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I. Summary

A variety of roles have been attributed to our tidal marshes. These wetlands serve as the natural habitat for a characteristic group of plants and animals that are involved in an ecological complex. There is a unique group of invertebrates, the best known being the mosquitoes, associated with particular vegetation zones, tidal reaches and salinity gradients. There is a particular assemblage of birds, mammals and other vertebrates that are identified with these marshes deriving food, shelter and sites for raising their young.

In recent years scientists have come to the realization that these tidal marshes are an ecological intermediate, an ecotone between the uplands on one hand and the open sea on the other; deriving input from both, contributing to both yet retaining its own unique identity. It is a place of receipt, reconstitution and deliverance of vital nutrients to that very highly productive system, the estuary.

Added to these natural roles are those that are vitally important to man. The marshes have served as sources of food and now recreation. Financial income has been derived. For centuries people have tried to use them for agricultural products, generally with limited success. Now, in addition to all these roles, we must add those of industrial and recreational development, sources of gravel, road building materials, building sites for industry and homes, and solid waste disposal. Add to this the ambiguities of ownership and we have the very real development of interest conflicts.

What will be the outcome on the floral and faunal associations of these tidal wetlands brought about by the interplay between these various and often conflicting roles?

There has been some kind of tidal marsh land manipulation for centuries. It has been motivated by the seeming need for more agricultural land, disease and insect pest control and the desire to restore an ecological balance with particular reference to wildlife. Much of the change in tidal marshes stems from a comprehension of the life cycle of the salt marsh mosquito.

Tidal marsh land management can take several forms centered about two distinct approaches, water manipulation and burning. The maintenance of the ebb and flow of the tide is a natural control. Drainage by ditching to remove water from the marsh surface as quickly as possible is another form of management. Impounding water behind a dike or to exclude water from an area is still another type. Burning will remove vegetation and the intensity of the burn will determine the magnitude of effect. These various forms of management are designed to control, an insect or other animal or plant, to change and by implication improve habitat, to increase the availability of food and to facilitate the successful reproduction of desirable species.

Drainage and diking have been employed for centuries for agricultural purposes. Drainage by ditching for mosquito control started at the turn of the century in this country. It reached its peak during the thirties when ditching was used as a means of putting the unemployed to work. Accomplishments were measured in the miles of ditches dug each year in the tidal marshes.

. Conflicts began to arise at this time between mosquito control efforts and wildlife interests. There was the advocation of biological control based on sound ecological principles and biological data pertaining to the species involved rather than the continuance of physical control methods. There was the insistence there were other organisms in addition to mosquitoes associated with the marsh land and all needed to be considered as a part of this complex. The outcome of these use conflicts instigated new concepts for mosquito control and wildlife restoration by enhancing tidal inundation through quality ditching rather than universal ditching, by the restoration, establishment and maintenance of permanent water pools, restoration of ground water levels and an increase in the diversity of habitats.

The effects of ditching are many. The flora is affected by the lowering of the water table as the vegetation at the lower levels of vertical zonation is replaced by more upland species, often at a very rapid rate. This is the generally recognized result although in a few instances ditching has been reported to have no effect.

Ditching tends to reduce the numbers of mosquitoes and may help control biting flies. But to be effective, the ditches must be dug straight, wide and deep and kept clear of vegetation. Considerable evidence has accrued which indicate it is not necessary to ditch a whole marsh to control these biting insects, and the ecological side effects may be greater than the objective of mosquito control.

The adverse effects of ditching include drastic declines in various invertebrates especially the molluscs and crustacea which serve as important items in the diets of many waterfowl, shore and wading birds. Bird numbers decline because of this lost food supply as well as from loss of pools drained by ditching. Ditching can in certain places enhance clapper rail production by stimulating _S. alterniflora_ growth. Muskrats also decline in numbers as well as individual weights through the change to less palatable food plants as well as less desirable house building material, lowering water levels in the area of the houses, or greater intrusions of higher salinity waters.

Impoundments have other effects. Vegetation tend to change to a more hydric association. A few pockets of marsh plants may hang on, but this is a reflection of extent of inundation. More emergent forms will appear and submergent vegetation is encouraged. Mosquitoes are not eliminated. The really obnoxious flooding water salt marsh group are replaced by permanent water species. Even these species can be controlled by manipulating water levels. Diking for salt hay production greatly enhances salt marsh mosquito breeding with an associated decline in wildlife activity.

There is little information available on the changes in invertebrate populations subjected to impoundments. Fish species are encouraged by increasing their ability to move about over the marsh surface fostering predation on mosquito larvae. There is a tendency to shift toward fresher water fish species and other vertebrates. Muskrats are encouraged so long as water levels do not become too great and emergent vegetation develops. Waterfowl and most other bird species greatly increase activity with the establishment of impoundments through increased food, shelter and nesting sites. Some of the passerine birds will decline in numbers due to a reduction of their particular forms of food supplies and nesting sites.

Each vegetational zone in a tidal marsh has its characteristic fauna. There is a progressive change with time culminating in a climax stage. This sequence can be temporarily reversed to some degree by natural phenomena such as a storm or a wildfire. The degree of retrogression is determined by the magnitude of impact. Man alters this succession. Ditching tends to hasten succession toward an upland community by lowering the water table or in effect raising the elevation. Impoundments, exclusive of diking for salt hay, and burning have a recessional effect to or toward an open water community. Such a regression from the climax community toward a lower vegetational stage is considered to be more valuable for wildlife species.

The edge effect, an important concept in wildlife management, can be increased with proper marsh land management, providing a greater diversity of habitats. This is particularly true for the various forms of impoundments and champagne pools by the construction of dikes and the establishment of patches of emergent vegetation in open water areas or along dikes and ditches. Spotty burns rather than clear cover burns also enhance the edge effect. This condition can also be created with ditching if water levels can be maintained.

Feeding activities of waterfowl and muskrats can have an impact. Goose "eat-outs" in a Spartina patens marsh can markedly change the amount of mosquito breeding. These same goose "eat-outs" can alter muskrat food supplies which will induce destructive muskrat "eat-outs". Such damage will drive muskrats from the area and induce a variety of successional changes in the vegetational associations. If severe enough, there will be a retrogression back to the open water community. While these "eat-outs" are destructive to geese and muskrats, they can for a short time be quite beneficial to ducks, and to wading and shore birds.

Competition for food can develop between geese, muskrats and/or cattle. This competition can be intensified by unwise selection of times for burning. Vegetational changes can also be induced by sheep grazing.

The role tidal marshes play in the biological economy of Delaware Bay has received considerable attention of late years. An understanding has been acquired of tidal stream hydrography and its relation to water quality with particular reference to flushing rates and levels of oxygen, phosphorus and nitrogen as well as the ichthyoplankton found in these streams. The inverse relationship between phosphorus and nitrate cycles has been described and possible explanations presented with reference to the sulfur and nitrifying bacteria. Productivity of the edaphic algae and spermatophytes has been recorded along with the seasonal patterns associated with this production. The environmental factors of temperature and light have received particular attention. The effect of various forms of physical marsh land manipulation as related to phosphate levels in marsh waters has been studied. Changes brought about by light manipulation and fertilizer applications on the short *Spartina alterniflora* plant community has been receiving attention.

Numerous workers have reported on the damages done to our tidal marshes by drainage practices and other uses not natural to the habitat. Wildlife species have suffered great losses. Mosquitoes have not been eliminated nor has agricultural production been increased by the use of these drained lands. Use conflicts have been generated. Any habitat management will alter the structure of the ecological community and the implementation of any management procedures must be based on sound ecological principles and done in a way to minimize the magnitude of ecological impact on the community. The use of these tidal lands should be based on a careful evaluation of the existing potentials for the various uses under consideration in relation to the ecological parameters of the area. Such evaluations must be carried out in conjunction with the long run values of the marsh in its natural state relegating short term goals to a secondary position.

II. Management Recommendations

1. A first principle should be that tidal marsh management should be kept to the minimum with as little impact on the environment as possible.

2. Ground water levels should be maintained at maximum heights. This will (1) retard the development of the *Spartina patens* climax stage with its associated high incidence of the salt marsh group of mosquitoes; and (2) provide more suitable foods for various wildlife species.

3. Wide spread ditching should be halted. If ditching must be carried out it should be in areas with a demonstrated high incidence of mosquitoes. It should be done in such a way that ground water levels are not lowered. Blind ditches would achieve this.

4. Permanent pools must be established or renewed where they once existed. Mosquito eating fish should be permitted to move about over the marsh during flood tide conditions. Such conditions can be enhanced by the creation of champagne pools where water levels can be manipulated.

5. High level and low level impoundments should not be developed further because of construction and maintenance costs and questionable value as a method for mosquito control.

6. Habitat diversity for wildlife should be enhanced. This can be done: (1) along the upland edge of the marshes by judicious land cultivation and plantings; (2) by careful construction and maintenance of spoil piles on the marsh resulting from quality ditching associated with the champagne pools so long as undesirable vegetation can be controlled; (3) by maintenance of a

patchy distribution of submergent and emergent vegetation associated with the permanent pools; (4) by the use of spotty cover burns, in the spring on prime muskrat marshes and in the fall on waterfowl marshes.

7. The tidal exchange between the marsh lands and the adjoining estuary should not be impeded by dikes, sluice gates, etc. Where champagne pools are established this tidal flow should be maintained commensurate with wildlife and mosquito control needs.

8. Sewer outfalls should not be placed in the upper reaches of tidal streams where flushing rates are the lowest. Such outfalls, if they must be established, should be placed in the lower estuarine portion of a tidal creek where the flushing rate is the greatest. Such discharges must be so processed that eutrophic and anoxic conditions cannot become established.

9. Consideration should be given to the possible use of sewage compost as a source of nitrogen for the enhancement of marsh primary productivity and its subsequent effect on the higher trophic levels of the marsh and estuarine food chains.

10. Communications must be maintained and encouraged between the various biological interests and the economic facets associated with tidal marsh lands.

11. Basic research pertaining to tidal marsh lands must be enhanced at all levels of ecological endeavor: effect of environmental factors on the individual marsh organisms, their populations, community structure and the marsh ecosystem.

III. Introduction

a) Role of Tidal Marshes

Warren (1911) reminds us that man has been manipulating tidal marsh lands for agricultural purposes since antiquity. Shaw and Fredine (1956) consider the Swamp Land Acts of 1849, 1850 and 1860 paved the way for a century of exploitation of these wetlands for agricultural purposes to their detriment and Penfound and Schneidau (1945) describe some of the ensuing results. Smith (1902) calls attention to the role of tidal marsh lands in mosquito breeding while Stearns, MacCreary and Daigh (1940) point out the economic role these marshes have played in muskrat production. Shaw and Fredine (1956) and Barske (1961) (see Bibliography for other references) stress the value of tidal wetlands in the lives of waterfowl and other wildlife by providing food, shelter and nesting sites. Niering (1961) talks about the contributions tidal marshes can contribute to education and scientific research. Their role as a source of food (Rankin, 1961) and mineral resources (Sanders and Ellis, 1961) has been identified. Odum (1961) calls attention to the very important role tidal marshes play in the great productivity of fish and shellfish in our estuarine and coastal waters. Daiber (1959) identifies the uses to which these wetlands are put with the ensuing conflicts of interest.

Richard Pough (1961) reiterates the natural beauty of these coastal marsh lands, of the near-sighted views of some people, and how, through the use of easements, we can retain this wild and muted beauty for ourselves and those that follow after us. Goodwin (1961) presents five ways for a course of action for maintaining our coastal lands in a clean and productive fashion: (1) land acquisition, (2) protection of lands already in public ownership, (3) control dredging and filling, (4) zoning and (5) education on a broad front. Odum (1961) reminds us in our concern for these tidal marsh lands we need to consider (1) a functional approach to both utilization and production, (2) that the estuary needs to be considered as a whole, (3) the great diversity inherent in this ecosystem and that one-crop development should be discouraged, and (4) ways to cope with the man-made alterations which originate from other than biological motives.

b) Natural Plant Distributions

Numerous authors have described the plant associations of tidal marshes and much of this has been brought together in Chapman's (1960) treatise. For the New England marshes he identifies the Spartina alterniflora glabrae (tall form of alterniflora) as the lowest most vegetation zone. This gives way with an increase in marsh level to Spartina patens which, in turn, is replaced by Juncus gerardi. Distichlis spicata is frequently associated with S. patens. Cottam et al. (1938) identified three vegetation zones as Spartina alterniflora, Distichlis spicata and S. patens. Penfound and Hathaway (1938) describe the vegetation zonation for the Gulf Coast marshes as does Purer (1942) for California marshes in San Diego County. Kerwin and Pedigo (1971) identify four marsh plant associations with their dominant species: (1) edge marsh, S. alterniflora (tallest forms); low meadow, S. alterniflora (low form); salt-grass meadow, Distichlis spicata; and high meadow, S. patens.

Many authors attribute various factors to this zonation. DeVido (1936) identifies (1) liability to submergence, (2) type of substrate, (3) salinity of the soil and water, and (4) adaptation to mechanical action of wind and sun. Adams (1963) mentions soil pH, depth of the water table and soil nutrients. Aeration of the soil as a factor is identified by DeVido (1936) and Chapman (1960).

However, tidal inundation and salinity are considered to be primary factors by many (Johnson and York, 1951; Penfound and Hathaway, 1938; Daigh, MacCreary and Stearns, 1938; MacNamara, 1952; Cottam and Bourn, 1952; Adams, 1963) in determining plant distributions. Cottam et al. (1938) say 0.1 foot change in water level can effect distributions. Penfound and Hathaway (1938) report a less than three-inch change in elevation can cause a transition from one community to the next. Adams (1963) identifies the mean elevation of occurrence above mean sea level divided by one-half of the mean tide range of the area concerned is a characteristic constant for each salt marsh species. Spartina alterniflora flourishes in open water, fresh water, and where frequent tidal flooding occurs but not where permanent flooding exists. It fails to attain normal growth flowering when the water table falls and is replaced by one of the hay species, S. patens, or Distichlis spicata which have smaller water requirements. The cattail Typha angustifolia prefers high water levels while Scirpus olneyi occupies an intermediate position (Daigh et al., 1938).

Salinity will effect plant distributions. In the Gulf Coast marshes Penfound and Hathaway (1938) identify the dominants in the fresh water marsh as *Typha* spp., *Scirpus californicus* and *Panicum hemitomon*, while the salt marshes are characterized by *Spartina patens*, *Distichlis spicata*, *Spartina alterniflora* and *Juncus roemariannus*. Bourn and Cottam (1939) relate that wild rice *Zizania aquatica*, smartweeds *Polygonum* spp. and wild millet *Echinochloa* spp. are found in the fresher marshes, and that wild rice occupies the same water level position as the tall form of *Spartina alterniflora* in saline areas, and as does *Spartina cynosuroides* in the intermediate brackish waters.

c) Natural Animal Distributions

There are characteristic animal distributions associated with the various plant communities. Many workers have pointed out the relationship between vegetation and mosquito breeding (Smith, 1902, 1907; DeVido, 1936; Connell, 1940; Florschutz, 1959(a); Catts et al., 1963; and Lake, 1965), the general consensus being that where the marshes are characteristically inundated by regular tides, there is little or no mosquito reproduction. However, *Spartina patens* is identified as having a heavy mosquito population, usually *Aedes sollicitans*. Darsie and Springer (1957) point out breeding is highest

Average number of *Aedes* larvae and pupae per dip (Ferrigno, 1958)

Plant species	*A. cantator*	*A. sollicitans*	Total
S. patens	0.31	6.95	7.26
S. alterniflora	0.01	0.37	0.38
mixture	0.29	2.42	2.71

adjacent to the uplands associated with Distichlis spicata, S. patens and S. alterniflora. Smith (1902, 1907) states mosquito breeding is reduced where fiddler crabs are abundant, providing surface drainage by their burrowing. DeVido (1936) relates mosquito abundance to vegetation which is frequently flooded but where mosquito predators cannot get among the plants. Along this vein Harrington and Harrington (1961) demonstrate that among fishes the area residents, such as the various Cyprinodont species, are the only important predators on mosquito larvae, that transients coming onto the marsh surface on a flooding tide generally ignore the larvae.

Surveys indicate larval green head flies (Tabanidae) are found in the wetter portions of the salt marsh (Hansen, 1952). However, Gerry (1950) pointed out these flies develop primarily in the higher portions of the salt marshes reached only by the higher tides. Depressions where water tends to accumulate are not attractive as larvae subjected to more than two days submergence are apt to drown. He went on to say evidence indicates the larvae originate in the creeks from which they migrate to thatch piles at the head of the marsh. Jamnback and Wall (1959) found the larvae associated with several species of salt marsh vegetation but most abundant in S. alterniflora and S. patens. They always found them in conjunction with vegetation or thatch piles. Contrary to Gerry they believe the larvae can survive in water for a long time. Olkowski (1966) found most larvae among the S. alterniflora with fewer individuals present as ground elevation increased toward S. patens. The mature larvae seem to be disseminated to higher ground by tidal action.

MacCreary (1940) describes ditches filled with water and overhanging vegetation as being excellent sites for egg deposition and larval development.

Davis and Gray (1966) identify the generally characteristic insect fauna for each North Carolina salt marsh plant community. They point out the highly dissimilar fauna for the two types of high marsh, Distichlis having a much larger number of insects than Spartina patens.

MacDonald (1969) has done a detailed study of the molluscan fauna of the Spartina-Salicornia salt marshes and tidal creeks of the Pacific coast. Each contains its distinctive fauna characterized by one or two widely distributed and abundant species. While other species are patchily distributed and low in numbers, the structure of each community is fairly uniform throughout the faunal province. Teal (1958) describes the distribution of fiddler crab species in a Georgia marsh being related to plant community and substrate. Kerwin (1971) reports Uca minax widely distributed among vegetation types within the salinity range of 2-16 $^{o}/oo$. High population densities are associated with the tall and short Spartina zones and the edge of the Distichlis-S. patens community. The snail, Melampus bidentatus, is associated with the brackish water marsh dominated by Spartina alterniflora-Scirpus robustus stage and Spartina cynosuroides, and in the salt water marsh with a percent frequency of 22.1 percent compared to 2.9 percent for the brackish, and an average density of $7.24/m^2$ compared to $0.23/m^2$ in the brackish water marsh (Kerwin, 1972).

There are various forms of bird life specialized to nest and feed in salt marshes (Urner, 1935). Their distributions are related to the wetness of the marsh, creek and pond depth, salinity and accessibility of tides. Clapper rails are associated with a low wet marsh while birds like the bittern, pied billed grebe and coot have a marked preference for a stable water level.

The distribution of muskrats is related to salinity, as salinity increases the populations of muskrats declines. They prefer the less saline types of vegetation for food such as the brackish water three-square sedges, Scirpus spp., and the cattails, Typha spp. (Stearns and Goodwin, 1941). Muskrats are most abundant in the upper reaches of tidal streams and marshes where the water is fresher and the tidal amplitude is reduced (Dozier, 1947). Higher average weights are recorded for muskrats taken from the fresher, less brackish portions of a marsh (salinity 0-10 $^{o}/oo$ and vegetation - Scirpus-Typha) as opposed to higher saline areas (salinity 15-43 $^{o}/oo$ and vegetation - Spartina spp., Scirpus, Typha, Juncus) (Dozier, Markley, Llewellyn, 1948).

d) Tidal Marshland Management and the Ensuing Changes in Ecological Associations

There has been some kind of tidal marsh land manipulation going on for a long time. It has been motivated by the seeming need for more agricultural land (Warren, 1911), the desire to reduce mosquito born diseases (Means, 1903) and the desire to restore an ecological balance with particular reference to wildlife (Gabrielson, 1936). Much of the present day tidal marsh changes have their bases in the understanding of the life cycle of the salt marsh mosquito Aedes sollicitans (Smith, 1902). Since there is a well established relationship between the natural distribution of salt marsh plant communities and their associated animal populations, how does tidal marsh land management affect these floral and faunal associations?

IV. Tidal Marshland Management

a) Types

1. Water. The management of tidal marsh lands can take several forms. Natural tidal inundation can be a factor limiting the distribution of mosquitoes. Connell (1940) points out that young Aedes larvae fail to appear in portions of a tidal marsh which is flooded by tides as frequently as 25 days per lunar month. He goes on to say abundant mosquito breeding can be expected in portions of Spartina alterniflora marsh where the frequency of tidal inundation is less than eight days per lunar month. This would imply that if all tidal wetlands were to remain as low marshes, as defined by Chapman (1960, p. 50), there would be few mosquitoes. However, it is well established that all tidal wetlands are not equally covered and flushed by the tides. Since the upper marshes characterized by Spartina patens retain pockets of water facilitating mosquito breeding some other form of water management is called for.

Stearns (1951) clearly states water management implies there can be various ways in which a water problem can be handled and, if used judiciously, such management might be the approach for those areas where there are conflicts of interest. Stearns considers drainage to be a form of water management in that it is a process of drawing off water from an area by degrees. To facilitate such drainage, ditches are dug by plows or entrenching machines or by blasting across the surface of the marsh in a regular pattern to move water into tidal creeks from the marsh surface. Any surface pools and low spots are connected to the streams by such ditching.

Another form of water management is to impound water behind dikes so an area is variously inundated. Christopher and Bowden (1957) consider water management, properly employed, as the single most potent mosquito control in impoundments. They go on to say that for proper management the purpose of the reservoir must be decided and this in turn will dictate the form of management that will be necessary which in turn will determine the kinds of mosquitoes such an impoundment will produce. Impoundments can take various forms: high level impoundments where water normally does not enter except when the manager wishes, low level impoundments where some water is retained behind a sluice gate as the tide recedes.

Permanent pools are often created on the marsh surface by blocking drainage from a low area, or by blasting (Provost, 1948). Such basins are shallow and are often called "champagne" pools, a name derived from Clarke's (1938) likening the action of mosquito predators to bubbles in champagne. There are often ditches radiating outward from these pools across the marsh surface forming an interconnecting network. Occasionally, such pools are associated with low-level impoundments.

Diking to exclude water from an area as in the production of salt hay (Ferrigno, 1959) is a form of water management. Levies constructed in parts of the Gulf Coast marshes enhance the use of these areas by cattle, and when properly constructed with earth plugs in the borrow pits, water management is improved (Williams, 1955).

2. Burning. Burning is another form of tidal marsh land management. Lynch (1941) considers fire before its use as a management tool to have had catastrophic effects, burning in an uncontrolled fashion the vegetation accumulated through several growing seasons. One purpose of controlled burning is to eliminate the holocaust created by such wild conflagrations. Marsh fires fall into three classes. Cover burns are the most widely employed method for removal of accumulated dead vegetation. These burns do not affect the structure of the marsh since the fire does not reach the basal parts of the plants which are protected by a water cover. A clean cover burn provides large open areas whereas spotty cover burns provide dispersed open patches amongst the dense vegetation.

On the other hand, root burns or deep peat burns are carried out during a dry period. Root burns kill off the climax vegetation which, if left unburned, becomes a dense mass. Plants of lower succession groups are considered more desirable. Deep peat burns remove the accumulated peat often to the underlying mineral soil, thus creating open water areas when it rains.

Burning may serve one or more functions: improvement of habitat, promotion of food production, increasing availability of food, protection from fire and facilitate trapping. (Lynch, 1941)

b) History

Embanking and drainage of tidal marshes for agricultural purposes dates back to antiquity. For nearly three centuries the coastal European countries bordering on the North Sea have engaged in this type of agriculture. There have been many failures in this country and few successes over the past two hundred years (Wright, 1911; Penfound and Schneidau, 1945). Successful ventures include rice growing in the South Atlantic coastal states and cranberries and truck farms along the North Atlantic coast (Nesbit, 1885; Means, 1903; Wright, 1907; Warren, 1911).

At the turn of the century there was the recognition of the role of the mosquito in disease transmission and where the mosquito was controlled diseases like malaria could be kept in check. It had long been recognized that tidal marshes breed mosquitoes, detracting from the peoples and their livestock's comfort and well being as well as a hindrance to the development of the country in such localities (Means, 1903; Wright, 1907).

Smith (1902), in describing the life cycle of Culex sollicitans Wlk (Aedes sollicitans), advocated filling those depressions on the marsh surface adjoining the uplands where the mosquito breeds or drainage by ditching so tidal action flushes out such areas. Smith (1907) not only advocated ditching for mosquito control but advised such drainage would enhance the production of salt hay, Spartina patens and Juncus gerardi by permitting water circulation and the reduction of water logged soils. This latter point was to become a focus of contention in subsequent years. Such ditches to be effective should be wide and deep, cutting through the sod into the mud because shallow ditches tend to fill up. He advocated complete water removal from a completely diked marsh or its value would be reduced.

Diking as a means of water management for agricultural purposes reached elaborate levels (Warren, 1911). Drainage by ditching for the rapid removal of water from the marsh surface became the primary means for mosquito control. With the passage of the years, many thousands of tidal marsh land acres became ditched; progress being evaluated in the miles of ditches dug each year. Such ditching propably reached its peak during the depression years of the 1930's when federal and state agencies with large appropriations for the relief of unemployment became involved in such activities (Stearns, MacCreary, Daigh, 1940).

Up to this point ditching was concerned only with the elimination of mosquito breeding. Little or no consideration was given to other consequences. While relief workers were making progress by digging miles of ditches, people with wildlife concerns began to question the wisdom of such activity; there were other organisms, both plant and animal, associated with these tidal marshes. Urner (1935) pointed out a number of game birds, waterfowl and other bird species would be adversely effected by ditching. Bradbury (1938) described the adverse effects of mosquito control measures on waterfowl and shore bird populations in the Duxbury, Massachusetts marshes. Cottam (1938) likened ditching for mosquito control to provide work for those on the relief roles to that of scalping an individual to cure a case of dandruff or burning the granary to get rid of the rats. Cottam and associates (Cottam et al., 1938; Bourn and Cottam, 1939, 1950; Cottam and Bourn, 1952) pointed out the vegetational zonation with their associated animal species in tidal marshes. They noted ditching lowers the water table and has adverse effects on the waterfowl populations and their plant and invertebrate food supplies. Stearns, MacCreary, and Daigh (1939, 1940) called attention to the adverse effects on muskrat populations.

While wildlife advocates were decrying the effects of ditches, mosquito control people adherred to the use of them for such control. Cockran (1935) did not believe ditching was harmful to muskrat production in tidal areas. He did say the water level should not drop more than 2-3 inches below the general marsh surface and such levels could be maintained by flood gates. Later (1938) Cockran definitely stated ditching improved muskrat trapping in the State of Delaware. He went on to say that where the marshes were flooded in Sussex County mosquito breeding increased with no increase in the growth of desirable vegetation. Headlee (1939) did not believe ditching lowered the water table and had no appreciable effect on marsh vegetation or adverse effect on wildlife. Travis et al. (1954) reported on the vegetation of 16 marshes in Volusia County, Florida during the years 1939-1942 and again in 1953. During the first three years after ditching there were no appreciable changes in the amount of cover for each plant species. During the ten year period from 1942 to 1953 they reported a decrease in Distichlis and an increase in Salicornia and Avicennia (Black Mangrove). They went on to say none of the vegetation changes altered the marsh character ten years after ditching was initiated. Any floral changes were related to tidal fluctuations in that in northern Volusia County where tidal ranges were small vegetation changes were smaller than in the southern part of the county where tidal fluctuations were greater.

While arguments raged about the value of ditching as a water management technique for mosquito control, the concept of biological control began to be put forward. Gabrielson (1936) stated the need for information about plant and animal distributions as related to tidal inundation, the use of natural pools for food, shelter and residence for the enemies of mosquitoes. He talked about artificial ponds associated with ditches for mosquito control. Glasgow (1939) pointed out biological control is not a simple thing. The effectiveness of mosquito control would be determined on a biological and ecological basis. Bradbury (1938) described their attempts in bringing waterfowl back to the Duxbury marshes. Prior to 1931 when mosquito control operations were completed there were many different species of waterfowl on these marshes. During a 1936 survey evidence of this earlier bird activity was still apparent with seven gunning stands evident in the marshes which had become dry and devoid of birds. The technique of restoration was based on the premise that mosquito larvae would be eaten by Fundulus heteroclitus, the mummichog minnow. The job was to create a habitat where fish could live at low tides and high temperatures. Former potholes were restored by damming outlets with sods. Care was taken to keep the water level about nine inches below the marsh surface, thus, keeping it free of water. Some potholes were deepened to assure sufficient water for Fundulus to live in during dry periods. Controlled burning of salt hay made a variety of insects available for shore birds and it helped control mosquitoes by enhancing water evaporation. Ditches were partially blocked so water was retained but did not flow out over the marsh surface. Bird use was reported to immediately increase without any loss in mosquito control.

At the same time Clarke (1938) erected three categories of fresh water marshes; (1) permanent, holding water at all times; (2) intermittent, periodically wet and dry; and (3) temporary, holding water for only a few days. Clarke advocated permanent and intermittent marshes need not be drained, that it was better to control mosquitoes by encouraging their aquatic enemies in permanent pools on these marshes. Intermittent ponds can be a wildlife oasis by creating a central water hole with channels connecting shallow pools throughout the marsh. Protection and a resting site would be provided to wildlife by the central pool while mosquito eating fish living in this pool would radiate outward through the channels as the water level rose.

Price (1938) advocated a new approach to ditching without draining the marsh land. The procedure was to dig a shallow ditch about 12 inches below the high tide mark but not to connect these ditches to tidal streams or guts, a blind ditch. Each high tide flushes the marsh potholes bringing in a new supply of fish flowing out over the entire marsh and on the ebb collecting in the ponds, potholes and ditches. The water level would be raised throughout the marsh, keeping water in the potholes and ponds that otherwise dried up. These depressions were freed of mosquitoes and maintained a good stand of widgeon grass, a prime habitat for ducks.

Cottam (1938) brought the concept of biological control into even sharper focus. Water control rather than drainage should be practiced in waterfowl areas in need of mosquito reduction. In important wildlife habitats where permanent ponds are involved mosquito control should be attempted by biological methods rather than by mechanical drainage because biological control methods ordinarily improve wildlife habitat rather than destroy it. Before any ditching is done a soil profile is needed followed by ditching adjusted to the soil type to produce a minimal ecological impact. Cottam advocated the establishment of permanent pools serving as reservoirs for mosquito eating fish with channels radiating outward, permitting these fish to get out over the marsh surface. Diking and water impoundment was advocated with the use of weir boards and sluice gates that would not restrict tidal flow yet would maintain a proper head of water in the marsh area.

Following the presentation of these several 1938 papers, numerous studies were carried out on the effects of water management through impounding and permanent pothole development on mosquitoes and on wildlife. MacNamara (1949) reported on the restoration of waterfowl and muskrats on a salt hay marsh that had earlier been important for waterfowl. In 1953 MacNamara reiterated the need for establishing permanent fresh water ponds and recognition of the relationship between vegetation types and water levels to recognize mosquito breeding areas. Several workers (Chapman and Ferrigno, 1956; Catts, 1957; Darsie and Springer, 1957; Florschultz, 1959a, b; and Tindall, 1961) noted the changes in mosquito species and numbers between natural, ditched and impounded marshes. Other workers reported the general increases of various wildlife species in conjunction with impounded marsh areas (Darsie and Springer, 1957; Florschutz, 1959a, b; Catts et al., 1963; Lesser, 1965).

High level impoundments have their problems. They continue to breed mosquitoes although different ones. They also interrupt nutrient flow between the impounded marsh and the estuary (Reimold, 1968). Following the principle established by Clarke (1938) low level impoundment and/or champagne pool systems have been established (Shoemaker, 1964; Bosik, 1967; Smith, 1968; Harrison, 1970).

Another conflict of interests began to make itself evident. Ferrigno (1959, 1961) and Ferrigno and Jobbins (1966) point out that the production of salt marsh hay, Spartina patens, has a degrading effect on wildlife. By diking water flow is excluded from these hay lands and the production of mosquitoes is greatly enhanced. Pesticides have been recommended as a control for mosquitoes within these diked areas but the use of these chemicals is so critical in terms of effects on waterfowl that Ferrigno and Jobbins (1966) strongly urged these diked areas be restored to their former naturally flooded condition.

Lastly, Ferrigno, Jobbins and Shinkle (1967) and Ferrigno and Jobbins (1968) advocate quality ditching of only heavy breeding areas. Deep, wide and straight ditches that will not fill in as rapidly should be used in open marsh management providing permanent flooding or good tidal circulation in breeding depressions. Sod should not be piled but mashed into the surface nor should it be placed on one side only forming a circulation barrier.

c) Effects of Ditching

1. Vegetation. Salt hay, Spartina patens and Juncus gerardi, production can be enhanced through drainage by ditching, facilitating water circulation. Smith (1907) was cognizant of the fact that diking would change salt marsh vegetation to that of a fresh water marsh or an upland. Florschutz (1959a) noted no drastic vegetative changes on a ditched marsh over a short term, however, he did expect changes when he stated the ditches may eventually lower the water table so that Hibiscus and salt hay would replace Spartina alterniflora. The long term effect of ditching is generally considered to have a deleterious impact on tidal marsh vegetation through lowering the water table and replacing it with less desirable species from higher levels such as salt marsh flea bane, Pluchea camphorata, and salt marsh aster, Aster subulata, followed by Iva and Baccharis (Cottam et al., 1938). Prior to ditching the mallows, Hibiscus oculiroseus and Kosteletzkya virginica, the seaside goldenrod, Solidago sempervirens, Aster novi-belgii, Bidens trichosperma, Pluchea camphorata and the swamp milkweed, Asclepsias incarnata, were scattered generally throughout most of the marsh area adjoining Delaware City, Delaware but never dominant. Yet, in three years (1936-1938) following ditching they dominated the marsh replacing Scirpus olneyi (Stearns, MacCreary, Daigh, 1940). The three-square

S. olneyi is found near the bordering high lands where fresh water enters. Ditching has the greatest effect on this species than on *S. patens* or *S. alterniflora* by lowering the water table and permitting intrusion of salt water in the Ocean City, Maryland marshes (Cory and Crosthwait, 1939). During a ten year period a pure stand of *Spartina alterniflora* covering 90 percent of the Mispillion marshes was replaced by *Baccharis halimifolia* (Bourn and Cottam, 1950). Ditching drains the permanent pools destroying the resident widgeon grass, *Ruppia maritima*, and dries out the marsh surface leaving it more vulnerable to destructive fires (Cottam et al., 1938). On the contrary, Cory and Crosthwait (1939) advocated ditching as a means for maintaining water levels in pools containing widgeon grass by permitting intrusion of water on the flooding tide. This would be particularly true in the summer when the pools would normally dry up. They maintained the ditches had to be shallow otherwise the pools would be drained. Both Headlee (1939) and Travis et al. (1954) asserted ditching did not lower the water table nor was there any adverse effect on vegetation. *Spartina alterniflora* production can be enhanced in some places through ditching by increasing the edge effect (Ferrigno, 1961).

2. Mosquitoes and Biting Flies. Smith (1902, 1907) advocated ditching as a means to control mosquitoes in those portions of the marsh considered to be good breeding areas. On the contrary, ditching *S. alterniflora* marsh is not considered an effective control of the salt marsh mosquito (Connell, 1940). During an experimental ditching study breeding was completely eliminated as no

larvae or pupae of mosquitoes (A. cantator, A. sollicitans, C. salinarius) were observed within the study area of the Appoquinimink marshes (Stearns, MacCreary, Daigh, 1940). However, these same researchers point out that while ditching may control mosquitoes, the ecological side effects may be greater than the original objective (1939). Eight species of mosquitoes were collected from a drained marsh in the Assawoman Wildlife area in 1956 with Aedes spp. making up 92 percent of the collections. The populations varied with local tidal and rainfall fluctuations and little breeding progressed beyond the first instar larval stage. This was attributed to the effectiveness of the drainage system as a means of controlling salt marsh mosquito production (Catts, 1957). This work was continued in 1957-1958 by Florschutz (1959a) who reiterated the effectiveness of drainage in that he collected very few pupae in contrast to thousands of larvae. Drainage was more effective where the ditches were kept clear of encroaching vegetation. Florschutz recorded an increase in the numbers of Culex salinarius during a rainy season in contrast to low numbers during a dry year. He attributed this to the greater permanence of puddles on the marsh surface in the wet year.

MacCreary (1940) was of the opinion ditching for mosquitoes may have helped control biting flies in some instances. However, to be effective the ditches have to be free of overhanging vegetation as stated earlier.

3. Other Invertebrates. Ditching has been deemed responsible for the marked declines in the invertebrate fauna of tidal marshes. Based on quadrat studies in ditched Delaware marshes in the course

of one season, the invertebrates, consisting largely of molluscs and crustacea, were reduced in numbers in the following fashion:

Spartina alterniflora association	43.5%
Scirpus robustus association	92.6%
Distichlis spicata association	71.9%
Spartina patens association	84.2%

Table 1 depicts the differences attributed to ditching for these four plant associations. Not only is there a decline in numbers but almost without exception there has been a reduction in the numbers of species. The years 1937-1938 were fairly wet years so the differences may have been even greater had the weather been drier. The greater differences for the Scirpus robustus association are particularly significant. The area occupied by this association is considerably smaller than for the others. The plants are more widely dispersed thus the fauna is more accessible to wildlife and, lastly, the substrate is more porous and thus more easily drained. (Cottam et al., 1938; Bourn and Cottam, 1939, 1950)

The lowering of the water table enhances leaching and oxidation which produces more acid conditions adversely affecting molluscs and crustacea dependent on alkaline conditions for shell building. Under anaerobic conditions sulfates in the sea water are reduced to sulfides in the presence of organic matter. In this form these sulfides combine with the iron in the clay to form polysulfides. No further changes will occur if the soils remain wet. If they dry out the sulfides oxidize to form sulfuric acid. This can reduce the pH to 2.5 or less. (Nealy, 1962)

Table 1. Invertebrate populations in 6-foot-square quadrats in relation to mosquito control ditching in four vegetation types on the Bombay Hook - Herring Creek marshes, 1936 to 1938 (modified from Table 2 of Bourn and Cottam, 1950).

	Mollusks		Crustaceans		Spiders and mites		Leaf-hoppers		Beetles		Miscel-laneous		Totals		Number of Species	
	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D
Spartina alterniflora association:																
TOTAL (1936-1938)	3812	1464	900	634	1301	749	12739	2088	594	231	10663	10545	30365	15713	160	121
AVERAGE	545	209	128	90	185	107	1819	298	84	33	1523	1506	4338	2245	23	17
Distichlis spicata association:																
TOTAL (1936-1938)	2957	215	1600	305	435	314	151	97	164	57	63	67	5370	1055	108	90
AVERAGE	591	43	320	61	87	63	30	19	33	11	13	13	1074	211	22	18
Spartina patens association:																
TOTAL (1936-1938)	1690	317	2309	110	630	280	143	151	166	23	59	117	4997	998	120	90
AVERAGE	281	53	384	18	105	47	24	25	28	4	10	20	833	166	20	15
Scirpus robustus association:																
TOTAL	4832	150	4286	171	511	183	430	269	111	44	194	96	10364	913	110	93
AVERAGE	966	30	857	34	102	37	86	54	22	9	39	19	2073	183	22	19

U = Unditched

D = Ditched

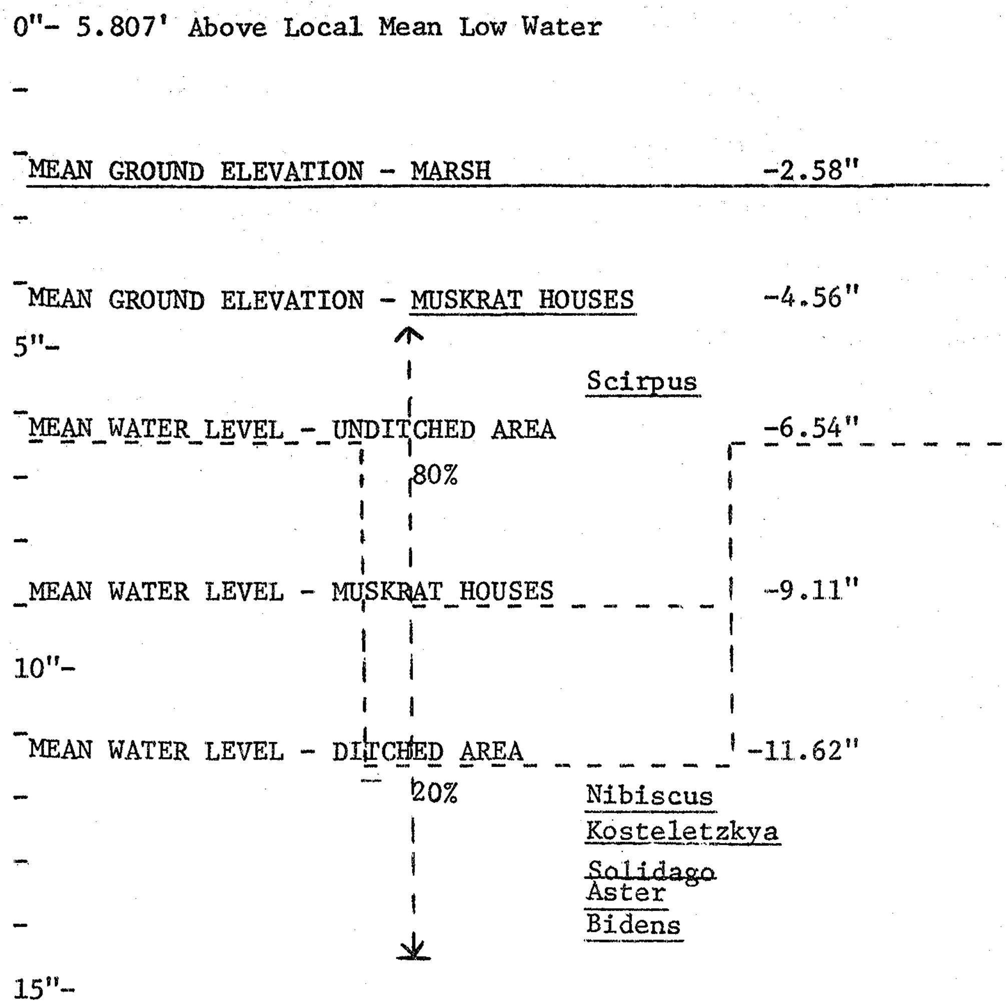
4. Birds. Most shore birds and waterfowl are adversely affected by ditching through a reduction in food supply, primarily molluscs and crustaceans as pointed out by Bourn and Cottam. Birds that need a low wet marsh such as the clapper rail will not be affected as long as the salinity and the water level are not changed. Birds that need a fairly constant water supply, like the bittern, piedbill grebe and coot, will be seriously affected by such drainage. Black ducks, Willet, Virginia rail and some of the herons will be adversely effected (Urner, 1935). Bradbury (1938) reports drastic declines in waterfowl and shore birds following ditching of the Duxbury marshes. However, Florschutz (1959a, b) observed little difference between a natural and a ditched marsh. Wildlife species numbered 19 for 1957 and 29 for 1958 while the ditched marsh had 20 for 1957 and 25 for 1958. The most common bird species observed on the ditched marsh during both years were gulls, green herons, crows and red-wing black birds. Little evidence of waterfowl usage was noted.

Ditching can encourage S. alterniflora which increases the edge effect providing more shelter and nesting sites for clapper rail and black duck (Ferrigno, 1961). Stewart (1951) found a high correlation between nest densities and the amount of edge between the tall (and dense) and the short (and sparse) growth form of Spartina alterniflora. The highest correlation (0.9747) existed when the edge consisted of 20 yards of short and 10 yards of tall Spartina. The lowest correlations pertained to pure stands of short (0.9180) and tall (0.9385) Spartina. Nest density in the best edge was 2.5 ± 0.3/acre with nests within 15 feet of the creeks. Stewart recommended ditches or creeks be constructed with sloping rather than vertical sides to produce the desired edge effect.

5. Muskrats. Cockran (1938) presents figures to support the contention that ditching has no adverse effects on muskrats in Delaware.

Sussex County	-	95% ditched-trapping increased 15%
Kent County	-	30% ditched-trapping increased 10%
New Castle County	-	0% ditched-trapping increased 0%

Stearns, MacCreary and Daigh (1939, 1940) strongly refute this contention. Their work in Kent and Sussex Counties showed that muskrat marshes ditched for mosquito control have lower water tables which adversely affects the vegetation needed for food and house construction, thus, the animals migrate out of the area. (See section on effects of ditching on vegetation). When the normal water level is at or very near the surface, the plants (Scirpus olneyi and Spartina cynosuroides), upon which the muskrat subsists, flourish best. Ground level in itself is not considered a factor in determining the location of a house but there is a definite relationship between ground elevation and the height of the water table at the selected house site. The mean water level at 101 houses was 4.55 inches below the mean ground elevation (5.43 feet above local mean low water) with a range of 0.08-9.98 inches. This meant that the mean water level for 80 percent of the houses was above and 20 percent below the mean water level in the ditched area. (See following diagram derived from Stearns et al., 1940).



d) Effects of Impoundments

1. Vegetation. Diking has been done to encourage the production of salt marsh hay, *S. patens*, (Smith, 1907; Ferrigno, 1959). Smith remarked the diked area loses its value unless the water is completely removed. Ferrigno agrees water removal is necessary to enable machinery to cut and process the hay.

Impounding produces vegetation changes from *S. alterniflora* - *S. patens* to pond weed, *Potomogeton berchtoldi* and *P. pectinatus*, widgeon grass, *Ruppia maritima*, and algal mats (during low water principally Rhizoclonium). Around the edges a variety of emergent species will appear; three-square Scirpus americanus, rose mallow Hibiscus moscheutos, cattail, Thypha, reed, Phragmites communis and switch grass, Panicum virgatum (Springer and Darsie, 1956).

This same pattern was noted by Florschutz (1959) and Tindall (1961) in the Assawoman and Little Creek Wildlife areas respectively in which salt marsh vegetation, Spartina, Distichlis, Scirpus, Hibiscus, Cladium, Baccharis and Iva were reduced and replaced by open water and emergent types, Potomogeton and Ruppia beds, Typha, Echinocloa, Cyperus and Chara. Florschutz noted Typha tended to expand in some places and decrease elsewhere. Spartina patens was greatly reduced on the inner portions of the marsh but flourished along the edge of the impoundment.

Mangold (1964), Shoemaker (1964), Smith (1968) and Harrison (1970) noted the replacement of S. patens by S. alterniflora during the flooding of low level impoundments and a champagen pool system. This was particularly true for early flooding. Distichlis associated with S. patens survived and flourished (Shoemaker) while it and Juncus gerardi survived, but not well (Mangold). Flooding caused the disappearance of Baccharis and Iva and the submergent horned pond weed, Zannichella palustris, increased and flourished. Smith (1968) noted the increase of Baccharis, common reed, Phragmites, poke weed, Phytolacca americana, and the fox tail grasses, Setaria faberii and S. magna, on the higher ground created by the embankments and spoil piles. The poke weed and fox tail grasses provide excellent food and shelter for wildlife. He also noted a decline of widgeon grass in the older impoundments when it had flourished in younger pools.

As Smith had noted in 1907, impounding a tidal marsh will change the salt marsh vegetation to that of a fresh water swamp or that of an upland.

2. Mosquitoes. Impounding sharply alters the numbers and species composition of the mosquito population as compared to a natural tidal marsh (Chapman et al., 1954, 1955, 1956; Catts et al., 1963; Shoemaker, 1964). Aedes sollicitans is invariably the most abundant mosquito in natural marsh conditions, making up as much as 96 percent by number of immatures dipped (Darsie and Springer, 1957; Tindall, 1961b). Chapman et al. (1954) identify A. sollicitans and A. cantator along with Anopheles bradleyi and Culex salinarius, the salt marsh group of mosquitoes, as being typical of a natural salt marsh. Aedes spp. can be essentially eliminated from impoundments while Culex and Anopheles, Uranotaenia sapphirina and Mansonia perturbans breeding increases after impoundment (Chapman et al., 1954, 1956; Tindall, 1961b; Franz, 1963). Mansonia deposits its eggs in sedge tussocks and under mats of cattail debris under flooded conditions. Water level manipulation would be the most effective control (Hagmann, 1953; Chapman and Ferrigno, 1956). Springer and Darsie (1956) report Anopheles being eliminated along with the two Aedes species. Darsie and Springer (1957) note many of the permanent water mosquitoes are unimportant because of short flight patterns, biting habits and other behavior.

Mosquito immatures dipped April to October, 1959 and 1960, Little Creek Wildlife Area, Little Creek, Delaware (Tindall, 1961b)

	Impoundment				Natural Marsh			
	1959		1960		1959		1960	
	No.	%	No.	%	No.	%	No.	%
A. sollicitans	56137	96.1	76	0.4	1502	96.5	7203	99.9
Aedes sp.	62	0.1	10	-	1	-	-	-
TOTAL	56199	96.2	86	0.4	1503	96.5	7203	99.9
A. bradleyi	19	-	677	3.5	1	-	1	-
Anopheles sp.	-	-	161	0.8	-	-	-	-
TOTAL	19	-	838	4.3	1	-	1	-
C. salinarius	2143	3.7	17163	88.7	25	1.6	-	-
Culex sp.	69	0.1	743	3.8	27	1.7	-	-
TOTAL	2212	3.8	17906	92.5	52	3.3	-	-
Uranotaenia sapphirinia	-	-	512	2.7	-	-	-	-

Manipulation of water levels within impoundments seems to control the magnitude of breeding. MacNamara (1952) reports constant water levels produces mosquitoes while draw-down decreases breeding. Chapman and Ferrigno (1956) note heaviest breeding for Aedes at water depths 5-10 inches below meadow level, slightly below meadow level for Culex and slightly above meadow level for Anopheles. Chapman et al. report summer draw-down controls Mansonia perturbans but they, along with Darsie and Springer (1957), report greatly enhanced Aedes broods following rains or reflooding. Catts et al. (1963) recommend moderate water levels of 9-12 inches compatible for reduced mosquito production and enhanced waterfowl usage. Tindall (1961b) suggests the higher water levels would reduce vegetation and expose the mosquito larvae to wave action and predators.

Diking done to enhance the production of salt hay, Spartina patens, by preventing flooding of tidal marsh land produces great broods of mosquitoes, primarily Aedes sollicitans and Culex salinarius (Ferrigno, 1959).

Mosquito production from diked and undiked marsh land (modified from Table 2 of Ferrigno, 1959).

Vegetation Type	Larvae-Pupae/Dip C. salinarius	A. sollicitans	Dips	larvae-pupae
Undiked				
S. alterniflora	0	0.0001	8280	1
S. patens	0.11	2.74	1080	3293
P. virgatum	0.003	0	600	2
Woodland swamp	0.02	0.01	840	620
Diked				
S. alterniflora	0.26	4.22	360	1701
S. patens	0.72	3.54	2760	13376
S. cynosuroides	2.94	4.66	240	1988
P. virgatum	0.21	0.75	1320	2219
D. spicata	0	3.52	600	2761
J. gerardi	0	2.86	240	780
Typha	2.01	0.21	120	707

Certain Tabanus spp. are controlled by the summer draw-down on high level impoundments. The species composition is altered in that T. lineola and T. atratus are more evident in the impoundment while T. nigrovittatus is more abundant in the natural tidal areas (Olkowski, 1966). Harrison (1970) suggests low level impoundments have little influence on tabanid breeding, at least during the first year after impoundment.

3. Other Invertebrates. There is little specific information about the effects of impoundments on invertebrates. The micro-crustaceans have received some preliminary attention (Ruber and Jobbins, 1963). Bosik (1967) lists some of the more obvious forms. Smith (1968) records fiddler crabs, Uca, grass shrimp, P. pugio, blue crab, Callinectes sapidis, the snail, Melampus bidentatus, and the mussel, Modiolus demissus, as being common but they are common in natural marshes as well. Under salt marsh hay management Uca, snails and mussels, decline in numbers. The first two are important in clapper rail and black duck diets (Ferrigno, 1961).

4. Fishes. Fish species typically associated with tidal creeks and marshes can be expected in impoundments. These include the mummichog, Fundulus heteroclitus, Striped killifish, Fundulus majalis, eel, Anguilla rostrata, and the sheepshead minnow, Cyprinodon variegatus. Carp, Cyprinus carpio, can be expected in less saline impoundments.

Part of the basic premise of water management and mosquito control on these marshes has been to provide a suitable habitat for mosquito eating fish and the means for these fish to get at the mosquitoes. Both Mangold (1962) and Shoemaker (1964) believe the attraction of herons, bitterns, terns, etc. to low level impoundments is due to the increase in fish numbers. For reasons not fully understood, several species of fish eating birds declined following impoundment in Florida (Provost, 1969). Fundulus spp. can survive in impoundments and will provide an effective control over mosquito larvae provided water levels are high enough to permit the fish to forage amongst the vegetation (Alls, 1969). The numbers of fish species increase and tend to shift toward the fresh water forms with the production of young following impoundment including the bullhead, Ictalurus nebulosus, the pickeral, Esox americanus, and the sunfish, Lepomis gibbosus. Bullfrogs, Rana catesbiana, and the snapping turtle, Chelydra serpentina, also appear in impoundments. (Darsie and Springer, 1957)

5. Birds. Impoundments have been established and developed for the restoration of wildlife, particularly waterfowl and shore birds. Bradbury (1938) reported on this for the Duxbury marshes while MacNamara (1949) demonstrated the fresh water impoundments on the Tuckahoe, New Jersey marshes were capable of producing large quantities of desirable waterfowl food by a complete draw-down. Eight inches of water tended to enhance muskrat food instead. MacNamara reported a kill of 1.91 ducks/hunter/day for the 1948 season compared to 0.79 ducks/hunter/day in 1947. Following restoration, several new species of ducks put in an appearance in the area; red head, ring-neck; surf-scoter and the shoveller.

Other investigators have reported the increased usage of impoundments by birds (Catts, 1957; Darsie and Springer, 1957; Florschutz, 1959; Tindall, 1961; Mangold, 1962; Shoemaker, 1964; Lesser, 1965; Smith, 1968; Provost, 1969). Darsie and Springer identified 86 bird species in contrast to 55 in the area prior to impoundment. Tindall reported a three-fold increase. Smith sited 62 species on the impoundments and 39 on the natural marsh areas. Several of these workers reported increased numbers of broods of young following impoundment, particularly black ducks. These impoundments offer emergent and submergent vegetation as food for ducks, fish and invertebrates as food for wading birds and open water for resting areas.

Some bird species have declined in number with the advent of impoundments. The clapper rail has often disappeared and has been associated with the absence of fiddler crabs (Darsie and Springer, 1957; Mangold, 1962; Shoemaker, 1964). Both Mangold and Shoemaker also noted declines in the small birds: song sparrow, seaside sparrow, sharptail sparrow and yellow throat warbler, primarily through loss of nesting sites and food. Smith (1968) reported marsh wrens and seaside sparrows relatively abundant, especially where the tide bush grew along ditch or pool margins; however, no comparative quantitative data was given. Provost (1969) indicated the decline in the dusky seaside sparrow following impoundment on Merritt Island, Florida. This bird is reported to prefer the Distichlis habitat. Fish eating birds also declined on Merritt Island, especially the merganser. Provost could give no reason for such declines and went on to say that while six species of birds were reduced, there was not apparent effect on seven species and an increase in number was noted for 22 species.

While most workers have shown enhanced bird usage following impoundment, Ferrigno (1959, 1961) reported a decline in diked salt hay meadows.

Waterfowl and clapper rail usage and mosquito breeding for a New Jersey salt marsh. (Modified from Table 3, Ferrigno, 1959)

Vegetation	Number of birds flushed. 10 censuses of 100 acres in each zone: Waterfowl	Clapper rail	Annual total larvae & pupae per dip
S. alterniflora tall form	1742	29	0
S. alterniflora short form	1239	33	0.0001
S. patens	285	3	3.05
diked hay meadow S. patens	111	1	4.13

6. Mammals. Evidence of mammals has increased with the creation of impoundments (MacNamara, 1952; Catts, 1957; Darsie and Springer, 1957; Tindall, 1961; Mangold, 1962; Shoemaker, 1964; Smith, 1968). Darise and Springer noted continued maintenance of high water levels within an impoundment tended to restrict muskrat usage but the recession of water from the vegetated margin during the summer enhanced plants attractive to muskrats and waterfowl. MacNamara and Tindall report increased numbers of muskrat houses while Mangold found muskrats to have preference for the fresher water impoundments. Whenever impoundments are flooded with high salinity water through storm action or by evaporation raising the salinity during a drought muskrat populations decline through loss of food and drinking water (Dozier, 1947). Smith (1968) noted no increase

in small mammal populations but increased evidence of predators about the impoundments suggested such small mammal populations had indeed expanded. Increased mammal activity was attributed to increased variety of habitat and increase in edge effect associated with embankments (Florschutz, 1959).

Annual muskrat house count in New Jersey impoundments
(from MacNamara, 1952)

Pond	County	1946	1947	1948	1949	1950	1951
1	Cape May	0	0	0	34	100	105
2	Cape May		12	37	8	22	56
3	Cape May		185	193	194	203	223
1	Atlantic	20	120	17	37	156	346
2	Atlantic			182	73	165	215
3	Atlantic				50	78	141

e) Effects of Burning

The magnitude of burning will determine the effects on vegetation (Penfound and Hathaway, 1938; Lynch, 1941; Smith, 1942). The character of the marsh vegetation is not altered during a cover burn when the marsh is flooded with water. Heavy accumulations of dead vegetation are removed in this fashion. The more severe root and peat burns kill off the climax vegetation and allows plants of lower successional stages to reappear. Intense and prolonged peat burns can bring about a reversion to the early hydric community with expanses of open water. Fire prevents the accumulation of organic matter and thus impedes the elevation of the marsh and succession to upland communities.

V. Biogeochemical Studies, Productivity and Management

a) Hydrography

The tidal creeks that flow through these salt marshes appear to be partially mixed estuaries. The Broadkill River has a flushing time ranging from 5.3 through 13.8 tidal cycles, depending upon inland fresh water discharge with a mean of 6.3 tidal cycles. The lower estuary, approximately 25% of the entire system, has a relatively constant flushing time of 0.7 tidal cycles with a range of 0.6 to 0.9. The mean volume of water discharged per ebbing cycle, $1.46 \pm 0.39 \times 10^6$ m^3, exceeds the mean flood discharge, $1.26 \pm 0.51 \times 10^6$ m^3. The salinity is essentially homogenious throughout this part of the creek and reflects the salinity of the adjoining area of Delaware Bay.

The upper estuary, approximately 35% of the entire system, has definite longitudinal and vertical salinity gradients decreasing with distance upstream and increasing with depth. The mean flushing time is 4.0 tidal cycles with a range of 3.2 to 4.6 cycles. The mean volume discharge per ebbing cycle, $0.55 \pm 0.21 \times 10^6$ m^3, exceeds the mean volume discharged per flooding cycle, $0.43 \pm 0.12 \times 10^6$ m^3.

The tidal fresh water section, approximately 40% of the entire system, is rarely invaded by saline water from the upper estuarine portion. The flushing time for this section ranges from 6.5 to 18.7 tidal cycles depending upon fresh water discharge with a mean of 9.8 cycles. The mean volume discharged per ebbing cycle, $1.7 \pm 0.1 \times 10^5$ m^3, exceeds the mean volume discharged per flood cycle, $1.2 \pm 0.7 \times 10^5$ m^3.

The Murderkill River possesses the same pattern as the Broadkill in that it can be divided into the same three dynamic sections with essentially homogenious salinity gradients in the lower estuarine and fresh water sections, and distinct gradients longitudinally and vertically in the middle section. During normal runoff the estuary discharges 1.9×10^5 m^3 of fresh water seaward per tidal cycle. The calculated flushing time during average conditions is 4.9 tidal cycles with a range from 3.8 to 20.1 cycles. (deWitt, 1968; Daiber, 1972)

b) Water Quality in the Broadkill

Oxygen progressively declines in an upstream direction often reaching zero below a sewer outfall, recovering at the point where fresh water spills over the Wagamon's Pond dam. pH values tend to decline in the same fashion while turbidity values increase in an upstream direction. Ammonia, inorganic phosphorus, total phosphorus and chlorophyll attain their highest values during the summer, while maximum mean concentrations of dissolved oxygen and nitrate appear during the winter. The highest mean concentrations of nitrite and organic phosphorus occur during the autumn. Nutrient and chlorophyll concentrations are usually low in the lower estuary and upstream from the sewage outfall near Milton. The upper estuary displays a longitudinal concentration gradient, with nutrient and chlorophyll concentrations increasing with distance upstream. The highest nutrient and chlorophyll concentrations have been found in the tidal fresh water downstream from the sewer outfall. (deWitt, 1971; Daiber, 1972)

c) Phosphorus Concentrations and Hydrogen Sulfide Production

Monthly sampling has been carried out over a three-year period of marsh surface drainage for total, organic and inorganic dissolved phosphorus concentrations in a natural marsh and in managed areas. The results indicate that phosphorus concentrations are considerably higher than previously reported levels for estuarine areas. The highest mean value for the three-year period was 25.8 ug-at/l for total phosphorus in the natural marsh drainage and 18.0 ug-at/l of inorganic phosphorus for the same area. There are seasonal variations in the concentrations of dissolved phosphorus with summer maximums of 150 ug-at/l and winter minimums of 10 ug-at/l (Reimold, 1968; Reimold and Daiber, 1970). This same basic seasonal pattern has been reported by Shlopak (1972) but his data includes particulate phosphorus as well.

Gooch (1968) gives one explanation for the seasonal pattern for phosphorus. Anaerobic micro-organisms produce the greatest amount of hydrogen sulfide in a natural marsh during the late spring continuing through the summer with enough iron sulfide to form pyrite. During the fall and winter ferric phosphate and ferric hydroxide remove dissolved phosphate from the water at a time when the pH is above 7.0 and there is a minimal production of hydrogen sulfide. With the advent of spring the pH falls below 7.0 and there is a shift from the ferric to the ferrous ion along with increased hydrogen sulfide and pyrite formation. This continues into the summer making more dissolved phosphate available from the precipitated condition. With the return of colder weather more alkaline conditions prevail and the cycle is repeated. About 60 percent of the microbial population of the higher sediments consists of sulfur bacteria. These numbers fluctuate more in the lower sediments. (Daiber and Gooch, 1968)

d) Nitrogen Concentrations and Nitrogen Bacteria

Canary Creek marsh has been characterized by low nitrate and high salinity while the Murderkill marsh is the opposite. The maximum nitrate values occur during the winter, minimal values in the summer. In Canary Creek marsh nitrate values range from zero to 35 ug-at/l with most values falling below 15 ug-at/l. The Murderkill values range from 40 to 100 ug-at/l while summer values have been 0-10 ug-at/l. There has been no clear cut difference in the amount of nitrate entering or leaving on the flood or ebb tides.

Nitrite values in both marshes have been primarily in the range of 0-2 ug-at/l with no clear seasonal pattern. (Aurand, 1968)

Ammonia is the dominant nitrogen form during the summer months particularily in the slowly flushed fresh water portion of the Broadkill. The highest mean concentrations oscillate tidally between two stations in that portion of the river. These mean values have been recorded at 32.7 and 28.8 ug-at/l. High ammonia values are usually associated with low oxygen levels (deWitt, 1971).

The studies on Canary Creek marsh indicate the microbial communities are climax ones. The heterotrophic population is always greater than the autotrophs. There has been reported an apparent increase in the percentage of the population composed of coliforms with lower sediment temperatures. A higher percentage of the population has been represented by autotrophic nitrifyers during the winter and early spring months.

Nitrification takes place at rates differing with sediment type and initial substrate. The most rapid nitrification takes place in the autumn and spring months and accumulations of nitrate occur during the winter. It is possible that the inorganic nitrate produced within the marsh sediments is used exclusively by the marsh flora and very little is available for release to Delaware Bay (Daiber and Gooch, 1968). More recent work where ammonium nitrate fertilizer greatly enhanced gross production supports this contention (Daiber and Sullivan, 1972). Nitrogen probably leaves the marshes and creeks in the organic form as detritus.

e) Primary Productivity and Diatom Habitats

The quantity of angiosperm material produced on the Canary Creek marsh during the 1960 growing season has been measured by the clip quadrat method. The calculated yield of living grass amounted to 397.5 gms dry weight/m^2. The calculated total yield including material that had died during the season amounted to 561.2 gms dry weight/m^2 which is equivalent to 5,007 lbs/acre (Morgan, 1961).

Gross edaphic algal primary production estimates have been reported for five areas in the Canary Creek marsh. Salt panne and bare bank (free of angiosperms) algal production do not vary significantly from one part of the year to another. Algal productivity is the lowest on the bare bank (16, 21, 16 mg C/m^2/hour) for the periods from mid-September to mid-December (Descendis), mid-January to mid-May (Ascendis), and mid-May to mid-September (Thermis), respectively. For the same time periods panne algal production has been recorded at 36, 44, 41 mg C/m^2/hour. Algal productivity in the tall _Spartina alterniflora_ (68 mg C/m^2/hour) and _Distichlis spicata_ (53 mg C/m^2/hour) areas is greatest in the period from mid-January to mid-May. In the short S. alterniflora area algal productivity does not drop in the warmest part of the year (59 mg C/m^2/hour) as it does in the tall Spartina (26 mg C/m^2/hour) and Distichlis (21 mg C/m^2/hour) areas. Yearly edaphic algal gross primary productivity is estimated in g C/m^2/year; short Spartina alterniflora 99; panne 91; tall S. alterniflora 79; Distichlis spicata 61; and bare bank 38. The annual gross production for the marsh algae has been calculated to be approximately 80 g C/m^2 or 160 g of ash-free dry weight. In terms of oxygen it represents 150 liters of oxygen/m^2/year. In contrast the edaphic community consumes 215 g C/m^2/year.

The gross algal production is estimated to be one-third of the net angiosperm production in Canary Creek marsh (Gallagher, 1971).

Each of the five marsh areas identified above is characterized by its own edaphic diatom organization. These floristic assemblages are seen to differ in their dominant species, association of species and environmental characteristics throughout the year. The three areas with grass cover are more diverse in total number of diatom species, particularly in the winter and spring. It is thought the amount of light reaching the marsh surface, temperature, dessication and salinity are prime environmental factors influencing diatom abundance and growth on the marsh (Sullivan, 1971).

f) Fish Eggs and Fishes

The great majority of the pelagic fish eggs and larvae are present during June and July. Most of them are found in the tidal creeks in the lower half of the state where the salinities are higher. This pelagic phase is not evenly distributed at any one time; large numbers of eggs and larvae may enter one creek but not another. It is suggested that little spawning occurs in the creeks. The greatest numbers of eggs and larvae enter the creeks on the flood tide that occurs after dark and primarily after the highest salinity is reached for that particular tidal cycle. The eggs and larvae remain with that particular water mass and are on their way out of the creek by the time the salinity begins to decline. They will penetrate only the lower estuarine portion of the tidal creeks (see hydrography sub-section above). Invariably there are fewer eggs and larvae collected on the ebb tide than on flood. (Daiber, 1963a, b).

Thirty-four fish species have been collected from tidal creeks, primarily Canary Creek and Little River and two state-wide samples during 1961-62. The Bay anchovy, *Anchoa mitchilli*, and Atlantic silversides, *Menidia menidia*, dominated the collections. The White perch, American eel and Mummichog, *Fundulus heteroclitus*, are considered as residents of tidal creeks. *Fundulus majalis* and *Cyprinodon variegatus* are associated with the creeks. The remaining species are present in these tidal creeks during certain stages of the life cycle, usually as juveniles or sub-adults. Most of them come in on the flooding tide and leave with the ebb. Food habits tend to separate the resident species from the transient forms. (Daiber, 1962).

g) Marsh Manipulation

The highest concentrations of phosphorus have been found in the natural marshes (3 year average of 25.8 ug-at/l) and are significantly different from all types of managed marsh areas studied. There did not appear to be any difference between new (13.2 ug-at/l) and old

(13.2 ug-at/l) champagne pools. The effects of high level impoundments (13.4 ug-at/l), low level impoundments (16.5 ug-at/l), and champagne pools (13.2 ug-at/l) are similar in that they all tend to depress the concentrations of phsophorus when compared to a naturàl marsh (25.8 ug-at/l). Of the management practices considered, the ditched marsh areas are significantly lower in phosphorus (19.2 ug-at/l) than the natural marsh, however, the ditched areas represent the least alteration. (Reimold, 1968)

The effects of light intensity and additions of super phosphate and ammonium nitrate have been evaluated for one year on the edaphic algae and grasses in a short _Spartina alterniflora_ marsh. Soil pH shows the short _Spartina_ soils to be mainly acidic favoring orthophosphate ions to be available for uptake by both algae and spermatophytes. Both fertilizers move into the soil rapidly in fairly large concentrations. Areas clipped to the ground level have shown an increase in amounts of edaphic chlorophyll and filamentous algae. Filamentous algae tends to be reduced in shaded areas although the edaphic chlorophyll levels do not decline. Additions of inorganic nitrogen tends to increase the edaphic algal standing crop in the unclipped areas, particularly during the spring (ascendis) period. Inorganic phosphorus fertilizer produces a greater effect in the natural areas in contrast to the artificially shaded plots. No such increase has been seen in the two (30% and 60%) shaded areas during the fall (descendis) period when phosphorus is at a minimum in Canary Creek. Nitrogen and phosphorus have no stimulatory effect in the clipped areas on the edaphic algal standing crop. The short _Spartina_ *alterniflora* responds greatly to additions of nitrogen fertilizer by increased shoot height and density. This effect is less dramatic in the two shaded areas. Phosphorus has no effect on grass growth. (Daiber and Sullivan, 1972).

VI. Discussion

a) Interactions. Each tidal marsh community has its characteristic fauna. Numerous workers have pointed out that each vegetation type can be categorized according to extent of mosquito breeding. Typically, as one proceeds from the frequently inundated tall form, *Spartina alterniflora*, toward the upland margin of the marsh or toward the less frequently flooded higher elevations, there is an increase in the numbers of the salt marsh group of mosquitoes, particularly *Aedes sollicitans*. Along with this increase in mosquitoes there is the tendency to find greater numbers of biting flies although there seems to be a question whether the eggs of these flies are always deposited on these higher elevations. The snail, *Melampus*, is found in these same locations with *Spartina patens*, *S. alterniflora* (short form), and *Distichlis*. The fiddler crabs, *Uca*, have an inverse relationship, being found near the creeks and among the *S. alterniflora* (tall form). With the presence of the snail and fiddler crab one can expect to see the black duck and clapper rail, respectively.

The life form and dispersion pattern of the tall *S. alterniflora* permits the mosquito eating fish to move about among the plants on a flooding tide. The dense mats of *S. patens* and *Distichlis* prohibits such fish excursions, thus, mosquito larvae are freer of their predators.

The surface pools, formed in a variety of ways (see Chapman's (1960) discussion of pannes and rotten spots), provide a residence for *Fundulus* and other mosquito eating fish. These pools also provide submergent vegetation, Ruppia for example, an attraction to many waterfowl. These pools also enhance the edge effect, providing a greater variety of habitats, thus enabling more species to associate with the marsh.

Progression along the salinity gradient sees a change in vegetation from the saline, Spartina alterniflora and Juncus roemarianus, through the brackish water species, S. cynosuroides and Scirpus olneyi, to the fresher water, Zizania and Polygonum. There is an associated reduction in tidal amplitude and increased numbers of muskrats along this gradient.

All of this changes in the natural sequence of events in ecological succession. There may be the orderly progression to a climax or through some storm action or changes in sea level or wildfire there will be a reversion to some earlier stage. In any case, the stage in the progression can be identified by its floral and faunal components.

Man can and does bring about changes in this ecological succession by his application of water management techniques to tidal marshes. While ditching may control salt marsh mosquitoes and biting flies at certain times and locations, its overall effect is open to doubt. Water flow must be maintained by digging straight ditches which must be kept free of silt and vegetation. In any case, marked ecological changes become evident in the marsh community. To begin with, the water table is lowered or, in effect, the elevation of the marsh is raised. There is a change from the low level, tall form of S. alterniflora marsh to the high level, short form of S. alterniflora, S. patens -

Distichlis spicata marsh. Ditches, while intended to reduce mosquito breeding, can encourage it by creating more of the higher *S. patens* marsh. Certainly, ecological succession to upland vegetation is speeded up by enhancing the invasion of such vegetative types and the decline of the more aquatic species such as *Ruppia*. The valuable muskrat foods, *Scirpus* and *Typha*, will give way in the process. Stands of *Scirpus olneyi* can also be adversely affected by the greater penetration of higher salinity water than would occur without ditching. Muskrat populations will decline because of changes in food and the lowered water table under their houses. The average weights of animals will also decline with the change to less nutritive vegetation.

While this play is being acted out another play of adversity is involving birds. Lowering the water table destroys the submergent food supply for the puddle ducks. Nesting sites are eliminated from the shores of these pools by a reduction of the edge effect. The food supply is also affected by the drastic reduction in invertebrates, especially molluscs and crustacea. While snails like *Melampus* are most frequently associated with the drier *S. patens* - *Distichlis* zone, its numbers are reduced following ditching. One should be reminded, as was pointed out earlier, that ditching can enhance the edge effect by encouraging the tall form of *S. alterniflora* with the associated fiddler crabs and clapper rails, provided water levels do not decline.

While ditches tend to hasten succession toward an upland community burning and impoundments exclusive of diked salt hay marshes, have a retrogressive effect toward or to the open water community by flooding or lowering the marsh elevation through reduced organic matter accumulation. The vegetational changes that occur are a reflection of the depth of flooding or burning. This regression away from the climax produces a vegetational community considered to be more valuable as food and shelter for wildlife species. Increased numbers and species of waterfowl are attracted to these new conditions. Deeper water encourages submergent vegetation but changing water levels promote production of emergent plants along the boundaries of the impoundments which muskrats and some waterfowl species find more attractive. Such impoundments also tend to encourage fresher water types of vegetation, again favoring muskrats and waterfowl, and provide fish predators more opportunities to get at mosquito larvae.

Impoundments don't eliminate mosquitoes and biting flies. They change species composition and the impact of these pestiforous insects. The permanent water mosquito species don't travel as far nor have the feeding and behavioral traits that make the flooding water salt marsh forms so obnoxious. This latter group of mosquitoes are eliminated within the impoundment but the marsh acreage outside still produces *Aedes* spp. mosquitoes. Cost prohibits the construction and maintenance of dikes surrounding all tidal marshes. Furthermore, a three year study has demonstrated phosphorus exchange between a high level impoundment and the estuarine system to be among the lowest for any kind of managed marsh thus having a retarding effect on the fertility of bays and coastal waters (Reimold, 1968).

The wildlife principle of the edge effect in a tidal marsh is stimulated by burns and flooding. Spotty burns will produce clear new vegetation for feeding surrounded by dense older plants for cover. Impoundments produce an edge in two ways. Dike construction provides a suitable habitat for upland vegetation valuable as wildlife foods such as pokeweed and foxtail grass. The less desirable high tide bushes, Baccharis and Iva, are also encouraged. These embankments and the adjoining emergent aquatic vegetation provide food, shelter and nesting sites for a greater variety of prey and predators (Smith, 1968). They also serve as avenues of travel along with the adjacent borrow pits and ditches (Lay and O'Neil, 1942; Williams, 1955). Lesser (1965, p. 38) suggests the extent of multiple edge effect of interspersed marsh vegetation can limit populations of resident waterfowl. When stands of emergent vegetation are in juxta-position with similar stands duck broods are observed more frequently and in greatest concentrations. In contrast, when only open water is available in the marsh and the dike abutted directly there are fewer duck broods.

While high level impoundments were orginally developed for wildlife usage the maintenance of permanent water conditions does not decrease mosquito breeding. These insects decrease with draw-down but any reflooding by salt water or rain water intrusion stimulates great broods of these pests. Pot-holing with radial ditching in heavy breeding areas can be a more effective control (Ferrigno, 1958). A diversity of habitat, including permanent pools, must be provided for wildlife. Mosquito eating fish must have access to the larvae to provide effective control yet have pools to retire to when the tide recedes. Nutrient exchanges between the marshes and the estuarine environment must be improved over that of impoundments. The champagne pool system appears to offer the best solution for these three needs.

Feeding activity of game birds and mammals can produce various ecological changes. Bourn and Cottam (1939) reported brant and snow geese turned to *Spartina alterniflora* with the disappearance of eel grass, *Zostera*. A natural marsh can be markedly modified and mosquito breeding changed by large flocks of feeding snow geese. Small "eat-outs" produce the most mosquitoes while large "eat-outs" tend to produce ponds which support populations of mosquito eating fish, sheepshead minnow, *Cyprinodon*, and mummichog, *Fundulus* (Ferrigno, 1958).

Mosquito breeding on Egg Island marsh (Delaware Bay area) affected by feeding snow geese (Ferrigno, 1958)

Percent denuded marsh within 70 ft. radius of station marker		Vegetation Type	Water depth inches	Number larvae-pupae per dip	Total	number dips
A	10-30%	*S. patens*	0-2	12.71	6607	520
B	19-40	*S. alterniflora*	0-6	1.56	2119	1355
C	50-90	mixed *Spartina*	1-8	0.05	25	460
D	50-90	*S. alterniflora*	1-6	0.03	-	490
E	100 (ponds)	mixed *Spartina*	5-24	0.002	3	1401

Geese (Snow, Blue, Canada) feed heavily on 3-square bullrush, *Scirpus americanus*. They feed most easily on this plant when the flats are flooded and do so by "puddling out" the rhizomes. In so doing they make the seeds that have dropped into the mud available to ducks (Griffith, 1940; Lynch et al., 1947).

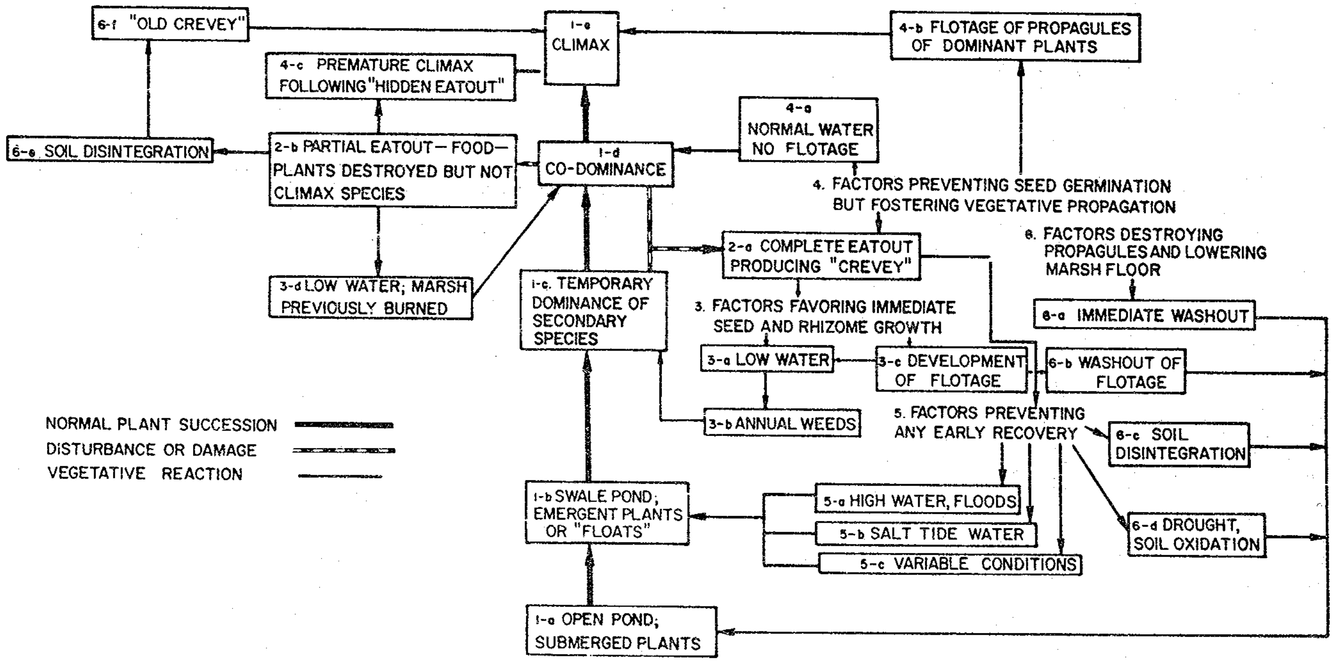
Geese can lay waste to large acreage of muskrat marsh when they congregate in a local area in large numbers. They invade *Typha* marshes when water levels are low and damage *Panicum repens*, the dog tooth grass, when marshes are flooded. Such goose damage may initiate a muskrat "eat-out" which can have a greater impact by destroying more vegetation (Lynch et al., 1947). There is a decline in animal weight and in population size following the ruinous effect on marsh vegetation brought about by over population and under trapping (Dozier et al., 1948).

The ecological consequences resulting from goose and muskrat damage to a marsh are discussed in considerable detail by Lynch et al. (1947) and summarized in Figure 1. There seems to be no way to foretell which of these changes will result from a particular type of damage. In general, the sooner recovery can start following an "eat-out", the better the chance the marsh will become productive. Repair delayed one to three years usually results in unproductive climax marsh.

Muskrats have not damaged coastal cattle range in Louisiana and Texas in recent years. In earlier times rat populations overran cattle range and rice crops but trapping now keeps their numbers down. During dry weather cattle can destroy muskrat houses (Lynch et al., 1947).

Geese can severely damage cattle range primarily in the fall in that two-fifths of the wintering grounds of blue and snow geese are classed as cattle range. The extent of damage is determined by water

Figure 1. Ecological consequences of muskrat and goose damage to marshes (from Lynch et al., 1947). (Reproduced by permission of the senior author and the editor of the Jour. Wildlife Mgmt.)


6-f "OLD CREVEY"
1-e CLIMAX
4-b FLOTAGE OF PROPAGULES OF DOMINANT PLANTS
4-c PREMATURE CLIMAX FOLLOWING "HIDDEN EATOUT"
4-a NORMAL WATER NO FLOTAGE
6-e SOIL DISINTEGRATION
2-b PARTIAL EATOUT— FOOD—PLANTS DESTROYED BUT NOT CLIMAX SPECIES
1-d CO-DOMINANCE
4. FACTORS PREVENTING SEED GERMINATION BUT FOSTERING VEGETATIVE PROPAGATION
2-a COMPLETE EATOUT PRODUCING "CREVEY"
6. FACTORS DESTROYING PROPAGULES AND LOWERING MARSH FLOOR
3-d LOW WATER; MARSH PREVIOUSLY BURNED
1-c. TEMPORARY DOMINANCE OF SECONDARY SPECIES
3. FACTORS FAVORING IMMEDIATE SEED AND RHIZOME GROWTH
6-a IMMEDIATE WASHOUT
3-a LOW WATER
3-c DEVELOPMENT OF FLOTAGE
6-b WASHOUT OF FLOTAGE
NORMAL PLANT SUCCESSION
DISTURBANCE OR DAMAGE
VEGETATIVE REACTION
3-b ANNUAL WEEDS
5. FACTORS PREVENTING ANY EARLY RECOVERY
6-c SOIL DISINTEGRATION
1-b SWALE POND; EMERGENT PLANTS OR "FLOATS"
5-a HIGH WATER, FLOODS
5-b SALT TIDE WATER
5-c VARIABLE CONDITIONS
6-d DROUGHT, SOIL OXIDATION
1-a OPEN POND; SUBMERGED PLANTS

levels. Low water causes geese to leave the cattle range and invade muskrat marshes. Normal water levels find the geese moving to new marsh areas before the any one feeding ground is denuded. High water produces severe competition between cattle and geese (Lynch et al., 1947).

"Eat-outs" are beneficial to a great variety of shore birds, waders and some ducks. They are attracted to the marsh plant seeds that become available and the minnows, crustaceans, insects, etc. that abound in new "crevys". Eat-outs" are most attractive during the first year. After that their wildlife value declines. "Eat-outs" in 3-square marshes not only destroy muskrat and goose habitat but that of mallards as well. (Lynch et al., 1947)

Burning can have an impact on such marsh land feeding relationships. Burns during the summer will remove the coarser plant material cattle find less palatable. Cattle will be attracted to the succulent new vegetation and can cause muskrat damage by destroying the latter's houses. Summer burns will also drive muskrats out of a marsh for lack of house building materials. Fall burning of S. patens and other marsh grasses produces an attractive fodder for both geese and cattle and, where the two co-exist in a marsh area, competition will be the outcome. Spring burning is more beneficial to muskrat populations (Griffith, 1940; Smith, 1942; Lay and O'Neil, 1942; Lynch et al., 1947; Williams, 1955; Neely, 1962).

Another interesting feeding relationship has been reported from England for marsh vegetation and sheep grazing (Yapp et al., 1917; Ranwall, 1961). Sheep seem to prefer the marsh to more upland pasturage. Practically all species on the permanent marsh are eaten except Juncus maritimus with a marked preference for Armeria maritima and Festuca rubra located in intermediate associations in a vertical zonation. Extention of pasturage was recommended by land reclamation, elimination of unproductive pans and prevention of the spread of economically useless Juncus by diking.

Another advantage to this kind of pasturage was the freedom of the sheep from infestation of the liver fluke, Fasciola hepatica, by the absence of the intermediate host, Limnaea trunculata, from brackish and saline marshes while prevalent elsewhere.

An interesting interaction was the suggested use of sheep grazed salt marsh to provide turf for golf or bowling greens, particularly the fine grass, Festuca rubra (Yapp et al., 1917).

Ranwell (1961) describes the vegetative changes in a tidal marsh brought about by sheep. Controlled sheep grazing can be carried out in the intertidal zone as long as it is confined to the upper reaches during the summer. Before the introduction of Spartina "townsendii", Puccinellia maratima predominated near the mean high tide mark and was considered to be a fine sheep pasturage. Spartina is more aggressive, prefers a softer soil, and can survive grazing except where the ground is packed along sheep paths. Ungrazed Spartina marsh will be transformed into Phragmites or Scirpus marsh, taking about eight years. Grazed Spartina marsh will be changed to a predominantly Puccinellia association in about 10 years. Succession to Puccinellia is favored in more saline and sandy areas while Phragmites or Scirpus are enhanced in less saline muddy locations. Grazing will favor Puccinellia in muddy places.

It is becoming increasingly evident that our tidal marshes are an extremely complex set of interactions. This has been born out by some of the recent local studies dealing with the biogeochemical processes.

The flushing characteristics of tidal creeks have a profound effect on the volume and rate of transport of materials. The rates of movement of plant nutrients, detritus, sewage, etc. through the system is determined by the place of entry. If introduced in the fresh water end movement will be slow and there will be a tendency to accumulate these substances. In contrast, any introductions in the lower end of the system will be removed very rapidly. The length of residence time will have an influence on the way materials will change. Organic phosphates become mineralized in the fresh water zone with a peaking of concentration of intermediate steps at successive downstream locations within the zone. The mineralization of these organic phosphates and the nitrogen compounds place a tremendous biological load on the system with a resultant oxygen sag. Further downstream this mineralization goes on but the effects do not accumulate and are diluted by the larger volumes of water moving through.

The landward distribution of planktonic bay organisms such as fish eggs and oyster larvae is determined by the flooding tide excursions and the short flushing times associated with the lower estuarine reaches of tidal streams.

There is a delicate interaction between kinds and numbers of bacterial populations, their metabolism and soil chemistry, seasonal temperature cycles and nutrient availability. This, in turn, has an influence on the kinds of plants found in the marshes. Certain algal species can better utilize ammonia and would be expected to flourish during the summer months. Others will do better during the colder months when nitrates are more available.

The standing crops as well as the rates of primary productivity for the edaphic algae and spermatophytes are determined by the interaction of the various biogeochemical components. The net productivity of marsh grasses amounts to approximately 5,000 lbs/acre. This plant growth is accomplished in half a year. The rest of the time the above-ground portions of these grasses are dead. They disintegrate releasing stored energy and plant nutrients. The death of the grasses permit greater light intensities to reach the edaphic algae on the marsh surface. This seasonal change in light intensities, temperature and other factors induce changes in these algal species associations. However, these associations are photosynthetically active all year. Their gross primary productivity has been calculated to be about one-third the net productivity of the grasses. There would be an even greater disparity if net productivities of both plant groups are compared. The important point is the algae are active producing oxygen and food during the cold half of the year when the grasses are dead. However, it must be kept in mind that on an annual basis the algae consume more than they produce. The deficit is probably made up by the breakdown of the grasses.

It is apparent phosphorus is not a limiting factor in tidal marsh productivity but that nitrogen is. Rates of growth and size of standing crops of both edaphic algae and spermatophytes is very much enhanced with additions of nitrogen. This increased productivity will release more oxygen; more detritus will be generated and presumably such detritus and associated nutrients will be transported out of the marsh lands into the adjoining estuarine waters. It is presumed that with an enlarged base to the food chain there would be increased productivity at the higher trophic levels. More time and work will answer that question.

Another question that still needs attention is related to the extent of recycling of plant nutrients, detritus, etc. within the marsh ecosystem. Do the amounts that are measured on the ebb tide, the net discharge of phosphate, etc. represent those amounts not needed within the marsh that then become available to the estuary or does it reflect amounts that could have been used in the marsh but "escaped"? The data suggest phosphorus falls in the former category while the marsh could use more nitrogen within its own system. The retention of organic nitrogen in the form of detritus could possibly boost nitrogen availability but only to a limited degree. Some organic nitrogen is undoubtedly lost to the sediments and, in fact, it may be of the same magnitude as is transported out of the system; a point that is unknown.

Marsh land manipulation through the construction of impoundments and ditching is going to have a depressing effect on estuarine productivity by inhibiting the flow of nutrients from the marshes into the bay waters. While these observations are based on phosphorus concentrations which in themselves are not limiting the evidence raises a question concerning current management procedure restricting water exchange. Therefore, the best management would place the least restriction on the transfer of plant nutrients to the estuary.

Numerous workers emphatically state great damage has been done to our tidal marshes by various drainage practices and other uses that are not natural to the habitat. Wildlife species and their habitats have suffered great and sometimes irrepairable losses. Kenny and McAtee in 1938 stated much drainage had been carried out that should not have been done, and there has been great abuse to animals and their rightful habitat through the persistence by man in the employment of trial and error methods. Ironically, mosquitoes have not been brought under control nor has agricultural production been enhanced by the use of drained marsh lands. The flow of energy and nutrients from the marshes to the estuarine ecosystem has been impeded.

Not only has damage been committed but conflicts of interest have arisen. There have been long standing conflicts between mosquito control people and wildlife interests but, in recent years, conflicts between fisheries interests, real estate and industrial development, waste disposal concerns and recreation have been added to the list. As Hawkes (1966) points out, with the exception of recreation, most uses tend to degrade a marsh and mosquito control has upset ecological balances. Ferrigno (1961) identifies a three-way conflict in the production of salt marsh hay. Development of hay production degrades a marsh for wildlife and encourages mosquitoes. As the climax vegetation, Spartina patens, is reached, mosquito breeding will be at a maximum and wildlife usage will decline.

Any habitat management will alter the structure of the ecological community. Marsh management includes drainage and impoundment as a physical practice while burning is identified as a cultural one (Smith, 1942). Various investigators have advocated that biological control, with particular reference to mosquitoes, must be based on sound ecological principles (see Cottam and associates, Clarke, Gabrielson, Glasgow, MacNamara, etc.). One must recognize that each ecological community has its own unique floral components, and that these develop in a normal sequence. Careful consideration must be given to the impact on this natural pattern by man's manipulation. Information is needed on species composition and distributions as related to the physical environment and associated species. In addition, data needs to be acquired on food and feeding habits, reproduction, population sizes and age structure. Marsh land management for wildlife and mosquitoes can be accomplished by inventorying the resource, determining relationships and then facilitating the production and maintenance of food and cover.

Among others MacNamara (1957) advocates the concept of multiple land use. He emphasizes that this does not mean an equality of land uses. He states these uses should be based on a broad interpretation of land classification and conservation along with careful evaluation of existing potentials for the various uses under consideration. Good land use is based on good planning in relation to ecological parameters of the areas under consideration.

Unfortunately, tidal marshes have been subjected to short term goals with long term consequences. Some areas may never recover their natural state. Protective legislation is slow in coming. Riparian rights are still vague in most states (Hawkes, 1966).

Conditions today have not advanced much beyond those reported by Kenny and McAtee in 1938. However, signs are increasingly evident that we are becoming aware of our impact on the environment. By cooperating in managment practices and by providing legal protection we will continue to see and enjoy the diversity of marsh land species in spite of the mosquitoes.

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