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By gaining greater understanding and appreciation of wetland environments, managers have developed creative insights for waterfowl conservation. Among the most exciting new developments in the understanding of functional wetlands has been the recognition of the important roles of invertebrates in aquatic ecosystems. These roles include trophic linkage from primary production to secondary consumers such as waterfowl, packaging of specific nutritional components such as amino acids and micronutrients for vertebrate predators, and detrital processing of wetland organic material. Although specific invertebrate responses to various management techniques are not always predictable and may differ among invertebrate species, patterns related to water regimes, water chemistry, and vegetative structure have emerged. Managers should consider the following invertebrate responses to natural and manipulated wetland complexes when managing for waterfowl.

Importance to Waterbirds

Although wetland systems are some of the most productive ecosystems in the world in terms of vegetation biomass, few duck species acquire substantial energetic or nutritional resources directly from consumption of plant material other than seeds. Much of the energy from plants is initially transferred to the primary consumers which include a diverse group of invertebrate species. A variety of invertebrates are consumed by waterfowl. Ducks rely heavily on invertebrates as a major food source throughout the annual cycle. Dabbling and diving ducks use invertebrates extensively during protein-demanding periods, such as egg laying or molt (Table 1). Duck species are adapted to consumption of invertebrate prey by selection of microhabitats, structure of the bill and lamellae and foraging strategies.

Relation to Water Regimes

Long-term hydrologic cycles have shaped the life history strategies of wetland invertebrates. These organisms have developed many adaptations that include:

- egg or pupal stages which can tolerate drought periods,
- initiation of egg development only after specific water/oxygen levels have been reached,
- marked seasonality in life cycle,
- rapid development,
- large number of offspring (high reproductive potential)
- obligate diapause (period of nondevelopment) tied to seasonal flooding, and
- parthenogenic reproduction (as in cladocera).

Invertebrates often move into deeper pools, wetland sediments within the water table, and other nearby wetlands when water levels drop or change within a specific wetland. Many species (e.g.,

Table 1. *Invertebrates consumed by laying female waterfowl collected from 1967 to 1980 in North Dakota. Data expressed as aggregate percent by volume. Modified from Swanson 1984.*

Food item	Blue-winged teal (20)	Northern shoveler (15)	Gadwall (saline) (20)	Gadwall (fresh) (35)	Mallard (37)	Northern pintail (31)
Snails	**38**	**40**	**0**	**4**	**16**	**15**
Insects	**44**	**5**	**52**	**36**	**27**	**37**
Caddis flies	7	tr	1	8	9	1
Beetles	3	2	16	4	5	3
True flies	32	2	26	18	6	3
Midges	20	1	26	17	4	20
Miscellaneous	2	1	9	6	7	0
Crustaceans	**14**	**54**	**20**	**32**	**13**	**14**
Fairy shrimps	5	6	tr	0	4	14
Clam shrimps	tr	7	0	14	6	tr
Water fleas	0	33	10	10	3	tr
Scuds	8	0	0	7	tr	tr
Miscellaneous	1	8	10	7	tr	tr
Annelids	**1**	**0**	**0**	**tr**	**13**	**11**
Miscellaneous	2	0	0	0	3	0
Total	**99**	**99**	**72**	**72**	**72**	**77**

leeches, crayfish) will burrow in sediments to avoid desiccation. Adults of several insect groups may fly to other wetlands if conditions become unsuitable. Flight distances may be less than a few yards to another basin within a wetland complex or more than 50 miles to a distant wetland.

Long-term hydrologic changes shape invertebrate life history strategies. Short-term hydrologic regimes may determine the actual occurrence and abundance of invertebrates. Flooding affects wetland invertebrate occurrence, growth, survival, and reproduction. Entirely different invertebrate communities (Fig. 1) are present in wetland basins with differing hydrological regimes (timing, depth, and duration of flooding). As litter is flooded, nutrients and detrital material (as coarse particulate organic matter) are released for a host of aquatic invertebrates (Fig. 2). As material is broken down into finer particles (fine particulate organic matter), organisms that gather detritus or filter feed will take advantage of the newly available foods. Grazing organisms (Fig. 3) feed on free-floating algae or periphyton, which grows on aquatic plant surfaces. When litter material is consumed, invertebrate populations decrease rapidly. Thus, prolonged flooding (longer than 1 year) of uniform depth leads to reduced wetland invertebrate numbers and diversity. Freezing may also lower spring invertebrate populations in northern locations.

Association with Vegetation Structure

Water regimes not only directly affect invertebrate populations, but indirectly affect other fauna through modification of aquatic plant communities. Hydrological regimes influence germination, seed or tuber production and maturation, and plant structure of aquatic macrophytes. Invertebrate associations are influenced by the leaf shape, structure, and surface area of aquatic vegetation. Macrophytes with highly dissected leaves, such as smartweeds, tend to support greater invertebrate assemblages than do plants with more simple leaf structure, such as American lotus (Fig. 4). The composition of invertebrate populations is associated with plant succession.

Discing and other physical treatments are regularly used to modify less desired plant communities. Initial invertebrate response is great following shallow discing in late summer when the shredded plant material is flooded immediately. The shredding of coarse litter material by discing results in quick decomposition in fall, but invertebrate numbers are reduced the following spring. Cutting robust, emergent vegetation above the ice in winter can also result in a rapid invertebrate response, after spring thaw.

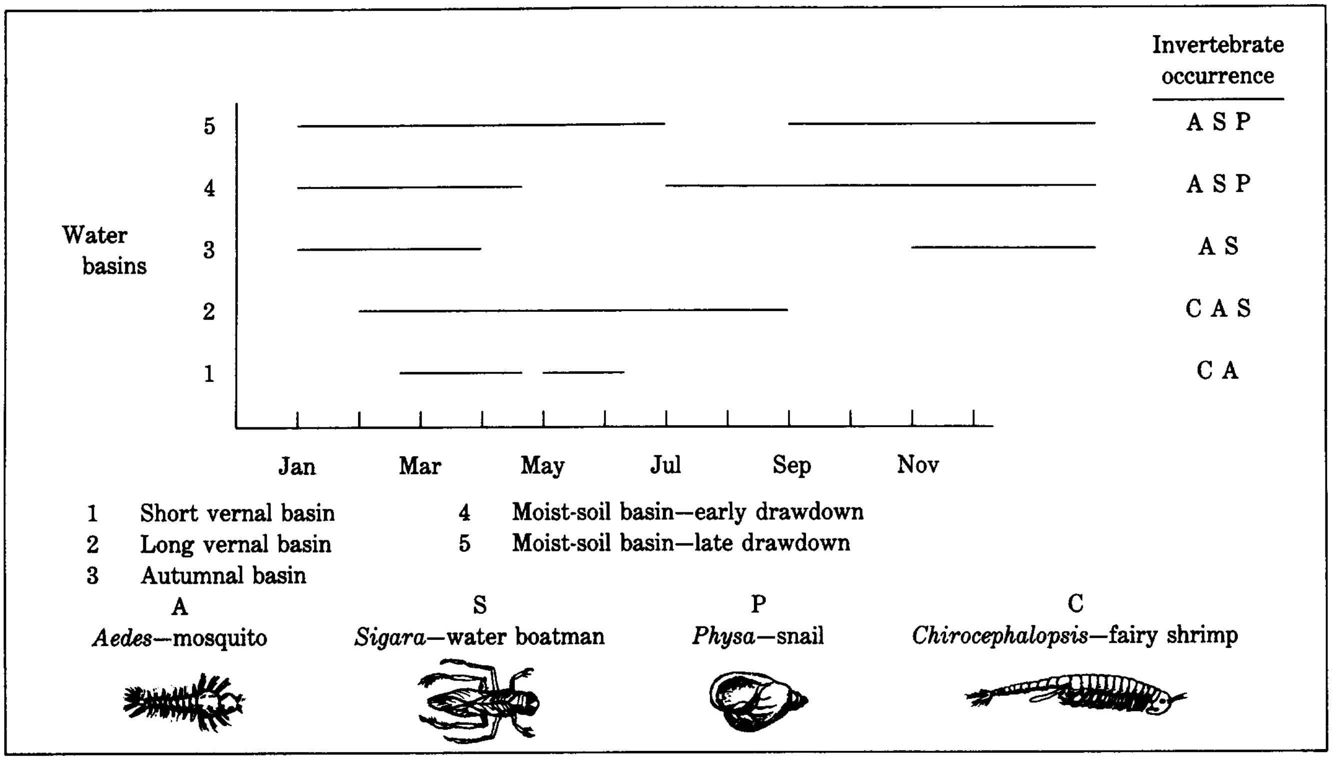

Figure 1. Occurrence of four common invertebrate genera relative to water regimes of five different seasonally flooded basins. Horizontal lines represent presence of water.

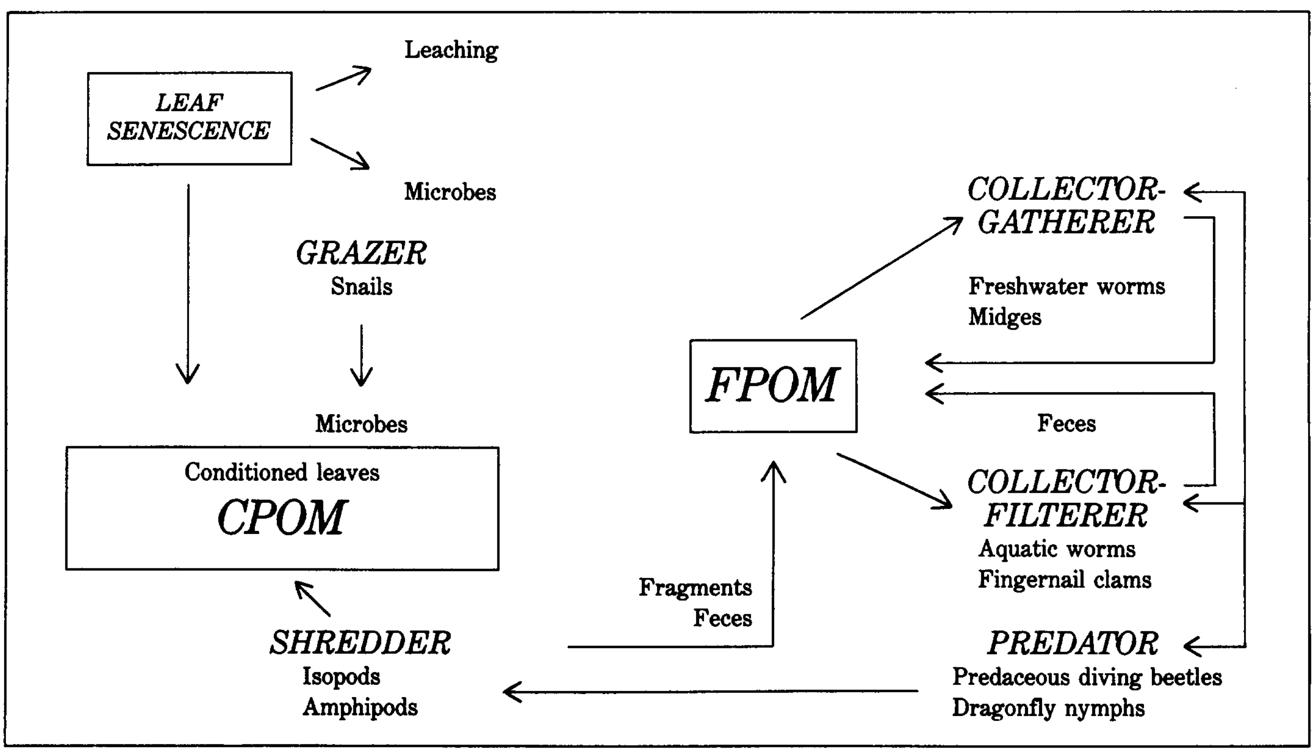

Figure 2. Invertebrate detritivore community. CPOM = Coarse particulate organic matter; FPOM = Fine particulate organic matter.

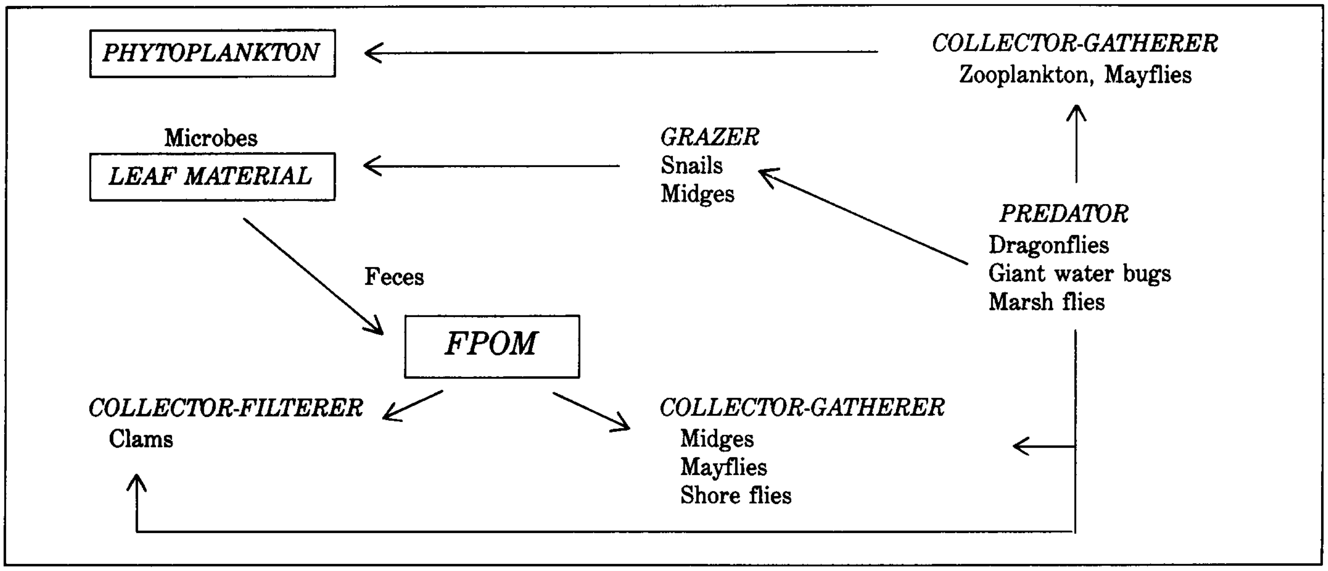

Figure 3. Invertebrate grazer community. FPOM = Fine particulate organic matter.

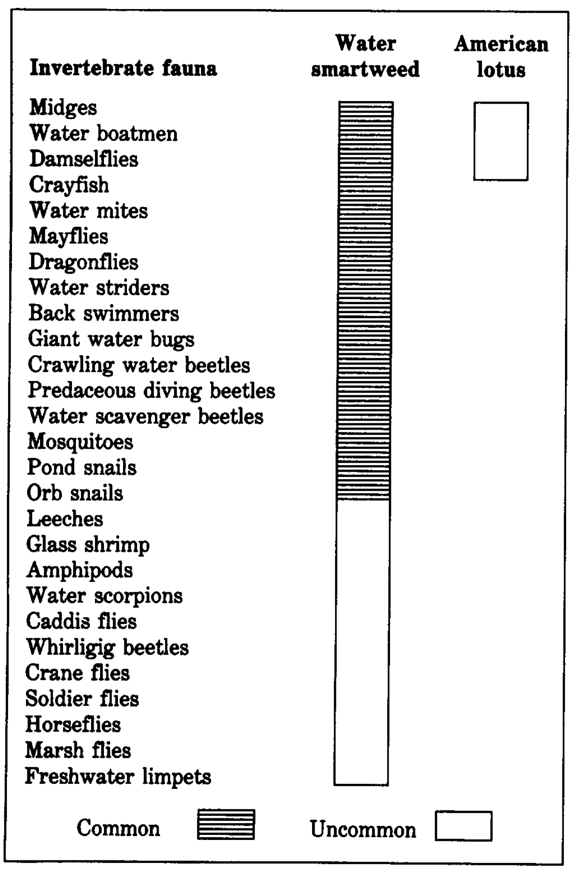

Figure 4. Macroinvertebrates associated with water smartweed and American lotus in seasonally flooded wetlands.

Management Implications

Acquisition of wetlands or protection of previously acquired wetland complexes will continue to be the best means to support diverse invertebrate fauna. The restoration of disturbed wetlands has its greatest potential in areas of marginal agricultural lands. Pesticide use should be eliminated on all refuge areas, regardless of proximity to urban sites where mosquito control is a concern, or the quality of such wildlife areas will be reduced. Inflow waters must be monitored for pollutants and pesticides. The timing of water movements should coincide with the exploitation of leaf litter by invertebrates. Waters should not be drained when nutrient export may be high, such as in early stages of leaf litter decomposition. Present knowledge of water manipulations suggests that management for specific aquatic or semi-aquatic plant communities may be the most practical means of increasing invertebrate production. Managers can enhance the potential for invertebrate consumption by waterfowl if peak periods of waterfowl use of wetlands coincide with reduced water levels. Exploitation of invertebrates by waterbirds can be optimized through shallow water levels, partial drawdowns that concentrate prey, and extended (3–5 week) drawdowns with "feather-edge" flooding to increase the available time and area for foraging.

Suggested Reading

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Appendix. Common and Scientific Names of Plants and Animals Named in Text.

Plants

American lotus	*Nelumbo lutea*
Smartweed	*Polygonum* spp.
Water smartweed *or* marsh knotweed	*Polygonum coccineum*

Birds

Northern pintail	*Anas acuta*
Northern shoveler	*Anas clypeata*
Blue-winged teal	*Anas discors*
Mallard	*Anas platyrhynchos*
Gadwall	*Anas strepera*

Invertebrates (Families)

Crayfish	Astacidae
Giant water bugs	Belostomatidae
Midges	Chronomidae
Water boatmen	Corixidae
Mosquitoes	Culicidae
Predaceous diving beetles	Dytiscidae
Water striders	Gerridae
Whirligig beetles	Gyrinidae
Crawling water beetles	Haliplidae
Water scavenger beetles	Hydrophilidae
Pond snails	Lymnaeidae
Water scorpions	Nepidae
Back swimmers	Notonectidae
Orb snails	Planorbidae
Marsh flies	Sciomyzidae
Soldier flies	Stratiomyidae
Horseflies	Tabanidae
Crane flies	Tipulidae

Invertebrates (Orders)

Scuds *or* sideswimmers	Amphipoda
Leeches	Annelida
Fairy shrimp	Anostraca
Water fleas	Cladocera
Beetles	Coleoptera
Clam shrimp	Conchostraca
True flies	Diptera
Mayflies	Ephemeroptera
Water mites	Hydracarina
Isopods	Isopoda
Damselflies, dragonflies	Odonata
Caddis flies	Trichoptera

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