peterson et al. 2018) extended the discussion, and asked, “Whatever happened to ecology and evolution in IPM?” In answer, they defined IPM as, “a comprehensive approach to managing host stress that is economically and ecologically sustainable”. The idea of focusing on the host, rather than the pest, allows plants or animals, including humans, to be part of the management plan. The implication is that the central management goal considers the importance of sustaining ecological diversity. In this way, IPM approximates some concepts of ecosystem-based management.

Ecosystem-Based Management

As noted in Wasson et al. (2015), ecosystem-based management (EBM) has been defined in many different ways, given the basic premise: "Ecosystem-based management is fundamentally about perceiving the big picture, recognizing connections, and striving to maintain the elements of ecosystems and the processes that link them" (Guerry 2005). Grumbine (1994) posed the working definition: "Ecosystem management integrates scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting native ecosystem integrity over the long term." Grumbine (1994) also listed ten themes of EBM, although all practitioners do not adhere to all of them. They can be paraphrased as:

1. Maintain the hierarchical context of biodiversity (genes, species, populations, ecosystems, landscapes).
2. Manage across ecological boundaries, not merely administrative or political boundaries.
3. Maintain the ecological integrity to of the entire ecosystem diversity, including the ecological processes and patterns that maintain that diversity.
4. Collect data and maintain existing data.
5. Managers must monitor the results of their actions.
6. Management is adaptive in the light of provisional and changing scientific knowledge.
7. Interagency cooperation is required.
8. Organizational change is most likely required.
9. Humans are embedded in nature.
10. Human values play a dominant role in ecosystem management goals.

At inception, EBM was applied towards the management of large swaths of public lands such as national parks and forest reserves (Grumbine 1994), but as noted by Wasson et al. (2015), it is currently mostly applied to marine systems, including coastal (Wasson et al. 2015), due to political failing. With regard to marine EBM, and in response to recommendations by both the Joint Ocean Commission and the Pew Oceans Commission, Levin and Lubchenco (2007) suggested that the concepts of resilience and robustness of complex ecosystems can be used to guide the development of marine EBM. In further support of the development of marine EBM, in 1997, NOAA established five Integrated Ecosystem Assessment (IEA) Programs, one of which focuses on the California Current.

Although the term EBM has applied to studies of bivalve aquaculture, the primary focus of the few relevant articles has often been more specific and involved involving carrying capacity (Kluger et al. 2016) and/or the use of mathematical models to simulate effects of management tactics (Kluger 2017, Cranberg et al. 2012).

Aquatic IPM

The primary application of IPM in aquatic systems is in response to invasions of non-indigenous species that threaten ecological processes. Hubert et al. (2021) described the integrated management of non-indigenous carp in the Great Lakes by multiple physical, cultural, and chemical controls. He also argued that Great Lake Fishery Commission's (GLFC) Integrated Management of Sea Lamprey Control Program in the Great Lakes Basin is the premier IPM program in the world. Because initial use of mechanical and electrical barriers to larval lampreys entering the Lakes from spawning streams was ineffective, the program screened 6000 compounds and selected two as chemical tactics. Both 3-trifluoromethyl-4-nitrophenol (TFM) and niclosamide have attributes that lend selectivity towards sea lamprey, especially when treated as larval in spawning streams (Fredericks et al. 2019). TFM is general piscicide and could affect other fish if applied in the lake proper. Niclosamide also impacts other invertebrates, including mollusks (World Health Organization 2002). The organization of the GLFC is complex and is informed by

Boards of Advisors from both the United States and Canada, with additional Boards of Technical Advisors, Technical Experts, Control Experts, and Research Experts, and working arrangements with six Committees. The GLFC also interacts with six Sea Lamprey related Task Forces. Hoff et al. (2021) noted that several policy challenges were associated with the development and implementation of Aquatic IPM, with special reference to the Sea Lamprey IPM Program.

Aquaculture of paneid shrimp in commercial ponds built above the littoral zone in coastal Nicaragua is negatively affected by burrowing shrimp species that are indigenous there (Felder 2003). The developing IPM program is primarily by applications of the pesticide Neguvon® (trichlorfon) to the ponds before introduction of paneids[3].

An IPM plan for burrowing shrimp that affects commercial bivalve aquaculture in Willapa Bay and Grays Harbor is unique worldwide. The ecological role of the pest is distinct. Most pests in terrestrial agricultural, and as noted above, almost all targets of aquatic IPM programs are invasive species that have escaped the biological and environmental population controllers of their native habitats. Burrowing shrimp in Willapa Bay and Grays Harbor are indigenous species that control their habitat. As ecosystem engineers, they "modulate the availability of resources (other than themselves) to other species, by causing physical state changes in biotic and abiotic materials. In so doing they modify, maintain and/or create habitats" (Jones et al., 1994). Consequently, burrowing shrimp are extremely well adapted to their fossorial habitats within the estuarine soft-bottom ecosystem.

The estuarine soft-bottom ecosystem is extremely harsh, especially at the depths to which burrowing shrimp can live (Atkinson and Taylor 2004, 2005). Such sediments are extremely low in oxygen but enriched in carbon dioxide and sulphides (Pillay and Branch 2011). Although burrowing shrimp ventilate their burrows via irrigation by beating their pleopods, the burrows still can become hypoxic, which the shrimp tolerate for long periods. Burrowing shrimp are also tolerant of high sulphide levels, which they can convert to less toxic thiosulphates. Weaver (2006) found that ghost shrimp could construct burrows in substrates with levels of densification much higher than those found in the field. Shrimp could only be crushed at stress levels found at least 1.5 m below the ground surface in association with very high surface loads.

<u>A Rescaled and Updated Paradigm for Burrowing Shrimp IPM</u>

The conceptual foundation of the IPM Plan to manage burrowing shrimp is based on Kogan (1998) paradigm for modern agriculture. The paradigm is comprised of three levels of IPM integration that increase in complexity according to the complexity and scale of the associated ecological, human, and agricultural communities (Figure 1). The scales are parallel and hierarchical among ecological systems and human social systems. Interactions among those two systems, also hierarchical and parallel in nature, define the agricultural system and thus the complexity of IPM. In other words, the level and complexity of IPM integration depends on both the ecosystem and the human society that define that agricultural setting.

At first glance, the ecological, socioeconomic, and agricultural settings as they relate to the management of pests of bivalve aquaculture in Willapa Bay and Grays Harbor appear to exist at a low level of complexity and scale. Commercial shellfish farming in Willapa Bay arose among a relatively small group of families that relied on similar tactics to grow primarily oysters on relatively small acreages. Although they comprise two separate species, burrowing shrimp might as well be the sole pest of economic

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[3] Trichlorfon is a broad-spectrum organophosphate compound currently up for reregistration with the EPA. The potential for its use against burrowing shrimp in Willapa Bay and Grays Harbor is extremely low.

importance. According to Kogan's paradigm, the suite of management tactics that target burrowing shrimp should be at a low level of complexity.

The terminated carbaryl-based management was, perhaps a Level I IPM strategy: the treatment of later burrowing shrimp life stages when densities were above an accepted damage threshold of ten burrows per m^2 with a mostly broad-spectrum compound that was slightly selective. The proposed imidacloprid-dependent management program was a step up in the hierarchy of IPM levels, as that compound is much more selective (i.e., selectively impacts the pest rather than non-target organisms) than carbaryl. When the use of imidacloprid was denied, the level of IPM declined, as burrowing shrimp are now barely "managed" at all. Currently, recruitment of shrimp is monitored at specific sites and time, but populations are not suppressed.

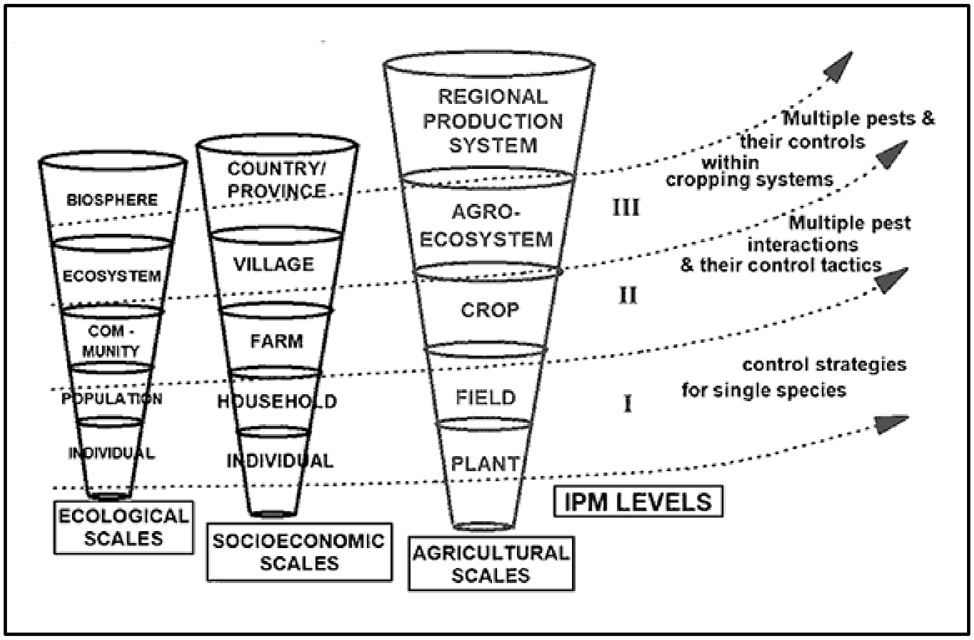

Figure 1. Graphical representation of the ecological and socioeconomic scales that define the scales of agricultural systems and, consequently, levels of IPM integration. [from Kogan 1998]

The scales of ecological, socioeconomic, and agricultural interactions are currently much more diverse, dynamic, and complex than in the early 1960s, when burrowing shrimp became a real problem in Willapa Bay oyster cultivation. The socio-economy of southwest Washington has expanded with greater contributions from outside the region in the form of recreation and tourism. Bivalve aquaculture has also become more complex as some oyster production has moved off-bottom. Oyster markets have expanded from primarily a shucked product to single oysters for the half-shell and restaurant markets.

Currently, there is also a better understanding of the complexity of the ecological setting relevant to bivalve aquaculture and burrowing shrimp management. For example, the development of burrowing shrimp populations is influenced by conditions in estuaries and ocean currents far from the coast of Washington (Johnson and Gonor 1982; Pimentel 1983). There is also increased understanding of seasonal movement of ecologically and commercially important populations of salmonids and crab through the bays.

We are also now more aware of how ecosystems and their biotic communities are structured and function. As "a semi-enclosed coastal body of water, which has a free connection with the open sea, and within which sea water is measurably diluted with fresh water derived from land drainage" (Pritchard 1967) an estuary contains a continuum of environmental gradients. These include changes in the salinity from seawater to freshwater, in sediments from coarse to fine, in the turbidity of the water column, and in nutrients, dissolved gases, and trace metals (Elliot and Mclusky 2002).

In addition to the environmental gradients that exist because they connect land and sea, estuaries are highly variable due to other factors. "Hydromorphology is a major driver of estuarine ecosystem functioning in that it can lead to both changed salinity conditions and/or the physical removal of organisms… Hydromorphology is regarded and can be interpreted as representing the links between the sediments and suspended sediment, water movements and tidal balance, all of which influence the estuarine biota and are superimposed on the underlying geology/geomorphology of the system…[and is] the primary determinant for the residence time of water within an estuary" (Elliot and Whitfield 2011). Variable environmental conditions also exist in estuaries due to continual change in the intensity of the tidal cycle (Elliot and Whitfield 2011). Natural disturbances (storms, floods, heat waves, cold waves, etc.) can also create environmental variability (Odum and Copeland 1974). VanBlaricom et al. (2015) noted six such natural disturbance processes common to Puget Sound in Washington State: 1) small waves associated with wind shear, 2) thermal stress at low summer daylight tides, 3) large waves associated with storms, 4) flooding events, and 5) sediment liquification associated with small tsunamis and even 6) submarine landslides.

Estuarine communities exhibit redundancy and resilience in response to such high variability and frequent disturbance (Pearson and Rosenberg 1978, Zajac et al. 1998, Elliot and Quintino 2007, Elliot and Whitfield 2011). Ecosystem redundancy is the idea that functions continue even if some elements (e.g., species) have been removed (Elliot and Whitfield 2011). Elliot and Whitfield (2011) note that estuaries do not necessarily possess redundancy for every species function, and that the loss of one or two key species could result in the loss of a specific habitat within the system. Folke et al. (2004) defined ecosystem resilience as: "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks". Individual species are resilient in their abilities to physically tolerate stress (e.g., hypoxia, temperature extremes, etc.) and are able to "withstand/tolerate/adjust/adapt to stressors" at the level of the individual, population, community, or ecosystem (Elliott and Quintino 2007).

The environmental homeostasis paradigm (Dyke and Weaver 2013) has been used to describe the structure and function of a stressed ecosystem. Estuarine resilience/environmental homeostasis is accomplished via life-history strategies and population processes that have long been associated with early successional stages of ecosystems in general (Elliott and Quintino 2007). Species in these early stages are opportunistic, highly mobile, small in size, and have high intrinsic rates of reproduction (r-strategists) (Odum 1969, 1985; Pianka 1970). Under the traditional paradigm of ecological succession, ecosystems trend through a series of successional stages following disturbance towards a more stable state characterized, in part, by communities with a greater number of species that are k-strategists (i.e., equilibrium species adapted to living in an ecosystem at carrying capacity) (Pianka 1970). Estuaries in a state of environmental homeostasis cannot trend toward stability so remain dominated by a few opportunistic species with r-selected life history strategies (Costanza et al. 1992, Elliott and Quintino 2007). Elliot and Whitfield et al. (2011): "Estuaries are systems with low diversity/high biomass/high abundance…".

Willapa Bay exemplifies an estuary in environmental homeostasis. Salinity, a primary environmental regulatory parameter in estuaries (Whitfield et al. 2012) is especially variable in Willapa Bay, which was characterized as "extremely unsteady" in salt balance, both between and within seasons (Banas et al. 2004). The estuary itself is relatively shallow, which leads to especially large maximum and minimum tides (Emmett et al. 2000). Associated laminar flows transport and distribute sediments across the tide flats (Wheatcroft et al. 2013) to erodible channels that carry "orders of magnitude" greater loads of suspended sediments during peak tidal flows (Wiberg et al. 2013). Water temperatures can reach 40°C within a few hours in shallow puddles left during low tides on sunny summer days (Pacific Shellfish Institute, unpublished monitoring data). The amount and type of vegetation and detritus also vary at small spatial scales based on tidal elevation, aspect, and proximity to rivers and other upland inputs.

IPM, as defined by Kogan and many others, differs from EBM on the basis of two defining tenets; 1) the ecological scale at which is usually applied, in terms of biodiversity and geographic size, and 2) the status of the socio-economy (e.g., Kogan's IPM) / humans (Grumbine's EBM) within each construct.[4] Terrestrial farms are smaller in area than national parks and the acreage of shellfish aquaculture in Willapa Bay and Grays harbor is immensely smaller than the estuary itself or the California coastal zone. Shellfish farms are also owned and managed privately as opposed to publicly. IPM recognizes that humans make decisions that will alter the environment to some degree. Kogan and Jepson (2007): "Which other species, of the now assumed 10–30 million that inhabit the Earth, has caused more destruction, changed the natural landscape more deeply and extensively, exterminated more of the other species, or killed more of their own, than humans? But ironically, we humans are, as far as it is known, the only species with a conscience." Humans are certainly part of the biosphere, but as the primary manipulators of the crop system, they are "outside" of it.

Accordingly, IPM, not EBM, provides the appropriate framework for burrowing shrimp management in Willapa Bay and Grays Harbor. Nevertheless, in light of the greater understanding of the complexity of the ecological scales, particularly regarding IPM of bivalve aquaculture in Willapa Bay, Kogan's conceptual diagram of the IPM paradigm should be revised and rescaled (Figure 2). The relatively greater conceptual role of ecology is mostly at the level of the ecosystem, which is characterized by adaptation to stress from frequent disturbance creating a state of environmental homeostasis. As in the original conceptual diagram, ecological factors still drive the development of IPM, but those factors may be different from, if not more complex, than those common to terrestrial IPM.

[4] IPM is not so distinct from EBM with regard to the status of humans when viewed at the scale of very large ecosystems (e.g., the Great Lakes Basin) or the biosphere.

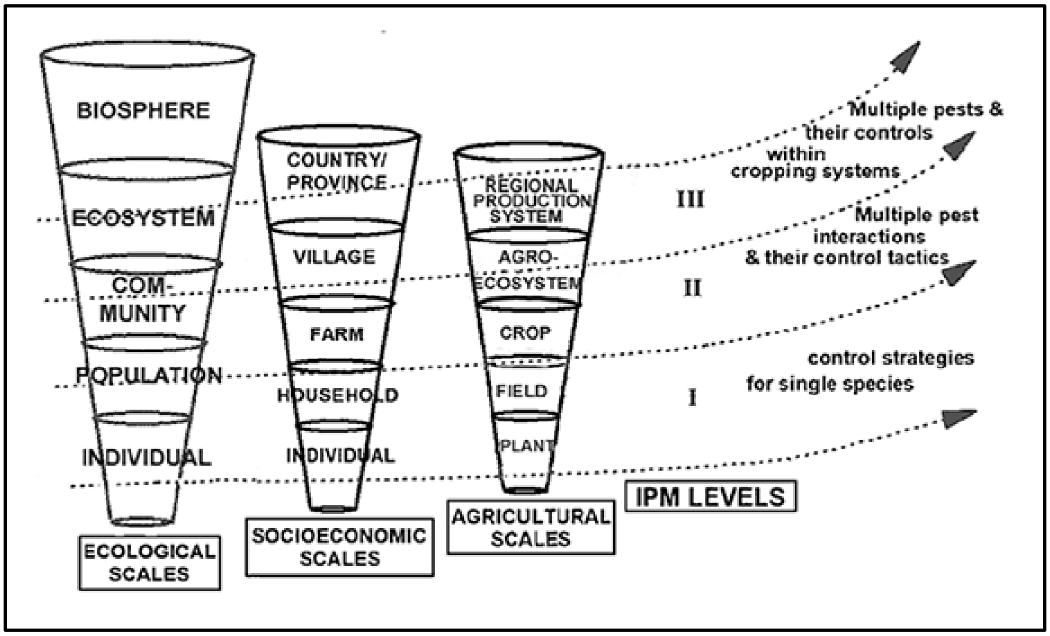

Figure 2. Rescaled representation of the ecological and socioeconomic scales that define the scales of agricultural systems and, consequently, levels of IPM of pests of bivalve aquaculture, particularly burrowing shrimp, in Willapa Bay. [adapted after Kogan 1998]

Updated IPM Plan Elements

IPM Program Coordination and Administration

The previous IPM Plans did not specify how the developing program should be coordinated, as those activities were implicit with the inception of that program in 2001 under a Memorandum of Agreement (MOA) comprising several groups to complete the IPM process. Signatories and participants in the MOA included WGHOGA, Washington State Department of Agriculture (WSDA), Washington State Department of Fish and Wildlife (WDFW), Washington State Department of Ecology (WDOE), Washington State University (WSU), Washington State Commission on Pesticide Registration (WSCPR), Pacific Coast Shellfish Growers Association (PCSGA), Pacific Shellfish Institute (PSI), the Toxics Coalition and the Ad-hoc Coalition for Willapa Bay. Per the MOA, an IPM Coordinator was hired and an IPM Committee formed with members from the signatory association and agencies.

Currently, IPM activities are not explicitly coordinated, but an IPM Advisory Committee is co-managed by the WSDA and WDOE. Members represent the two agencies, the Washington Department of Natural Resources, Washington Sea Grant, WSU Extension, shellfish producers, and other regional natural resource stakeholders.

Funding

Funding Sources

Sources include the Willapa Grays Harbor Oyster Growers Association (WGHOGA), Washington Sea Grant, the Washington Department of Agriculture, National Oceanic and Atmospheric Administration (NOAA), the United States Department of Agriculture - Agriculture Research Service (USDA-ARS), WSDA and additional potential grant funding sources.

Funding Cycles

Funding and budgeting cycles should coordinate with research cycles. Budgeting should align with the cycles of bivalve aquaculture and burrowing shrimp. Usually, research cannot begin until late spring and funds must be provided long enough before that to allow for adequate planning, study site assessment, and coordination with collaborating growers and other researchers. The budget cycle should be long enough to allow for project completion, which includes data analysis and write-up.

Research & Development of Management Tactics

Research Personnel

Personnel currently conducting research and development include WGHOGA, USDA-ARS, UW, PSI, and private consultants. However, future research personnel will likely be different than those who have conducted many of the studies of alternative management tactics for the last couple of decades. A prominent investigator in much of the previous research of potential management tactics for burrowing shrimp, Dr. Kim Patten (WSU Extension) retired in 2020 and his position is currently unfilled. In addition, another senior investigator, Dr. Brett Dumbauld, USDA-ARS, has studied burrowing shrimp biology and estuarine ecology in Willapa Bay for nearly fifty years but will likely retire within five to ten years.

Although graduate students and post-doctoral fellows conduct a lot of good and relevant studies in Willapa Bay, their tenure is relatively short (<3 years) and often involves seasonal relocation. Principle Investigators (i.e., Dr. Jennifer Ruesink) have usually been superbly qualified and the results have led to consistent progress. However, the future of such programs is always tenuous, especially at research sites remote from university campuses. Additional ways to help graduate students and post-doctoral fellows conduct research in Willapa Bay, such as finding housing or part-time jobs could be helpful.

Most of these investigators know one another well and have collaborated on several projects, and sometimes on projects with different funding sources. That collaborative is currently being fostered by Dr. Dumbauld on efforts to further map the density and distribution of burrowing shrimp in Willapa Bay. WSG has extended that collaborative effort.

Research Topics

The rescaled and updated IPM Paradigm suggests that burrowing shrimp in Willapa Bay and Grays Harbor could be managed with multiple tactics and research towards that should continue. Dr. Dumbauld is studying the potential of biological sculpin and associated parasitic nematodes as potential biological controls. John Chapman (Oregon State University) has continued to study the potential of a bopyrid parasite, also for potential biological control but currently lacks funds to proceed. Paradox Natural Resources is studying the efficacy of combined mechanical habitat destruction and treatments with 25b materials (e.g., aromatic oils and azadirachtin compounds).

A range of management tactics were discussed and prioritized for future research by participants and attendees following a workshop organized by WSG, and its Washington Coast Shellfish Aquaculture Study group in South Bend in October 2019. Specific management tactics proposed for research and development will ultimately be prioritized by the existing IPM committee and their selected advisors within state agencies. Criteria for prioritization will include potential for expected efficacy, potential for sustainability (but see “Regulatory Compliance / Policy” below) and expected timeline to implementation. Studies will also be judged in terms of their cost, so research grants and awards should be actively sought.

Implementation

As in the original IPM Program, management tactics will be implemented using conventional extension tactics such as demonstration trials, workshops, and newsletters.

This Framework for IPM of Burrowing Shrimp suggests that some management tactics that have been demonstrated as useful but may have been discontinued along with the carbaryl management program and the incipient imidacloprid program, should be reinstated. In particular, the density and distribution of burrowing shrimp on commercial shellfish ground should be monitored annually by a single independent expert, as it was prior to the applications of carbaryl. The resulting information would inform growers, agency personnel, and other stakeholders of the continued impact of burrowing shrimp to the local shellfish industry.

Regulatory Compliance / Policy

The regulation element related to burrowing shrimp management in Willapa Bay applies mostly toward agency (i.e., Washington State Department of Natural Resources, Washington State Department of Ecology, Washington State Department of Agriculture) and requirements to assess tactics for their potential to impact non-target organisms and the environment. In keeping with the rescaled IPM Paradigm, regulatory guidelines, requirements, and policy should align with current and developing understanding of estuarine ecology and utilize currently accepted and applicable experimental methodology. Currently, that is not always the case.

For the most part they do not at present. Agencies are often given wide discretion to interpret regulations, even within the Washington Authority Code (WAC). That discretion should sometime be applied, or in other cases, regulations should be revised, or new policy developed.

The assessment of impact to the benthic infauna following chemical application is a case in point. To be fair, the Sediment Management Standards for Washington State (WAC 173-204) were developed primarily to assess impacts and cleanup from an isolated accident such as a chemical spill. They were likely not originally intended to address the effects related to the management of a benthic pest of shellfish aquaculture. Furthermore, particular aspects of WAC 173-204 were not directly applicable to the situation until Washington State adopted EPA authorization of an NPDES requirements for a such a pesticide in 2002.

Although the Sediment Management Standards grants some leeway to Ecology regarding its application towards the chemical treatments previously used to manage burrowing shrimp, Ecology focused on the Puget Sound marine criteria for benthic abundance (WAC 173-204-320 (3)C) as applied to describe the size and magnitude of the Sediment Impact Zone affected by the chemical treatments both for carbaryl and imidacloprid. Basically, the criteria for effects were based on 6 metrics: numerical abundance and taxonomic richness of each primary taxonomic assemblage of polychaetes, mollusks, and crustaceans. An effect was considered to have occurred if a metric from data in a treated plot was 50% less, by a t-test, and significantly different (p=0.05) than its value, from data in an untreated (reference) plot.

Rather than a statistical comparison of the two most basic community descriptors, current comparisons of ecological communities feature a multivariate approach (see Gauch 1982 for a description of the analysis and VanBlaricom et al. 2015 for a relevant example). Booth et al. (2019) re-examined the benthic invertebrate data from the 2011, 2012, and 2014 imidacloprid field trials using Principal Response Curve (PRC) analysis.

Another obstacle to complying with WAC 173-204-320 (3)C, and to study impacts to the estuarine environment in general is the difficulty to distinguish anthropogenic from natural stress in estuaries in general. This problem has been termed the Estuarine Quality Paradox (Dauvin 2007, Elliott and Quintino 2007). The paradox is especially characteristic of an estuary in environmental homeostasis (Elliott and Quintino 2007). The highly variable estuarine habitat confounded the identification of suitable reference or control sites in studies of both the impacts of imidacloprid (Booth et al. 2019) and geoduck aquaculture in Puget Sound (VanBlaricom et al. 2015).

Dissemination

Washington Sea Grant is currently the primary party responsible for dissemination of past and current progress toward IPM of Burrowing Shrimp. A comprehensive list of management tactics previously studied from the late 1950s to ~ 2018 for their potential use against burrowing shrimp is presented in WSG's forthcoming document, "Willapa Bay and Grays Harbor: A Synthesis of Knowledge". Recent and on-going research studies were presented at a workshop organized by WSG, and its Washington Coast Shellfish Aquaculture Study group in South Bend in October 2019. Related topics have also been organized and presented by the group via on-line workshops. Related studies have also been presented at Washington Sea Grant's Annual Shellfish Growers Conferences.

Washington Sea Grant should remain the primary organizer of such workshops for IPM program dissemination for the foreseeable future, provided adequate funds are available.

Research investigators should be encouraged and given the opportunity to publish results in peer-reviewed scientific journals.

Evaluation of the IPM Program

In keeping with the conceptual emphasis placed on the ecosystem described above, and following Peterson's (2018) adage to focus on the host rather than the pest, the IPM Program for burrowing shrimp should be evaluated, at least in part, on farm productivity rather than burrowing shrimp density. In this regard, shellfish growers will be the ultimate evaluators of program success.

The IPM Program for burrowing shrimp will ultimately be evaluated by its degree of implementation and its ability to allow for the sustainable production of oysters and clams in Willapa Bay and Grays Harbor. These and other variables should be quantified, if possible, by using grower surveys, both in writing and conversation.

Maintain a Centralized Knowledgebase of Relevant Literature, Reports, etc.

A centralized knowledgebase of relevant literature has already been established, in part, while producing Washington Sea Grant's forthcoming comprehensive document "Willapa Bay and Grays Harbor: A Synthesis of Current Knowledge". The synthesis includes in depth literature reviews of the ecology and socio-economy of the estuaries with separate chapters on: 1) Geography, history, and socio-economy, 2) Species of concern, including oysters, manila clams, burrowing shrimp, eelgrass, and important migratory species (salmon, green sturgeon, waterfowl, and migratory mammals, 3) Ecological interactions between shellfish aquaculture, burrowing shrimp, and eelgrass, 4) burrowing shrimp management, and 5) Future directions. The knowledgebase was established on the "Sciwheel Reference Manager and Developer" website by former Washington Sea Grant Aquaculture Specialist, Alex Stote with contributions by the authors of the synthesis and is currently maintained by the current Aquaculture Specialist, Nicole Naar.

The Sciwheel site currently holds 484 scientific manuscripts in pdf format, many with extensive notation. Because it was constructed for the Synthesis project, most of those citations are not directly relevant to this IPM Framework project. Most articles are scientific articles written for an audience already steeped in the subject; they are technical and not directly accessible to the audience of this document.

Accordingly, a preliminary "Annotated Bibliography Relevant to the Integrated Management of Burrowing Shrimp" has been created and will be presented as a supplement to this Framework. Content is mostly the literature cited here, arranged according to these sections. The full citation is presented followed by a very concise description of what the article is about. We suggest the annotated bibliography should be regularly updated and made available to selected parties via password-protected website(s) such as Washington Sea Grant, an established Google Drive, or social media.

The person or persons that maintain the bibliography, as well as how the project might be funded is yet to be determined.

Summary

Management of burrowing shrimp in Willapa Bay and Grays Harbor is unique worldwide. There are no similar IPM programs to provide a model for Integrated Pest Management, even in aquatic systems. Still, the basic processes and tenets provide the means to provide a conceptual paradigm and framework for an IPM program for burrowing shrimp in Willapa Bay and Grays Harbor.

In the most general terms, Integrated Pest Management (IPM) describes processes to make a pest management decision that will impact, in one way or another, not just the production of an agricultural crop, but also both the ecological functions and socio-economy associated with the pest(s), the crop and the surrounding environment. For several decades, the management of burrowing for bivalve aquaculture in Willapa Bay and Grays Harbors estuarine tidelands has resembled IPM at its primary levels (small farms, single crop, single pest, minimal monitoring, single management tactic). The program also resembled a "reduced risk" management program.

Currently, the scale of the bivalve aquaculture in southwest Washington and its associated socio-economy is more extensive and broader than before. We also now understand that the structure and function of estuarine biotic communities is more complex than previously understood. Estuarine conditions are extremely variable and that has resulted in resilient biological communities, even in response to irregular large disturbance. This has implications for how those communities respond to a pulse treatment against burrowing shrimp. It also implies a larger conceptual role of the ecosystem in the management of burrowing shrimp. Although it is tempting to consider an Ecosystem Based Management (EBM) program, IPM remains a suitable framework. The IPM paradigm for burrowing shrimp was revised and rescaled to reflect the greater conceptual role of the ecosystem. The revision also implies that some aspects of the IPM Elements (Funding, Research & Development, Implementation, Evaluation / Regulatory Compliance, and Dissemination) should also be revised. For example, this updated framework for IPM of burrowing shrimp separates the Regulatory element from the Evaluation element.

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