A Review of the Potential Impacts of Mechanical Harvesting on Subtidal and Intertidal Shellfish Resources

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PREFACE

This summary was developed to address recent concerns expressed by the U.S. Army Corps of Engineers (USACOE) and other agencies regarding use of hydraulic/mechanical shellfish harvesters in South Carolina. The document reviews relevant issues and existing information on the use and potential impacts of subtidal and intertidal mechanical shellfish harvesters, with emphasis on subtidal escalator harvesters. Information included in this report summarizes all pertinent literature (both "gray" and "primary") that could be located which provides direct or indirect information on concerns voiced by state, federal and private citizen groups, as well as an extensive bibliography of the above-mentioned literature (see Appendices). Specific recommendations regarding proposed research directions that address potential impacts are also provided.

The document includes a brief summary of the types and location of shellfish harvesting activities that occur in South Carolina, and the environmental concerns related to those harvesting activities. General environmental issues related to these harvesting activities include: (1) resuspension/turbidity effects; (2) direct burial/smothering; (3) release of contaminants; (4) release of nutrients; (5) decreased water quality due to elevated BOD from #4; (6) direct disturbance or removal of infauna; (7) effects on economically important finfish and crustacean resources and (8) multiple-use conflicts (see Kyte and Chew 1975, Kyte et al. 1975, Vining 1978, Barnes et al. 1991 for overview).

Throughout this document, distinctions are made due to obvious inherent differences between the two harvesting methodologies (SCDNR's harvester versus commercial subtidal harvesters), habitats (intertidal and subtidal) and associated target species collected (oysters versus clams, respectively). Wherever possible, gaps in our understanding of above issues, as they relate to deficiencies in available data for South Carolina systems are identified. These are presented to aid in developing an agreed upon scope and study plan for all concerned agencies.

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MECHANICAL HARVESTING METHODS AND ACTIVITIES

Historical Background

Historically, shellfish in shallow waters have been harvested by hand and mechanical means. The mechanical methods include the use of rakes, tongs, dredges (towed, escalator, suction, hydraulic) and patent tongs (Haven et al. 1973, Barnes et al. 1991, Peterson et al. 1983). Hydraulic dredges are often confused with a dredge used for excavating navigational channels. A hydraulic clam dredge is a shellfish harvesting device that has been utilized since the 1940s for the harvesting of soft clams, (Mya), hard clams (Mercenaria), oysters and bar clams, with obvious benefits being high efficiency, rapid harvests, continuous fishing and lower mortality (MacPhail 1961).

Hydraulic escalators are devices designed expressly for the purpose of the efficient commercial harvest of certain shellfish species (e.g., hard clams and oysters in South Carolina). They are typically considered "traditional" harvesting gear (since the 1940s, Kyte and Chew 1975, Kyte et al. 1975, Haven et al. 1976, 1979, Vining 1978). The evolution of the design of these harvesters has produced machines that can efficiently remove only the sought after bivalves, along with some associated material such as shell debris, without permanent removal of the sediments that serve as the substrate, although the disturbance to these sediments may be substantial.

Fletcher Hanks developed one of the first successful escalator harvester designs in the 1950s for use in Chesapeake Bay. It was first used commercially in 1952 and has been utilized successfully in both intertidal and subtidal habitats to collect bivalves in Canada, Europe, and in the United States, including Florida, Maine, New York, North and South Carolina, Oregon, Virginia, and Washington. Its use in sand and mud habitats has been investigated for over 30 years, including variations in design, CPUE, direct and indirect catch mortality, recruitment and environmental effects (reviewed in Kyte and Chow 1975; see also Dickie and MacPhail 1957, Manning 1957, 1959, Manning and Dunnington 1956, Manning and McIntosh 1958, Medcof 1959, MacPhail 1961, Pfitzenmeyer and Drobeck 1967, Haven 1970, Godcharles 1971, Kyte et al. 1975, Westley 1976, Tarr 1977, Goodwin and Shaul 1978, 1980, Vining 1978, Adkins et al. 1983).

Despite the numerous escalator harvester studies cited above, only a few "adequately" test one or more of the potential effects listed above (Glude and Landers 1953, Godcharles 1971, Kyte et al. 1975, Tarr 1977, Goodwin and Shaul 1978, 1980, Vining 1978, Adkins et al. 1983). Importantly, most have focussed on subtidal, vegetated or coarse sediment systems, from which one cannot extrapolate to systems dominated by fine sediments (Kyte et al. 1975).

The Maryland, soft-clam or Hanks type hydraulic escalator harvester (Dickie and MacPhail 1957, 1961, Manning 1957, Kyte and Chew 1975, Barnes et al. 1991) consists of a water pump supplying a manifold with numerous water jets mounted in front of a conveyor belt that dislodges buried organisms from the sediment (see Figure la, b). These vessels are generally in the range of 30' to 50' in length. Substrate and overburden containing clams are broken up by a cutting blade and eroded by the water jets as clams are washed onto the upward moving conveyor. Water jets often penetrate sediments to depths > 18" at high pressures (Goodwin and Shaul 1978) creating a "trench" or "furrow". The conveyor brings clams and oyster shells to the surface, where two or three crew members cull shellfish from the bottom material. A general rule of thumb for working depths seems to be about 25 % of the escalator length (MacPhail 1961), which restricts working depths based on gear limitations. Dead shells and other material remain on the conveyor after culling and are returned immediately to the water, possibly providing a tilling effect of the bottom that has been observed to be beneficial to subtidal oyster and clam populations (e.g., Mackenzie 1977, Haven et al. 1978, W. Anderson pers. comm.).

In contrast to hand harvesting, mechanical harvesters (e.g., escalators) typically produce an order of magnitude less mortality to target bivalve species (Kyte and Chew 1975, Peterson et al. 1983, 1987). Trench depth and duration (i.e. time to disappearance) are generally a function of forward speed (slower in silt/clay), operator skill, sediment type, water depth and local hydrological and meteorological conditions (Kyte and Chew 1975). Shallower trenches, with shorter residency times are typical of coarse sediments (sands), whereas trenches generated in muddy, finer sediments are typically deeper, often persisting for extended duration (often > 18 months, Kyte and Chew 1975, Kyte et al. 1975).

Operation of harvesters usually proceeds without a set pattern, with dredge "tracks" crossing or recrossing each other many times (Godcharles 1971, Kyte and Chew 1975, Barnes et al. 1991). Previous studies often report: (1) lower harvesting mortalities, (2) diminished effects on benthos, (3) greater CPUE, and (4) reduced labor intensity than other previously employed non-mechanical methods (Glude and Landers 1953, Dickie and MacPhail 1957, MacPhail 1961, Godcharles 1971, Peterson et al. 1983, 1987, Barnes et al. 1991). Numbers of permitted operating vessels are generally limited by the state. States also prohibit their use where they affect navigation in channels (Barnes et al. 1991). Various states have responded to calls for information on local harvester permitting (Anonymous 1989b). For example, in Connecticut, no prior approval is required for use on leased or private grounds; in North Carolina, no dredges permitted in most areas; in Alaska a state permit is required; in New York mechanical harvesting is permitted on leased grounds or for transplantation elsewhere; and in Maine, a special license is required due to low clam stocks (for South Carolina see below).

Shallow hydraulic escalator harvesters should not be confused with other "hydraulic dredges" (including suction or venturi) also used for shellfish harvesting throughout the world. These dredges work by towing a hydraulically-operated remote dredge (generally in deeper water) that gathers shellfish in a catch container (e.g., a chain-link bag) which is then raised to the surface. The potential effects and efficiencies of this gear type are better understood than for escalator dredges (see Caddy 1973, Pickett 1973, Meyer et al. 1981, Smolowitz and Nulk 1982, Haskin and Wagner 1986, Froglia 1989, Murawski and Serchuk 1989, Brambati and Fontolan 1990, Hall et al. 1990, Michael et al. 1990, Grenz et al. 1992) and whenever appropriate, this information is introduced to aid in understanding potential effects of hydraulic escalators.

Use **of Commercial Subtidal Hydraulic Escalator Harvesters in South Carolina**

This type of harvester first operated in South Carolina on the extensive shallow (< 15 feet) hard clam resources in the Santee Delta during the fall of 1973. Encouraged by its productivity, other fisherman purchased vessels and harvested clams and subtidal oysters in the delta until the fishery was terminated by the USACOE Santee-Cooper Rediversion Project. During the early years of the hard clam fishery (1974-1976), over 90% of the State's clam production came from hydraulic escalators. Mechanical harvesting operations stimulated the fishery to the extent that a seasonal market developed in the State for the first time. As many as 10 hydraulic escalators were permitted in the Santee Delta during its highly productive years, and three bottom areas were rotated for harvest on a tri-annual basis. Clam harvesters contributed significantly to the McClellanville economy, with approximately 40 million clams harvested from 1974-1989. Unfortunately, -the USACOE Santee-Cooper Rediversion Project resulted in a "restricted" reclassification of this vast estuarine area by SCDHEC, ending direct harvesting of shellfish for marketing. Over 680,000 clams were harvested by six escalators in the Santee from February to April 1989, several years after rediversion (see Burrell 1975a,b, 1980, Anderson and Keith 1982 and pers. comm.). Hurricane Hugo destroyed nearly all the harvesters in McClellanville in September 1989 and there was no "fleet" to harvest the Santee in 1990.

The genesis of the clam fishery contrasts with today's escalator harvests (Table 1, September-May, 1991-1994). The majority of wild stock clams now are harvested by hand in the intertidal zone, although hydraulic escalator harvesting, tonging and drag dredging continues. The recent commercial escalator fishery (1993-1994 shellfish season) consisted of five vessels: four located in McClellanville (Dorothy Elizabeth , Top Neck I, Top Neck II, Gsell and the fifth in Hamlin Creek, near Breach Inlet, Isle of Palms (Tony Lynn). The majority of the permits issued (45) were for subtidal bottoms in approved waters of shellfish culture permits as indicated in Table 2 and Figure 2a-c. Three vessel permits were also jointly issued by SCDNR and SCDHEC from April 4 - 28, 1994 for a ten day period allowing harvest from restricted subtidal waters in Winyah Bay (Figure 2a,c). Mean CPUE for all escalators was 15.23 bags/hour (3,809 clams/hour). Total Winyah Bay production was 683,750 clams (see Figure 3). Clams were shipped to the Ware River, Gloucester County, Virginia for depuration.

Areas in Charleston Harbor, a prohibited area, were harvested in January, February and April, 1984 with over 1.2 million clams harvested by nine vessels; in March to April, 1993 harvesting for 4 days yielded over 290,000 clams taken by five vessels (W. Anderson pers. comm.).

Operating Areas

Hydraulic escalator operations are permitted to occur in two habitats, larger open water bodies such as Winyah Bay (Figure 2a,c) and in smaller creek habitats (Figure 2a-c). Shellfish culture permit holders may apply for special escalator permits to operate subtidally within the perimeter boundaries of their culture permits. In addition, culture permit holders who do not own escalators may obtain hydraulic escalator permits. Although the clams are harvested by the hydraulic escalator, the permit is issued to the culture permit holder. Table 2 compares the acreage permitted for harvesting in culture permits to State Shellfish Ground open water bodies. Even though the amount of acreage appears extensive, particularly in open water State Shellfish Grounds, only a small area within the perimeter boundaries is harvested. The large boundary area allows for exploration and facilitates management of the fishery.

State Shellfish Grounds are usually large open water bodies [e.g., Little River/Dunn Sound (P-997), Winyah Bay (P-905, P-910, P-944), North Santee River (S-337), North Santee Bay (S-337), South Santee River (S-336), Hamlin Creek (P-255), Charleston Harbor (X-929), Ashepoo River (S-135)] and they are all restricted or prohibited areas for shellfish harvesting (with the exception of Hamlin Creek, which is conditionally approved). Shellfish in these subtidal bottoms may be harvested and relayed to approved waters for depuration. The application process consists of a joint permit with SCDHEC and in situ daily monitoring by SCDNR and SCDHEC of harvesting activities.

Permit Requirements

Mechanical shellfish harvesting permits are issued by the permitting office of the SCDNR's Office of Fisheries Management (OFM). Mechanical harvesting permits are required for hydraulic escalators, drag dredges, patent tongs and other mechanical gear operating from floating platforms. Vessel licenses must be obtained from the DNR's Coastal Fisheries License Office prior to receiving a permit . Hydraulic escalator operators must meet the following criteria before being issued a hydraulic escalator permit (see Appendices 1 & 2):

(1) the operator must hold valid licenses for the vessel and harvesting equipment;

(2) the operator and all crew members must obtain commercial shellfish harvesting licenses ($25.50);

(3) the operator must hold either a land-and-sell or captain's license;

(4) the harvest area within perimeter boundaries of a culture permit must be:
   (a) subtidal
   (b) wide enough to allow the vessel to turn around in the creek or operating area
   (c) a part of the individual's culture permit ($5.00/year rental and a 125 U.S. bushels/acre planting requirement);

(5) the operator must meet a daily reporting requirement to the OFM's Shellfish Management Program, including production and hours of operation.

Permit Protocols

The Shellfish Management Program maintains a resource assessment and production (CPUE) database and cartographic file on each of the eight S.C. State managed hard clam populations. Prior to opening an area for harvest by a commercial hydraulic escalator, a resource assessment is conducted to determine recruitment, population density, and condition of the resource. Since the majority of the areas are in restricted waters, the SCDNR forwards a letter to SCDHEC, stating the location, time of proposed operations and the area(s) clams will be relayed for depuration.

Following coordination with SCDHEC, a written notice is mailed to all licensed escalator harvester operators announcing the opening date and, in some cases, when a short term fishery is anticipated, the actual time and dates of harvest. No direct sales of shellfish are permitted.

Interested commercial hydraulic escalator harvesters apply to the DNR for a permit. The permit restricts harvesting to subtidal bottoms only, specifies the hours of harvesting and has a map attached to the permit as well as a list of permit conditions (Appendix 2). A joint SCDNR/SCDHEC permit is. issued by SCDNR following review of the application packages by SCDHEC. In addition, forms which report total daily production and fishing hours are required as a condition of the permit (Appendices 2 & 3). Failure to report in a timely manner may result in permit cancellation. SCDHEC inspectors monitor the harvest, transportation, storage and relay operation in accordance with FDA guidelines. Clams are sometimes placed in cages following the harvest for a minimum two week depuration period in approved areas.

Permits may include provisions for retaining oysters harvested by clam escalators for relay/depuration, or for meeting planting requirements on culture permit areas. Additional considerations concerning the issuance of permits on State shellfish grounds are: (1) condition of the resource, (2) environmental and water quality issues (SCDHEC, (3) historical use of the harvest area, (4) number of permits to be allowed and (5) current market conditions. The number of permits may be limited or the fishery terminated earlier than expected to prevent over harvesting (see Appendices 2 & 3).

SCDNR Intertidal Hydraulic Oyster Escalator Harvester

In the 1970s, the SCWMRD, in conjunction with Clemson University, designed and constructed a mechanical oyster harvester and tested whether this machine could economically harvest intertidal oysters. This project was a direct consequence of the difficulties of hand harvesting oysters and an ever decreasing available labor pool in South Carolina. Experimentation with modifications to the Maryland, soft-clam or Hanks type hydraulic escalator harvester "clam head" (Dickie and MacPhail 1957, 1961, Manning 1957, Kyte and Chew 1975, Barnes et al. 1991) facilitated the harvest of oysters growing intertidally along shorelines of estuarine creeks and shallow bays which are the primary growth areas for 95 % of South Carolina's oyster resource (W. Anderson, SCDNR). Although the commercial oyster industry has not applied this modification to commercial activities, MRD adopted this design variation to enhance the efficiency of transplanting or relaying oyster populations for management for both commercial and recreational harvest in areas specified for State maintenance.

The harvester can be utilized for controlled shellfish relaying for transplantation, growout, depuration, oyster harvesting, surveys and other department research objectives (e.g., Loesch 1974, Collier and McLaughlin 1983, 1984, Anderson et al. 1986, Barnes et al. 1991, Burrell et al. 1991, W. Anderson pers. comm.). Working depths are 1-3 in during high tide (Collier and McLaughlin 1983, 1984, A. Jennings pers. comm.). Earlier MRD harvester prototypes supposedly generated less damage to the oyster bed matrix (live and dead shell) than hand harvesting (SCDNR-OFM Shellfish Section, pers. comm.).

A preliminary study by MRD-SCDNR personnel (Burrell et al. 1991) evaluated potential harvester effects on "donor" and "recipient" individual oysters and overall bed "health". Results obtained which were based on an earlier harvester design, suggested that oyster damage due to harvesting was high and mortality was nearly 100% in the upper intertidal transplants during the summer season. Better short-term transplant survival and growth were observed in the lower intertidal during the winter and spring months. Overall, they concluded that transplantation to upper intertidal areas was not viable. Subsequent planting strategies have been modified based on these 1980s results. Little quantitative data are available regarding the effects of harvesting on donor reefs; however, some observations suggest that donor reef growth may be enhanced by oyster removal (W. Anderson and A. Jennings, pers. comm.).

BIOLOGICAL RESOURCES HARVESTED AND RELATED HABITATS

Subtidal Hard Clam Habitat

The hard clam, Mercenaria mercenaria, is a shallow infaunal burrower, found from the Gulf of St. Lawrence to Florida. Throughout South Carolina there are numerous subtidal softbottom areas where hard clams have been historically found (Anderson et al. 1978). In many Atlantic states, the distributions of other shellfish species (e.g., other hard clam species, soft clams, scallops) overlap with subtidal oysters, Crassostrea virginica, (e.g., Manning and Pfitzenmeyer 1957, Haven et al. 1970, 1978). Seagrass beds (or submerged aquatic vegetation, SAV) are generally not found in South Carolina (cf. North Carolina Mercenaria populations, Peterson et al. 1983, 1987 and references therein), so that hard clams are generally associated with unvegetated, soft-sediments exclusive of fringing marsh habitat. In South Carolina they are quite common in areas with fine sediments, muds (Anderson et al. 1978). Hard clams are generally abundant in unvegetated sands, muddy sands and shell hash, in intertidal and subtidal habitats (Stanley 1970, Peterson et al. 1983, 1987, N. Hadley pers. comm.). These fine sediments primarily harbor infaunal species and some epifauna. (e.g., Leptogorgia). Certain subtidal bivalves (e.g., oysters) are rare in the subtidal zone, due to enhanced predation, sponge boring and diseases (Lunz 1955, 1959, 1960).

Intertidal Oyster Reefs

The American oyster, Crassostrea virginica, occurs over a broad geographical range, including the east coast from Canada to Florida, throughout the Gulf of Mexico to Yucatan, Mexico to the West Indies and Venezuela (Stanley and Sellers 1986). Oysters are unique in their ecological role in that they form living reef structure in the estuary that supports a host of other associated organisms not found in the surrounding sand or mud habitats (Dame 1979, Bahr and Lanier 1981, Stanley and Sellers 1986, Zimmerman et al. 1989). Oyster reefs can have important direct and indirect effects through their tremendous processing capacity as filter feeders, removing sediments and affecting hydrodynamic flow (e.g., Heck 1987, Haven et al. 1978, Newell

1988, Dame 1993, Dame et al. 1984, 1992, 1993) and through the creation of new habitat structure (e.g., Zimmerman et al. 1989).

Human activities, in concert with nature, have greatly affected the distribution and abundance of oysters. Oyster production throughout its range has declined precipitously in recent years due to causes as diverse as: (1) diseases, (2) physical disturbance by storms, oyster harvesting or human traffic, (3) over-harvesting, (4) nutrient enrichment through runoff, (5) natural predators, (6) alteration of natural flow regimes and salinity patterns and (7) removal of appropriate habitat for new recruits (e.g., Stanley and Sellers 1986, Anonymous 1989a, Berrigan et al. 1991, Rothschild et al. 1994).

Although there is no SAV in South Carolina, there is an abundance of salt marsh and intertidal oyster reefs in higher salinities (> 54,000 ha, Lunz 1955, 1959, Collier and McLaughlin 1983). The functioning and value of SAV and Spartina -dominated salt marsh has been the subject of numerous studies (Thayer et al. 1978, Weinstein 1979, Orth and Montfrans 1990, Thomas et al. 1990, Wilson et al. 1990, Wenner and Beatty 1992, Peterson and Turner 1994). Although intertidal oyster reefs are a conspicuous habitat in South Carolina (Lunz 1959, 1960, Dame 1993 see references herein), almost nothing is known about how these extensive areas contribute to the broader functioning of the inshore waters in which they occur. We know that South Carolina oyster reefs improve water quality by their vast filtering ability (Dame et al. 1980, .1984, Dame and Libes 1993 and references therein) and offer a substrate for new oysters and associated small organisms (Dame 1979, Bahr 1974, Bahr and Lanier 1981, Klemanowicz 1985). However, information is lacking on the value of oyster reefs as habitats for young and adult fishes, crabs and shrimps, which may be associated with reefs at high and low tide (cf. Weinstein 1979, Zimmerman et al. 1989, Orth and Montfrans 1990, Thomas et al. 1990, Ruiz et al. 1993 for other submerged habitats).

Since oysters are the basis for a structurally complex habitat in the southeastern United States, this species can in many ways be considered a "keystone" species. By forming extensive intertidal reefs, oysters often provide the only shelter on otherwise soft sediment bottoms. In areas normally devoid of naturally occurring rock and other complex substrates, the many crevices and expansive surface area found in an oyster reef provide the only source of shelter and attachment for numerous small invertebrates (Klemanowicz 1985). Anecdotal data for South Carolina indicate that bait fishes such as anchovy and silversides are also attracted to oyster reefs because of their complex three-dimensional structure, which enables them to hide from predators such as spotted sea trout and paralichthid flounders. These important recreational species cruise the oyster reefs on an incoming tide for food, as do sheepshead, black drum and red drum, which consume small crabs and shrimp that reside in and around reef structure. Densities of these food items can be > 750/m2 of reef habitat (Knott, Coen and Wenner pers. obs.). The association of these desirable sport fish with oyster reefs makes them a frequently fished habitat in South Carolina estuaries (C. Wenner pers. comm.). Oyster reefs in high salinity waters are also an important habitat for juveniles of several important fish species such as sheepshead, gag grouper and snapper, as well as stone crabs (Wenner and Stokes 1984, R. Beatty unpublished data).

BIOLOGICAL AND ECOLOGICAL ISSUES

As noted previously, the general ecological issues related to the effects of mechanical shellfish harvesting include: (1) resuspension/turbidity effects; (2) direct burial/smothering; (3) release of contaminants; (4) release of nutrients; (5) decreased water quality due to elevated BOD from #4; (6) direct disturbance or removal of infauna and (7) effects on economically important finfish and crustacean resources. These is sues are briefly reviewed in the following sections. An extensive annotated bibliography also follows.

In South Carolina both intertidal and subtidal shellfish beds are located within inshore, estuarine areas. As with all estuarine environments they undergo large scale physical and biological fluctuations. This occurs on both a temporal and spatial scale (Levinton 1982), including semi-diurnal macrotides (often exceeding 2 m), sediment resuspension during daily flood and ebbing tides, highly variable salinities, temperatures and seston levels (Cyrus and Blaber 1987b) among others (see Settlemyre and Gardner 1977 for Charleston, SQ. Hence, estuarine species are typically considered more "tolerant" of environmental fluctuations and physical disturbance (Rhoads 1973, Levinton 1982, Simenstad 1990).

Resuspension-Turbidity Effects

Turbidity is an optical property of liquids that gives some measure of the scattering of light due to material suspended in solution (absorption vs. transmittal). The latter is often termed suspended solids or "seston", which includes solids or colloidal material (organic and inorganic) and living organisms held in suspension. Suspended solids are often difficult to adequately quantify due to their various optical (e.g., NTU, JTU) and physical (shape, material) properties (Moore 1977, Wilber 1983, Sigler 1990).

Human-induced resuspension-turbidity effects often result from large-scale dredging operations to remove or redistribute sediments, ship and boat traffic, and land runoff (Sherk 1972, Moore 1977, LaSalle 1990, Simenstad 1991). Observed effects are typically site specific as a consequence of sediment grain size and type, hydrological conditions, faunal influences, currents, water mass size and configuration, etc. (Hayes et al. 1984, Herbish and Brahme 1984, Barnes et al. 1991, LaSalle 1990).

Potential effects of turbidity and sediment resuspension have received a great deal of attention due to runoff and sediment dredging concerns (e.g., Peddicord et al. 1975, Hayes et al. 1984, Herbish and Brahme 1984, LaSalle 1990). The extensive literature on this subject will only be briefly reviewed here, primarily with respect to how turbidity can affect eggs, larval, juvenile and adult fishes and shellfish in <u>freshwater</u> (Swenson and Matson 1976, Vinyard and O'Brien 1976, Gardiner 1981, Gardiner et al. 1989, Gradall and Swenson 1982, Matthews 1984, Sigler et al. 1984, Diehl 1988, Crowl 1989) <u>estuarine and marine</u> ecosystems (reviewed in Peddicord et al. 1975 for invertebrates, Simenstad 1990 for fish; see also Loosanoff 1962, Loosanoff and Tommers 1948, Ingle 1952, Davis 1960, Young 1971, Sherk 1972, Rhoads 1973, O'Connor et al. 1976, 1977, Auld and Schubel 1978, Johnston and Wildish 1982, Berg and Northcote 1985, Boehlert and Morgan 1985, Minello et al. 1987, Breitberg 1988, Cyris and Blaber 1987b, Grant et al. 1990). Many other studies (e.g., Ellis 1936, Lunz 1938, Cyris and Blaber 1987a, Anonymous 1989b) have pertinent anecdotal information which relates to concerns derived from shellfish harvesting (i.e. potential effects on recreationally and commercially important species).

The majority of the behavioral studies cited above, have been conducted in semi-controlled or controlled laboratory situations, rather than in the field. Many of those focussed on fish have addressed primarily the effects of reduced light and/or turbidity on predator-prey interactions, especially pursuit times, perceived risks, reactive distances, prey movement and visual cues (e.g., Vinyard and O'Brien 1976, Gregory 1990).

Turbidity reduces light levels, thereby generally decreasing predator feeding success and enhancing prey survival in some cases (Vinyard and O'Brien 1976). However, results are system- or species-dependent, being highly variable and often conflicting (cf. Johnston and Wildish 1982 and Boehlert and Morgan 1985). For example, in these two studies with larval herring <u>(Clupea)</u> as predators, the former found depression of prey capture with increased turbidity, while the latter observed enhanced prey capture. Boehlert and Morgan (1985) suggested that this result may have been due to increased visual prey contrast for these larval predators, which have minimal visual search distances/volumes. Alternatively, adult fishes may have reduced success due to inhibition of their much larger visual fields. Breitburg (1988), however, found variable results as a function of prey species (copepods vs. Daphnia using striped bass larvae and Minello et al. (1987) observed variable predator success with three adult estuarine fishes on shrimp in different turbidity levels and substrates. Predation success and turbidity can also interact as prey change position and behavior with affected light levels (Gradall and Swenson 1982, Servizi 1990).

Chronic turbidity affects aquatic organisms through: (1) behavioral (Moore 1977, Berg and Northcote 1985, Crowl 1989, Simenstad 1990), (2) sublethal (Moore 1977, O'Connor et al. 1977) and (3) lethal (O'Connor et al. 1976, Moore 1977, Simenstad 1990 and chapters therein) effects. Behaviorally, turbidity can affect stream choice (e.g., salmonids), conspecific interactions (e.g., gill flaring, dominance hierarchies), migration and spawning. Sublethal effects include decreased adult fitness and performance (disease resistance, hatching success, larval survival and foraging). Lethal consequences may also be the result of suffocation (e.g., gill clogging) or loss due to enhanced predation success (Auld and Schubel 1978, Sigler 1990, Simenstad 1990). All are a function of exposure duration and timing.

For bivalve eggs, larvae, and adults, laboratory studies with various natural and artificial substances of different mean particle size and mineral composition have demonstrated sublethal (e.g., reduced pumping rates, growth, egg development, reviewed in Moore 1977) and lethal effects (see Davis 1960, Loosanoff 1962, Loosanoff and Tommers 1948, Moore 1977) at turbidity levels considerably lower than those observed in nature. Whether these conflicting lab bioassays and field (Lutz 1938, Young 1971, Rhoads 1973) results have any relevance to field bivalve populations is still under debate since shellfish species of concern in South Carolina thrive in turbid estuaries (Kennedy 1989).

In addition to organismal and population effects, turbidity can affect immunological, physiological and histopathological systems (Servizi 1990, Simenstad 1990). Estuarine fishes have been classified in lab studies as tolerant, sensitive or highly sensitive, to turbidity levels (I, II, III in O'Connor et al. 1976). For example, O'Connor et al. (1976) found that mummichog, striped killifish, cusk eel, toadfish, hogchoker were suspension-tolerant, whereas Atlantic silversides, juvenile bluefish and menhaden and young-of-the year white perch were highly sensitive to suspended mineral solids. Neumann et al. (1975) found that toadfish (Opsanus) respiration appears unaffected by elevated turbidity. Larval fish are probably less likely to suffer from gill clogging than older individuals, as their gills are poorly developed and without an operculum. (Auld and Schubel 1978).

Shellfish "dredging" operations have typically not been considered to have deleterious results, since its effects are perceived to be negligible compared to natural environmental variation (e.g., currents, winds and waves, Godwin 1973). Many of the potential effects are also limited by the scale of the operation (both spatial and temporal), particle grain size (see above), the process itself (immediate return to the bottom) and local hydrology, among other factors (Barnes et al. 1991). Of primary concern are short-term effects such as shading and decreased primary production, fish gill clogging and irritation (Simenstad 1991) and effects on filter-feeding invertebrates (Kyte et al. 1975, Kyte and Chew 1975, Barnes et al. 1991).

Although the effects of shellfish dredging on turbidity levels have not been studied, the organisms that live in these highly variable, estuarine ecosystems typically encounter elevated and highly variable suspended sediment loads (and seston) throughout their life histories, with ambient seston levels often varying by several orders of magnitude over short durations (e.g., daily, Young 1971, Sherk 1972, Rhoads 1973, Kyte et al. 1975, Settlemyre and Gardner 1977, Auld and Schubel 1978, Gregory 1990, Barnes et al. 1991). Hence, they are generally considered tolerant of short-term perturbations (Lutz 1938, Kyte et al. 1975). Also, most of the fishes and crustaceans (with the exception of barnacles) are highly mobile, whereas molluscs (clams and oysters) are less so or immobile.

Interestingly, some molluscs may actually have enhanced growth in areas with high turbidities when held off the bottom in experimental trays (reviewed in Moore 1977; see also Young 1971, Rhoads 1973). Potential shading effects may be offset by nutrient stimulation from harvesters resuspension (Barnes et al. 1991) and many estuarine fish larvae often enter during spring runoff times when turbidity values often peak (Gregory 1990) further supporting tolerance to turbidity.

In summarizing potential effects on fishes, Simenstad (1990) concluded that most estuarine fishes move out or are adapted to elevated suspended sediments and that most behavioral or sublethal effects seen in the lab are even more ambiguous when extrapolated to the field. Auld and Schubel (1978) concluded the same for eggs and larvae of six Chesapeake Bay species. Thug, while the effects remain unknown, it is unlikely that the limited turbidity plumes created by subtidal or intertidal shellfish dredging operations have a major impact on the biological resources in those habitats (see Auld and Schubel 1978 also). Currently we need to quantify ambient turbidity levels and those adjacent to and downstream of both harvester types during operations. There may be substantial differences in effects in open embayments (e.g., Winyah Bay) versus small creeks (e.g., Conch Creek behind Isle of Palms/Sullivans Island). The former open area is typical of most sites previously studied elsewhere (Kyte et al. 1975, Kyte and Chew 1975, Tarr 1977, Goodwin and Shaul 1978, 1980, Vining 1978). The proposed study of mechanical harvester effects should include a limited sampling effort to define turbidity levels associated with these operations and to confirm that turbidities are not elevated above naturally occurring levels (e.g., Settlemyre and Gardner 1977).

<u>Direct Burial-Smothering</u>

Most of the literature on effects of burial by mechanical harvesting is anecdotal or nonspecific (Peddicord et al. 1975). Most studies have dealt with commercial bivalves. Sediment type and the amount of sediment overburden, as well as size and the habits of a particular infaunal or epifaunal organism appear to be critical in tolerating the effects of burial (Glude 1954, Schafer 1962, Shulenberger 1970, Oliver and Slattery 1973, Rose 1973, Kranz 1974, Mauer et al. 1978, 1981, 1986). In laboratory experiments, most estuarine infaunal species that have been tested were able to survive burial to depths of 20 cm or more. Epifaunal or non-motile species (e.g., oysters) suffer higher mortality rates after burial however (see Oliver and Slattery 1973, Rose 1973).

Generally, mortality from direct burial or smothering caused by harvesting or sediment dredging is an issue only for organisms with restricted mobility (e.g., attached eggs, juveniles, burrowing infauna, oysters; Lutz 1938, Barnes et al. 1991). Normal sediment movement as a direct result of escalator harvesting is less than 10-30 cm, a depth not considered to cause mortality to small infauna (Barnes et al. 1991). As an example, winter flounder which produce demersal eggs could be affected by sediments if harvesting operations coincided with seasonal reproduction (Barnes et al. 1991). Most mortality under normal harvesting is a direct result of sublethal or lethal damage to adult and juvenile bivalves during harvester operation; however, actual rates are almost always much lower than hand methods (Kyte and Chew 1975, see above, but see Naidu 1988 with scallops).

Intertidal oyster harvesting has been limited to South Carolina with high mortality sometimes resulting to that species during transplantation (see Klemanowicz 1985, Burrell et al. 1991). This probably is due partly to the stress of summer transport and redeposition at the recipient site rather than direct harvester-generated mortality due to smothering/burial.

Based on the extensive dredge literature (reviewed in Peddicord et al. 1975) and more limited harvester studies, it appears that the issue of subtidal burial/smothering is not of primary concern. However, we know virtually nothing about the potential effects of harvesting intertidal oysters on their associated resident invertebrate and vertebrate faunas (but see unpublished data in Klemanowicz 1985). A major emphasis of the proposed study should focus on the potential effects of harvesting within this system.

Release of Contaminants

One major concern during resuspension of sediments is the possible release of contaminants (Tramontano and Bohlen 1984, Barnes et al. 1991). LaSalle (1991) states that sediment dredging can release natural and industrial chemicals and the magnitude and spatial extent of this release is a function of dredge type and material, density, grain size, and organic content, as well as local hydrological conditions.

Barnes et al. (1991) have summarized relevant concepts for shellfish dredging as they relate to sediment disturbances that release hydrocarbons or metals. They review important ideas regarding transfer mechanisms across the sediment-water interface, especially as they occur in fine-grained sediments. These fine sediments have large surface areas per unit weight and a high exchange capacity for the adsorption of metals. In fine sediments, bonding typically takes place through one of four processes: (1) adsorptive bonding; (2) coprecipitation by hydrous iron and manganese oxide; (3) complexation with organic molecules and (4) incorporation into crystalline minerals. Remobilization of metals from suspended material (e.g., dredging or harvester resuspension) occurs typically as a result of one of four chemical changes in seawater: (1) elevated concentrations of salts; (2) changes in redox (e.g., due to eutrophication); (3) drop in pH and (4) increased use of complexing agents. Less is understood regarding the release of hydrocarbons via chemical reactions (Barnes et al. 1991). Bioaccumulation is another possible mechanism for uptake and transfer of contaminants.

Most importantly, physical processes can initiate the release of contaminants from sediment pore waters into the water column through: (1) natural resuspension (waves, currents); (2) disturbance by benthic organisms (bioturbation) and; (3) dredging. All of these maintain a dynamic equilibrium with regard to surface sediments. Deeper sediments, however, are mixed during dredging (Barnes et al. 1991).

There is presently little or no evidence to support the hypothesis that the use of escalator harvesters causes the release of contaminants, based on data from large-scale sediment dredging work and observed slow rate processes. However, this is largely due to the fact that areas where shellfish are harvested for consumption usually require high water quality, even when shellfish are transplanted elsewhere for depuration (Vining 1978, Barnes et al. 1991). Without contaminant data for specific sites being harvested, it is difficult to resolve whether the effects of shellfish dredging results in the release of contaminants. SCDHEC has monitoring stations throughout the state (e.g., see DHEC 1987); however, most of these stations do not overlap with areas open to shellfish harvesting. Some data exist for Charleston Harbor, North Inlet and Winyah Bay (e.g., Blood et al. 1992, Davis et al. 1992). These reports suggest that some areas within these South Carolina estuarine systems have elevated pollutant levels (e.g., heavy metals, pesticides), but data specific to the areas where shellfish are harvested are generally not available. Therefore, the proposed SCDNR study should evaluate whether or not consistently harvested areas should be included for future monitoring by the state or other agencies. Based on limited budgets, it is unclear as to whether a characterization of all sediment contaminants can be evaluated within the scope of the proposed study plan.

Nutrient Release and Associated Elevated BOD

A major concern for dredging, and possibly escalator harvesting, is the potential release of nutrients and their associated effects (Goodwin 1973, Kyte et al. 1975, Kyte and Chew 1975, Tarr 1977, Goodwin and Shaul 1978, Vining 1978, Barnes et al. 1991, Grenz et al. 1992). As with contaminants, pore water release during sediment "disturbance" (either physical, biological or dredging) can lead to the release of nutrients. Excessive nutrients may stimulate algal growth and increased BOD, potentially leading to local eutrophy (Kyte et al. 1975, Kyte and Chew 1975, Barnes et al. 1991). However, as stated above (see Turbidity section), such increases in primary production (i.e. "blooms" or short-term effects due to elevated nutrients) are probably offset by shading due to enhanced turbidity (Barnes et al. 1991).

Kyte et al. (1975), Kyte and Chew (1975), Tarr (1977) and Vining (1978) examined the literature for evidence that escalator harvesting causes short-term chemical changes in the environment. Most changes are transient and indistinguishable from ambient natural variation in pH, dissolved oxygen (DO), H_2S, chlorophyll a (chl a), organic, inorganic and total phosphate (P), salinity, etc. Godwin (1973) considered increased BODs due to elevated nutrient release, but concluded that these occurrences would be of very short duration. Kyte et al. (1975) and Tarr (1977) have the only available data for either water chemistry effects or nutrients released by harvesting.

Tarr (1977) examined water quality in Washington, in association with escalator harvesting at several sites with different attributes, although all had fairly coarse-grained sediments. He measured BOD, light absorbance, chl a, salinity, inorganic and total P, transparency, suspended solids, temperature and salinity. For all of the above he found little or no detectable effect caused by the harvester.

Kyte et al. (1975) made measurements that are more relevant to the finer sediments in South Carolina. They measured oxygen, pH, dissolved H_2S before, during and after harvester operation at varying distances. No consistent patterns of depression or release were noted throughout the process. Only in the area of the plume at the harvester did they measure even a temporary reduction in DO and pH. An odor of H_2S was detected, but never measured by analyses.

Barnes et al. (1991) concluded that potential impacts of nutrient release by harvesters are very limited in both time and space (short-term and very localized), since the magnitude of released nutrients is small compared to an overall estuarine ecosystem nutrient budget (see Tramontano and Bohlen 1984 for dredging). Based on the previous studies and the high variability likely to occur as a result of typical wind or storm events and fluctuations in daily loadings from point and non-point sources, it seems highly improbable that nutrient release would have major consequences related to shellfish harvesting in South Carolina. Concurrent nutrient measurements should probably not be a major concern in the proposed study plan.

Direct Disturbance or Removal of Infauna

Most studies agree that dredging causes some mortality to small and large infaunal and epifaunal organisms in the direct path of the device (Godcharles 1971, Kyte et al. 1975, Kyte and Chew 1975, Vining 1978, Meyer et al. 1981, Mackenzie 1982, Peterson et al. 1987, Barnes et al. 1991). However, since many of these small benthic organisms (crustaceans, polychaetes, molluscs) have rapid generation times, high fecundities and excellent recolonization capacities, it is generally accepted that this community effect is only short-term (e.g., Godcharles 1971, Peterson et al. 1987, Bennett et al. 1990, Hall et al. 1990). Hall et al.

(1990) suggest that the effects will be apparent and protracted only if the fauna are primarily immobile or if the affected area is large relative to remainder of the habitat. Van Dolah et al. (1979, 1984) also documented that benthic assemblages in South Carolina estuarine habitats appear to recover relatively quickly after channel dredging, which represents a much greater disturbance than shellfish harvesting where the fauna are generally not removed. They have also shown that commercial shrimp trawling, which involved disturbance of the superficial sediments, does not have a demonstrable effect on benthic communities in South Carolina estuaries (Van Dolah et al. 1991; see van der Veer et al. 1985, Eleftheriou and Robertson 1992, Hall 1994 also).

In contrast to these finding, field experiments using various "hydraulic dredging" methods (see above section) have demonstrated sublethal and lethal effects to infauna, and epifauna. These include, soft-tissue cutting (foot or siphon), shell breakage and low bivalve reburial rates (see Ingle 1952, Medcof 1959, Pfitzenmeyer and Droebeck 1967, Caddy 1973, Kyte et al. 1975, Meyer et al. 1981, Haskin and Wagner 1986, Peterson et al. 1983, 1987, Naidu 1988, Hall et al. 1990).

Other experimental studies using various hand and mechanical shellfish harvesting gear in diverse habitats in Florida (Godcharles 1971), Washington (Tarr 1977, Vining 1978, Goodwin and Shawl 1978, 1980), Maine (Kyte et al. 1975), North Carolina (Peterson et al. 1983, 1987), Rhode Island (Glude and Landers 1953), Scotland (Hall et al. 1990), and Canada (Adkins et al. 1983) have found no discernible long-term effects on local infaunal populations, with the exception of the harvested bivalve species (e.g. compare Kyte et al. 1975, Peterson et al. 1987, Hall et al. 1990). The role of filter-feeding bivalves in ecosystems is well known (see Dame 1993) and their reduction and/or removal over a larger scale (e.g., Chesapeake Bay) can cause major changes to the system (Newell 1988, Rothschild et al. 1994).

In certain physical environments, changes in sediment characteristics can alter community composition after extensive sediment dredging (Kaplan et al. 1975). Shifts from fine- to coarse-dominated sediments can markedly affect the benthic community; in the example above a shift was seen from a mud community dominated by errant polychaetes to one dominated by a bivalve fauna more indicative of sandy bottoms.

Based on all direct and indirect evidence, short-term and localized infaunal population depression (i.e. invertebrate fauna) does not appear to be of primary concern for subtidal habitats. However, so little is known about the harvesting of intertidal oyster communities that this potential effect should be examined. Extensive literature exists with respect to human disturbance on rocky intertidal shores due to human trampling (discussed in Brosnan et al. 1994) and the results of studies on this less severe disturbance may give us some insight into potential effects of mechanical oyster harvesting (see also Pickett and White 1985).

Effects on Economically Important Finfish and Crustacean Resources

Few studies have directly addressed this potentially important effect. Most have not even attempted to collect information on large motile fauna adjacent to the harvesting site. Hence, we do not even have good quantitative estimates of oyster reef utilization by fishes and crustaceans (L. Coen, pers. comm.). In South Carolina, as in most shallow estuarine habitats, direct observations are nearly impossible due to natural turbidity. Netting or "trapping" are probably the only viable alternative sampling methods to evaluate this issue (e.g., Weinstein 1979, Minello et al. 1987, Zimmerman et al. 1989, Ruiz et al. 1993).

Vining (1978) states that previous studies on harvesting have detected no direct impact on fishes or birds associated with the areas harvested. The best available information comes from subtidal studies in deeper waters where "hydraulic dredges" were used (see above Historical Background section). These studies included diver observations and photographic documentation (e.g., Ingel 1952, Manning 1959, Caddy 1973, Meyer et al. 1981, Haskin and Wagner 1986) and all found that predators and opportunistic species (e.g., fishes, crabs, shrimp, gastropods, echinoderms) were attracted to the dredged areas immediately after dredging operations. Manning (1959) observed that hogchokers, spot, eels, white perch, blue crabs and grass shrimps were attracted to harvested areas and Caddy (1973) found that the abundance of crabs and shrimps increased by three-thirty fold within trenched areas versus adjacent, undisturbed areas after only one hour. (see also van der Veer et al. 1985, Eleftheriou and Robertson 1992, Hall 1994, Kaiser and Spencer 1994).

Thus, indirect evidence suggests that mechanical harvesting might attract large numbers of fishes and decapod crustaceans to the "disturbed" area. This potential effect will be addressed in the proposed study of harvester effects, using indirect censusing measures (traps, nets, etc.).

Effects on Harvested Shellfish Resources

From most of the studies cited above, one could conclude that the major effect of mechanical harvesting is the potential over-exploitation of the bivalve resource (e.g., for hard clams, Mercenaria, soft clams, Mya, razor clams, Ensis; see Haven 1970, Mackenzie 1982, Pfitzenmeyer 1972, Peterson et al. 1987, Naidu 1988, Froglia 1989, Murawski and Serchuk 1989, Hall et al. 1990). In South Carolina, OFM rotates harvesting areas and monitors CPUE to reduce the chances of over-exploitation. If anything, significantly less sublethal and lethal damage occurs during mechanical harvesting (see above Direct Burial-Smothering section) versus alternative hand methods.

Interestingly, there are reports from Maine and the Chesapeake Bay area, where clam recruitment appears to have been enhanced by escalator harvesting (Pfitzenmeyer 1972, byte et al. 1975, Vining 1978). One possible mechanism to account for this pattern is that the escalators loosen compact sediments, allowing easier entry and burial by recruits. Peterson et al. (1987) have probably the best long-term data set for recruitment related to harvesting "disturbance"; their results were equivocal. It is unclear whether this particular effect should be studied in the proposed work plan, as this issue is not directly related to regulatory agency or public concerns.

CASE STUDEES WITH RELEVANCE TO SOUTH CAROLINA SITUATION

The following two situations have a direct bearing on the relevant issues presently of concern in South Carolina. The first case in Maine involves the only study of intertidal and/or subtidal effects in fine sediments. The second closely parallels current ACOE permit requests here in South Carolina.

State of Maine (1970s)

This investigation (1973-1974) involved an extensive study of an intertidal soft clam (Mya) mud flat habitat in Maine (Kyte et al. 1975). Public concern initially arose due to the appearance of a turbidity plume caused by harvester use. Their review of the literature revealed that no previous studies were directly applicable, therefore Maine DNR developed and initiated a comprehensive study evaluating the potential effects of escalator harvesting in a benthic habitat with fine sediments (pre-harvest values, silt/clay fractions > 94 %).

Their extensive physical and biological study sampled replicate areas prior to, during, and after harvesting (10 months). Data collection included: aerial photography with ground delineation (intertidal scars evident from air), hydrography, physical parameters (grain size, stratigraphy, salinity, pH, DO, H_2S), seston flux (sediment traps), secchi, turbidity, water chemistry (nutrients), sediment structure and infauna by coring (shallow and deep), recruitment by Mya, and direct harvester effects (tracks and trenches).

In general, they found that harvesting had little long-term effect on the local ecosystem. Ambient seston levels (6.9-441 mg/1) often met or exceeded those associated with harvesting (near maximum encountered turbidity level of 584 mg/l, but only for short duration), thus obscuring any potential short-term effects. Few consistent effects on water column chemistry were observed (e.g., nutrients, DO, H_2S). Extensive sediment trap studies indicated that the plume material apparently did not settle out in any specific area, diluting potential effects. Effects on the infaunal community (primarily polychaetes, amphipods, bivalves) were limited due to rapid recruitment. Only Mya a populations underwent population fluctuations. Interestingly, soft clam recruitment appeared to have been enhanced in "harvesting scars" (Kyte et al. 1975), with trenches still evident 15 months later (initially 30-45 cm deep, 1 in max. width). It was noted that the compacted nature of the fine sediments encountered in their study sites made escalator harvesting unfeasible due to poor CPUE and high clam mortalities.

State of Washington (1970s)

Harvesters have been used in Washington since 1958 (Kyte et al. 1975, Vining 1978). From 1962-1976 the ACOE did not require a Sec. 10 permit for harvesting; however, in 1976 the North Pacific Division of USACOE reversed its position, requiring a permit only in Washington. The court had reinterpreted the statute such that any activity affecting water quality alone was under Sec. 10 jurisdiction (see Westley 1976 also). The Department of Ecology was responsible for water quality certification; the Department of Natural Resources assumed the role of permit applicant on all harvesting operations carried out on state lands under lease. The Corps then allowed ongoing harvester operations to continue while applications were processed.

The State of Washington conducted an EIS evaluating potential effects on the state's clam habitats in general, rather than on specific sites (see Tarr, 1977, Vining 1978). Their evaluation was based on information available at that time. To meet their physical and biological criteria for example, an acceptable area had to have sediments with 10% on average greater than 500 1Lm, and 15% or less being smaller on average than 63 /,Lm. This decision was based on the fact that there were no detailed studies available at that time to evaluate potential impacts (see pgs. 25-27). Other physical and biological criteria included sediment nutrient concentrations, volatile solids, BOD and biota of significance (e.g., in Washington SAV, geoducks).

Overall the EIS summarized several projected effects including: (1) temporary reduction in clam stocks; (2) short- and long-term effects on sediments; (3) creation of a turbidity plume; (4) affects on fauna in harvester path; (5) removal of grass (SAV) and algae; (6) sound disturbance and (7) potential for dredge to "stray", damaging other habitats. Further, no alternative technology was deemed technically or economically feasible. Mitigative options for the above stated effects (#1-7) included: (1) temporary reduction not permanent; (2) none available (to avoid this effect); (3) selection and permitting in areas meeting minimum physical (e.g., sediment size) and biological parameters; (4) avoidance of critical areas with particularly "sensitive" fauna; (5) no operations where grasses (SAV) are dense; (6) sound muffling and potential time restrictions and (7) delimiting appropriate permitted areas with markers. Lastly, unavoidable adverse impacts included sediment disturbance (i.e. tracks or trenches), mortality of benthos (infauna, and epifauna.) in the path, removal of algae and some SAV and perceptible sound levels (10-25 dBA).

SOCIOECONOMIC CONSEDERATIONS

Previous studies (e.g., Vining 1978, Anonymous 1989) have justified the permitting of mechanical harvesters due to: (1) economic gains to the shellfish industry; (2) enhanced state revenues; (3) employment opportunities; (4) increased shellfish availability to the customer and (5) an indirect means of maintaining high water quality at shellfish sites due to incompatibility with potentially detrimental alternative uses.

Vining (1978) mentions visual impacts, sound, and navigational conflicts as potential negative considerations against mechanical harvesting. Most states appear to protect the use of traditional hand harvesting methods from displacement by mechanical harvesting in public shellfish areas (see Anonymous 1989b, Barnes et al. 1991).

GEAR AND GROUP CONFLICTS

Conflicting Use Issues in South Carolina

The SC Department of Natural Resources has received complaints from the public (e.g., recreational fisherman) and has been involved in hearings with various Federal Agencies (ACOE, USFWS, NOAA, EPA) to address issues related to the use and potential effects of mechanical harvesters, particularly with respect to the subtidal clam escalator harvesters in South Carolina (see Appendix 1). Specifically, complaints have been received from -members of the East Cooper Outboard Club concerning a perceived disruption of fishing caused by a hydraulic escalator (Tony Lynn operating on a culture permit in the area. In addition, property owners adjacent to the Hamlin Creek State Shellfish Ground (P-255) have complained during harvester operation. These concerns can be generalized as conflicting uses and access to public trust resources (i.e. state bottoms and harvestable fisheries resources).

SUMMARY OF FINDINGS

Overall, findings consistently support the same conclusion: the short-term effects of subtidal escalator harvesters are minimal, with no long-term chronic effects, even under worst case scenarios. Observed effects are often indistinguishable from ambient levels or natural variability. These conclusions are based on field experimentation and knowledge of natural estuarine variation (physical, chemical and biological). The most obvious effects (e.g., sediment plume) cease when operations are halted, but natural events are continuous. Only the Maine study critically evaluated operations in a fine-sediment habitat (albeit intertidal and compacted) similar to those habitats typically encountered in South Carolina. However, even in Maine, the overall conclusions were that effects were minimal given a brief recovery time (months). Naturally high turbidities and variable river discharges are common to South Carolina, hence it is predictable that direct effects are probably within previously observed norms.

In terms of effects and associated problems generated during operation of the SCDNR's R/V Oyster Catcher II for use with intertidal oysters, we can only infer from the previously cited studies, which involved the collection of either subtidal or intertidal clams as in the Maine study (Kyte et al. 1975). Some of the anticipated effects parallel those observed with clam harvesting, since the harvesting operation occurs during submersion at or near a high tide. For example, less turbidity may occur relative to subtidal harvesting, since a portion of the harvested bottom consists of live and dead oyster shell. Also, most areas harvested are typically quite turbid. It is not known whether the damage to "donor" sites harvested is significant or whether translocation (removal and placement of the shellfish elsewhere) can initiate a new, enhanced and stable "recipient" oyster reef site is as productive as the area that was harvested. As we learn more about how these systems function, we will then need to decide on what the best options are regarding their "disturbance" and habitat value, including potential benefits of thinning.

Estuarine communities appear, in general, to be tolerant of the short-term harvester effects including resuspension/turbidity, direct burial/smothering, nutrient release and decreased water quality due to elevated BOD, and direct disturbance or removal of infauna. Information from related studies (e.g., large-scale dredging), with much greater magnitudes of disturbance suggest that infaunal recruitment, burial and physico-chemical effects are probably of lesser concern for harvesters (Simenstad 1991, but see Kaplan et al. 1975).

Finally, at this time it is difficult to directly assess the potential effects on economically important finfish and crustacean resources or to evaluate the direct release of contaminants since both of these are site-specific (macrotides, pollutant history, local ecosystems).

RECOMMENDATIONS

The following recommendations and associated key study objectives for each system are discussed separately due to the inherent differences between the two harvesting methodologies and targeted habitats.

Subtidal Clam Harvesting

Because there are few previous studies in areas with sedimentary characteristics like those typically encountered in South Carolina (see Settlemyre and Gardner 1977 for Charleston, SQ, we suggest that a study be undertaken to evaluate potential effects from subtidal escalator harvesting for hard clams. The proposed study to evaluate effects of harvesting of subtidal clam beds should include:

(1) study areas in both large and small systems (i.e. bays or sounds versus creeks), as there are potential differential harvesting effects between these two types of systems;

(2) limited monitoring of turbidity levels to evaluate turbidities associated with harvester operation for comparison with ambient conditions typically found in similar environments;

(3) limited benthic sampling to identify impacts to infaunal communities as a result of harvesting and recovery rates of these assemblages after harvesting;

(4) sampling of fish and crustacean resources in smaller creeks where short-term . effects may be detectable and;

(5) limited sampling of sediment contaminants in areas where contaminant levels may be of concern. Sampling of contaminants will **depend on available project funds,** given **the high costs involved for the detection of certain contaminants.**

Based on the previous literature, the following potential subtidal effects do not appear to be of concern and should not be included in the proposed study. These include nutrient release and related water quality changes due to elevated BOD. Based on previous studies and high estuarine variability relative to natural and anthropogenic loadings, it seems highly improbable that nutrient release and elevated BOD should be a major concern related to shellfish harvesting in South Carolina.

Intertidal Oyster Harvesting

Mechanical intertidal oyster harvesting is unique to South Carolina's DNR, and it is therefore difficult to make very many predictions based on previous studies concerning its potential effects with the exception of those to the oyster reef (i.e. ecosystem) itself. However, since harvesting usually occurs at high tide, one can infer effects from many of the previous subtidal studies. We recommend that the proposed study evaluate the effects of intertidal oyster reef harvesting:

(1) on "donor" reef oyster growth; (2) on associated fish and crustacean resources and; (3) on recruitment of oysters, comparing both harvested and unharvested ("control") donor systems.

Of importance in the study is an evaluation of potential effects (positive or negative) of mechanical harvesting on the "donor" reefs. Especially since little information exists beyond anecdotal observations that moderate oyster reef harvesting may enhance overall oyster growth rates by reducing competition.

In contrast, elevated turbidities, faunal burial/smothering, nutrients and associated BOD changes derived from harvesting are probably not of direct concern in the operation, since the oysters and associated community are primarily epifaunal and bottom sediments are less disturbed than in subtidal operations.

Finally, for both subtidal and intertidal systems, although not an issue here, other studies have focussed on concerns due to potential over-exploitation of the targeted bivalve resource. Data from Maine and the Chesapeake Bay suggest that clam recruitment may be enhanced by escalator harvesting. Similar claims have also been made for post-harvested intertidal oyster reefs in South Carolina. This particular effect needs to be studied in the proposed work plan using field experiments with carefully monitored pre- and post-harvester "donor" reefs (e.g., rotation and thinning effects).

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TABLE 1

Total Hard Clam Production for South Carolina*

Shellfish Season	Escalator	Hand Harvest	% Mechanical
1991-92	5,416	20,515	26%
1992-93	10,275	27,876	37%
1993-94	9,281	38,625	24%

*bags of clams (250/bag)

Source: Office of Fisheries Management (SCDNR)

Table 2.

1993-1994 SHELLFISH SEASON
PERMITTED SUBTIDAL ACREAGE SHELLFISH CULTURE PERMITS

PERM1T NUMBER	ACREAGE
ES94-0492	12.8
ES94-0453	10.1
ES94-0452	29.0
ES94-0430	12.1
ES94-0429	16.3
ES94-0428	10.1
ES94-0427	16.3
ES94-0404	9.5
ES94-0333	46.6
ES94-0337	92.6
ES94-0322	33.5
ES94-0262	13.9
ES94-0179	13.3
ES94-0084	10.5
ES94-0085	22.2
ES94-0086	5.3
ES94-0087	47.7
ES94-0088	8.5
ES94-0089	6.5
ES94-0090	10.0
ES94-0091	2.0
ES94-0092	5.5
ES94-0056	5.3
ES94-0460	76.7
SUBTIDAL ACREAGE	**516.3**

STATE SEELLF19H GROUNDS
(Open Water Bodies)

ES94-0419	2,293.6 (Wando)
ES94-0499	335.9 (S.Santee)
ES94-0444	4,590.0 (Winyah)
SUBTIDAL ACREAGE	**7,219.5**
TOTAL SUBTIDAL ACRMGE	**7,735.8**

Note: A total of forty five permits were issued for culture permit areas, however a number were being used for the same area. The subtidal acreage above reflects the harvested areas during the 1993-94 shellfish season.

Source: Office of Fisheries Management

Vessel	RV Duchess
	Double ended dragger
	Converted stop seiner
LOA	47'3"
Beam	App. 13'
Draft	App. $3^1/_2$'
Built	1955 - Beals Is, ME
Engine	GM 3-71 Diesel
	2:1 reduction
Speed	8 knots

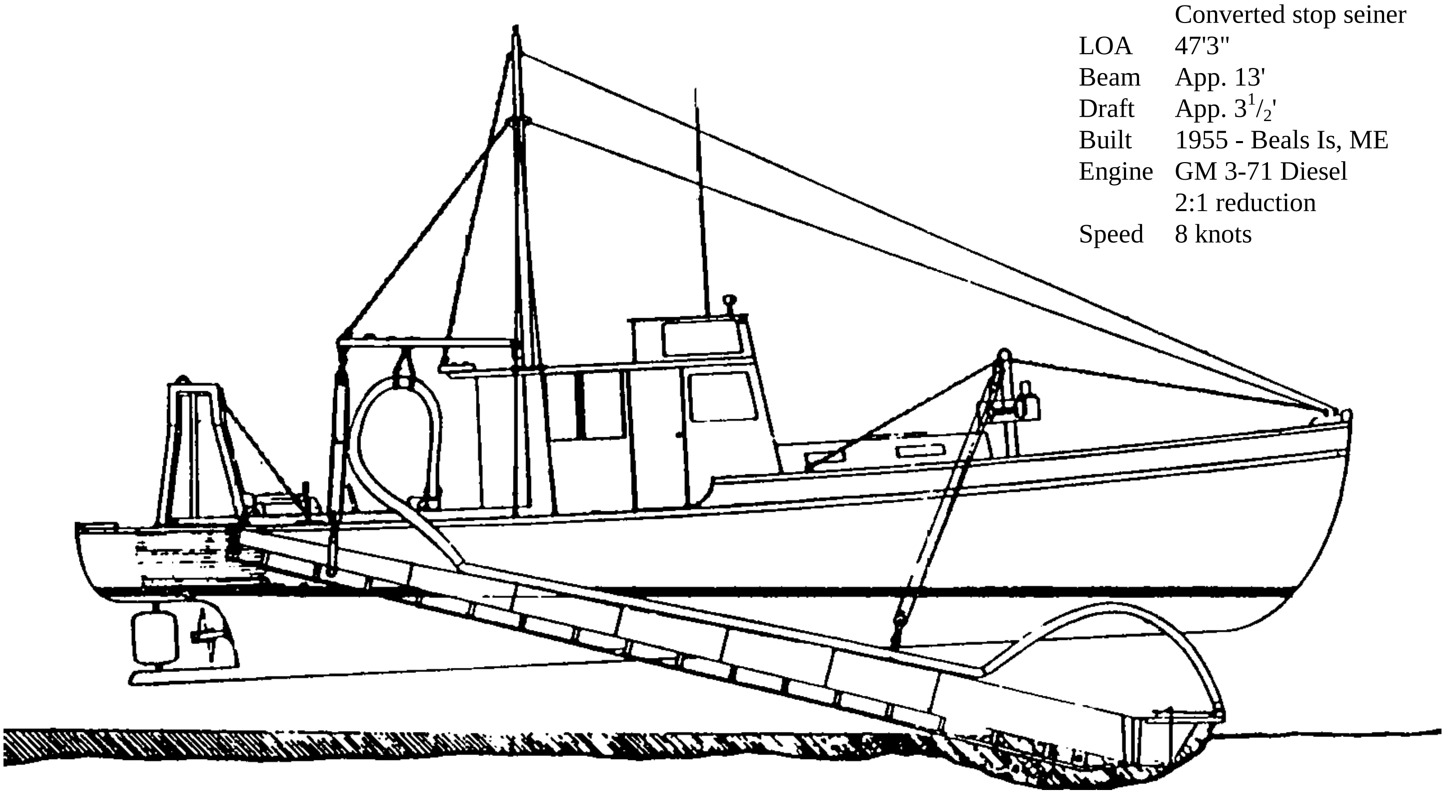


Figure 1a. The schematic details of the hydraulic escalator dredge mounted on a Maine Department of Marine Resources research vessel (from Mathieson and DeRocher, 1974).

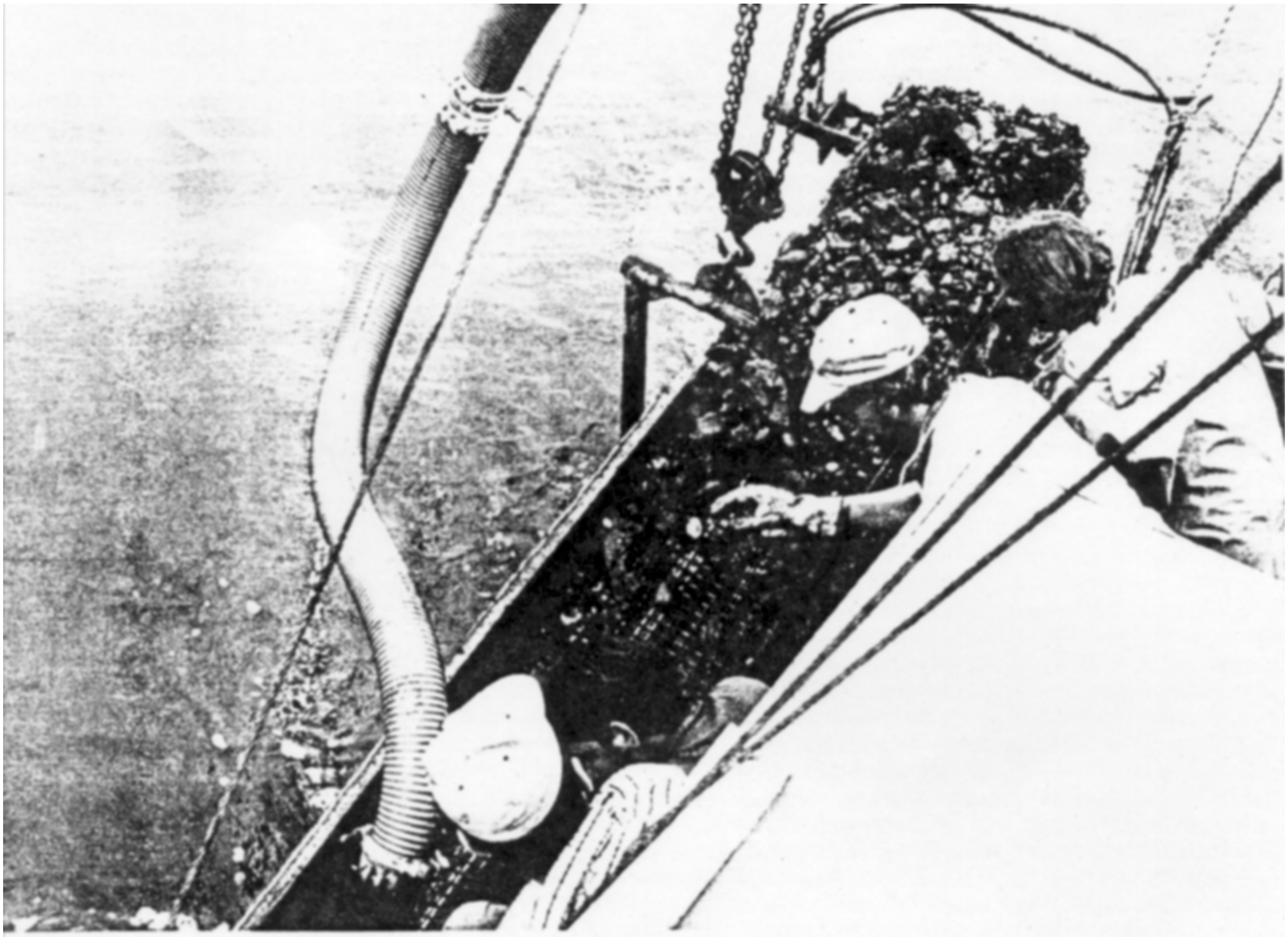


Figure 1b. Operating escalator dredge with culling crew.

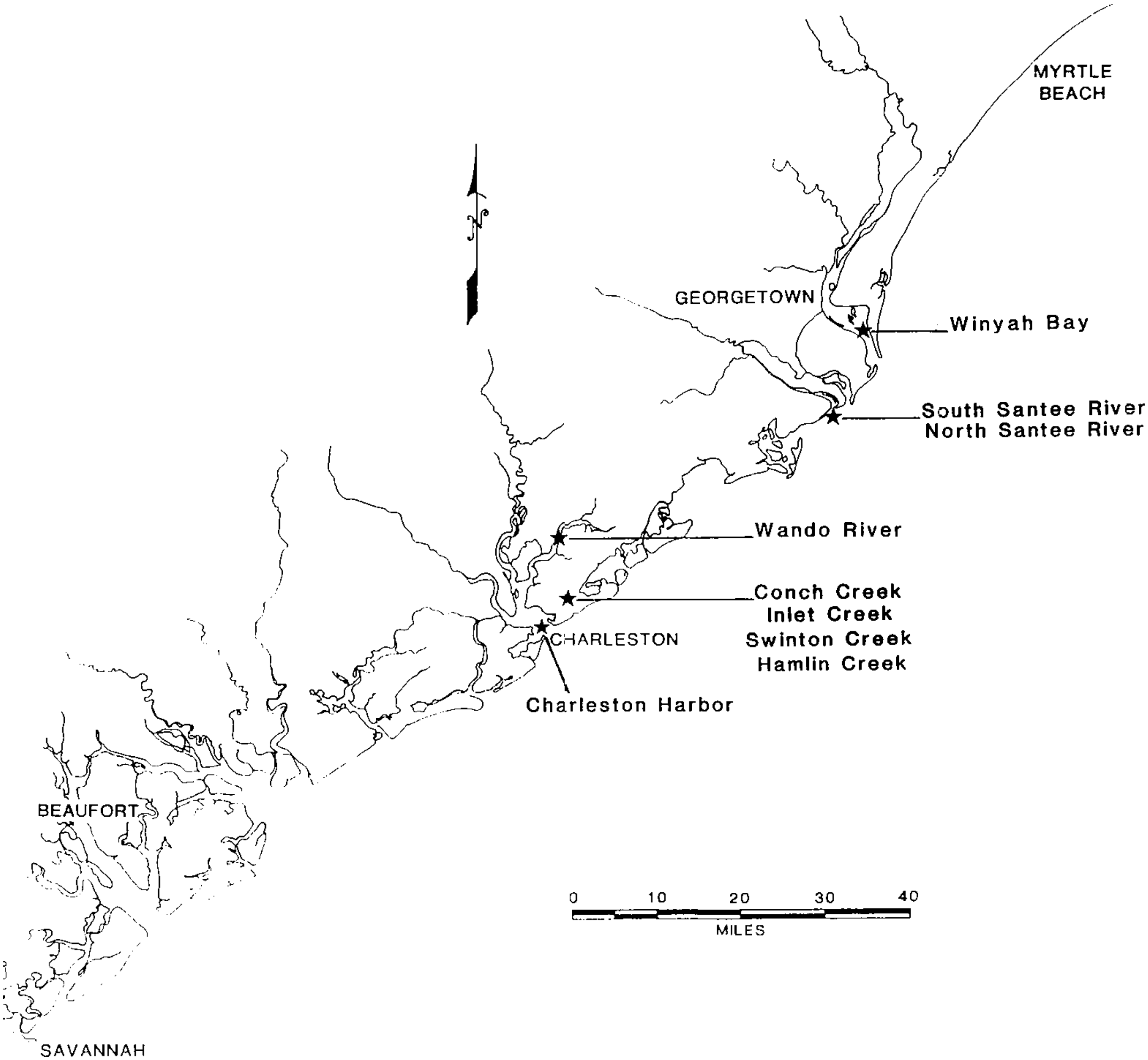

MYRTLE BEACH
GEORGETOWN
Winyah Bay
South Santee River
North Santee River
Wando River
Conch Creek
Inlet Creek
Swinton Creek
Hamlin Creek
CHARLESTON
Charleston Harbor
BEAUFORT
SAVANNAH
0
10
20
30
40
MILES

Figure 2c.

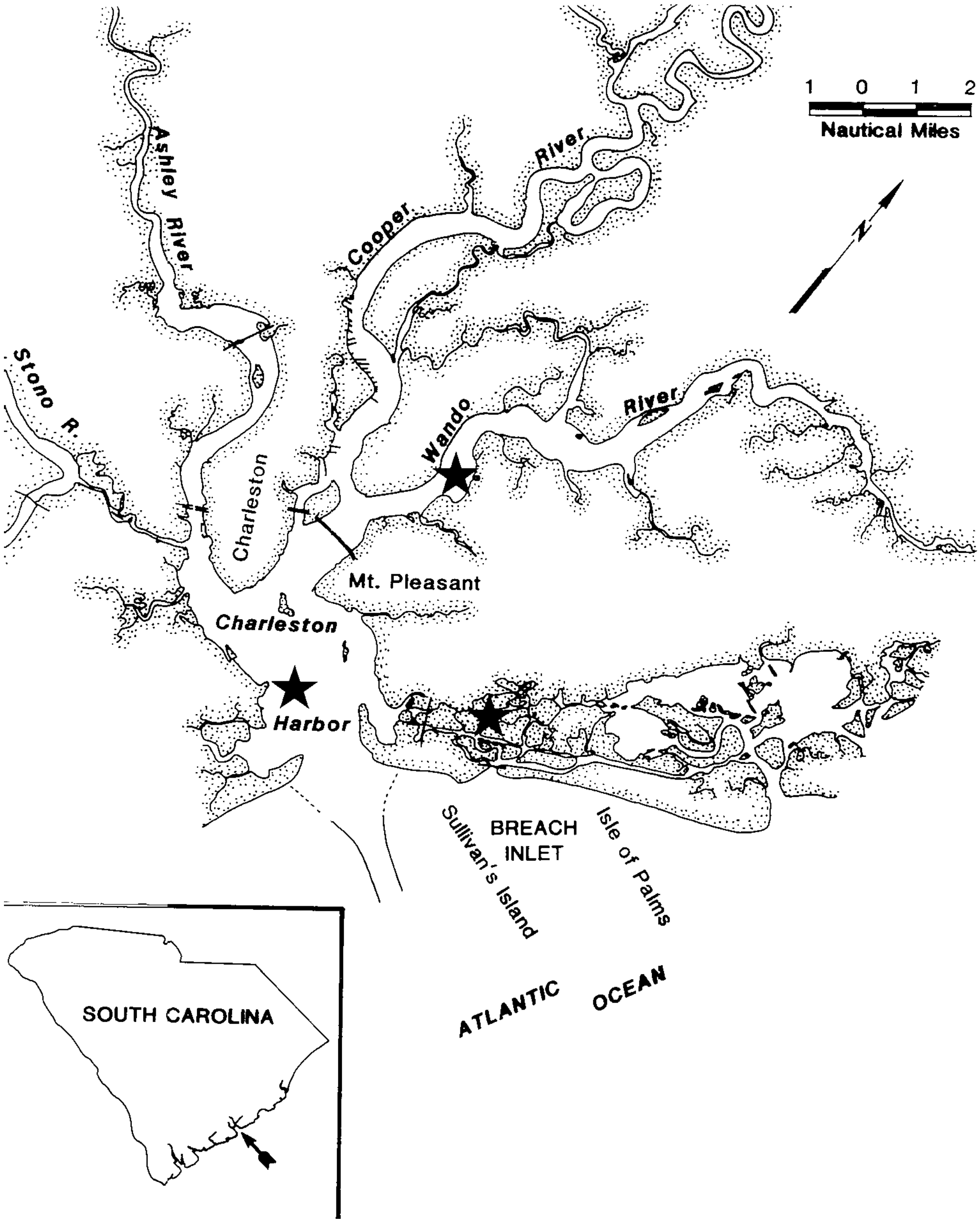
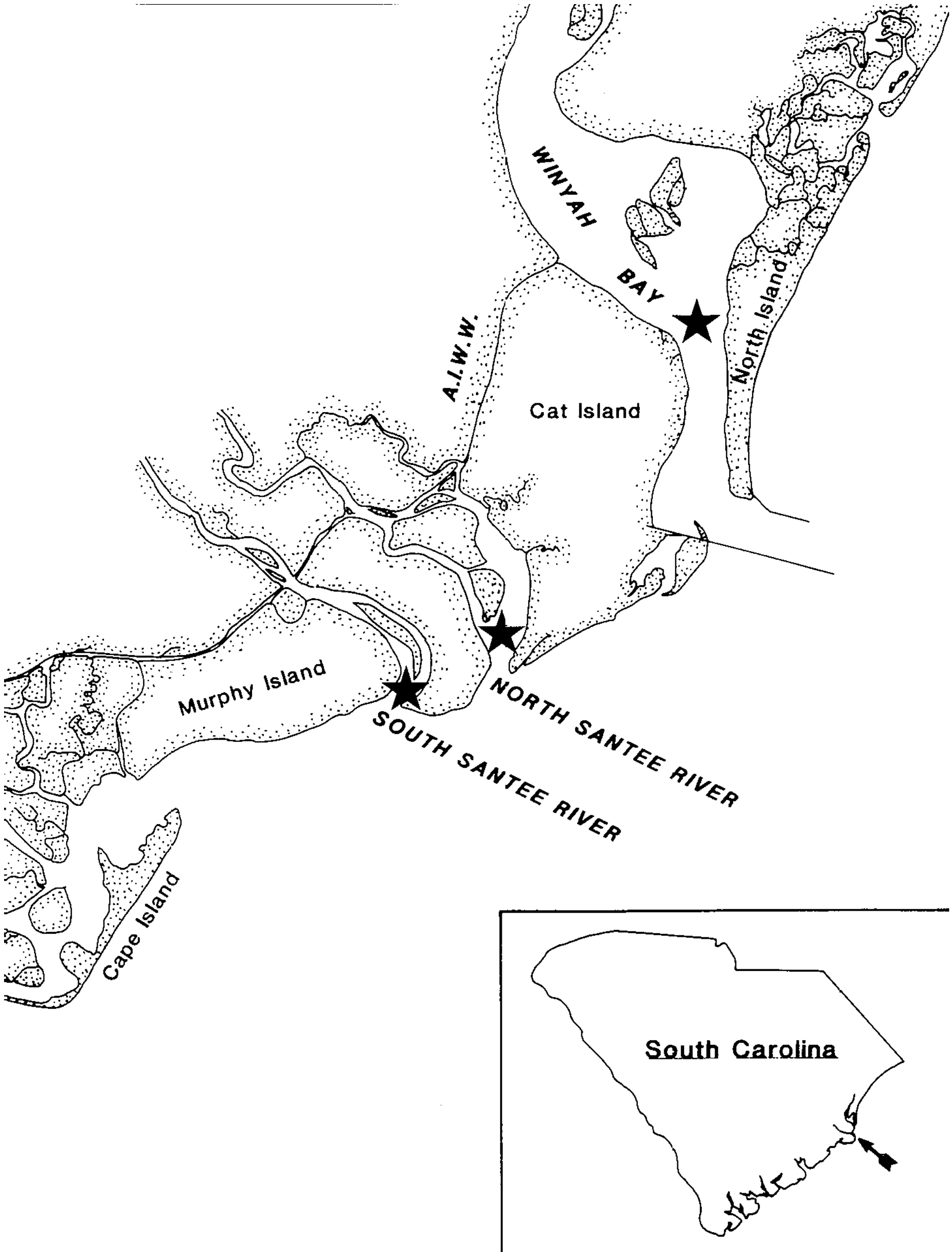
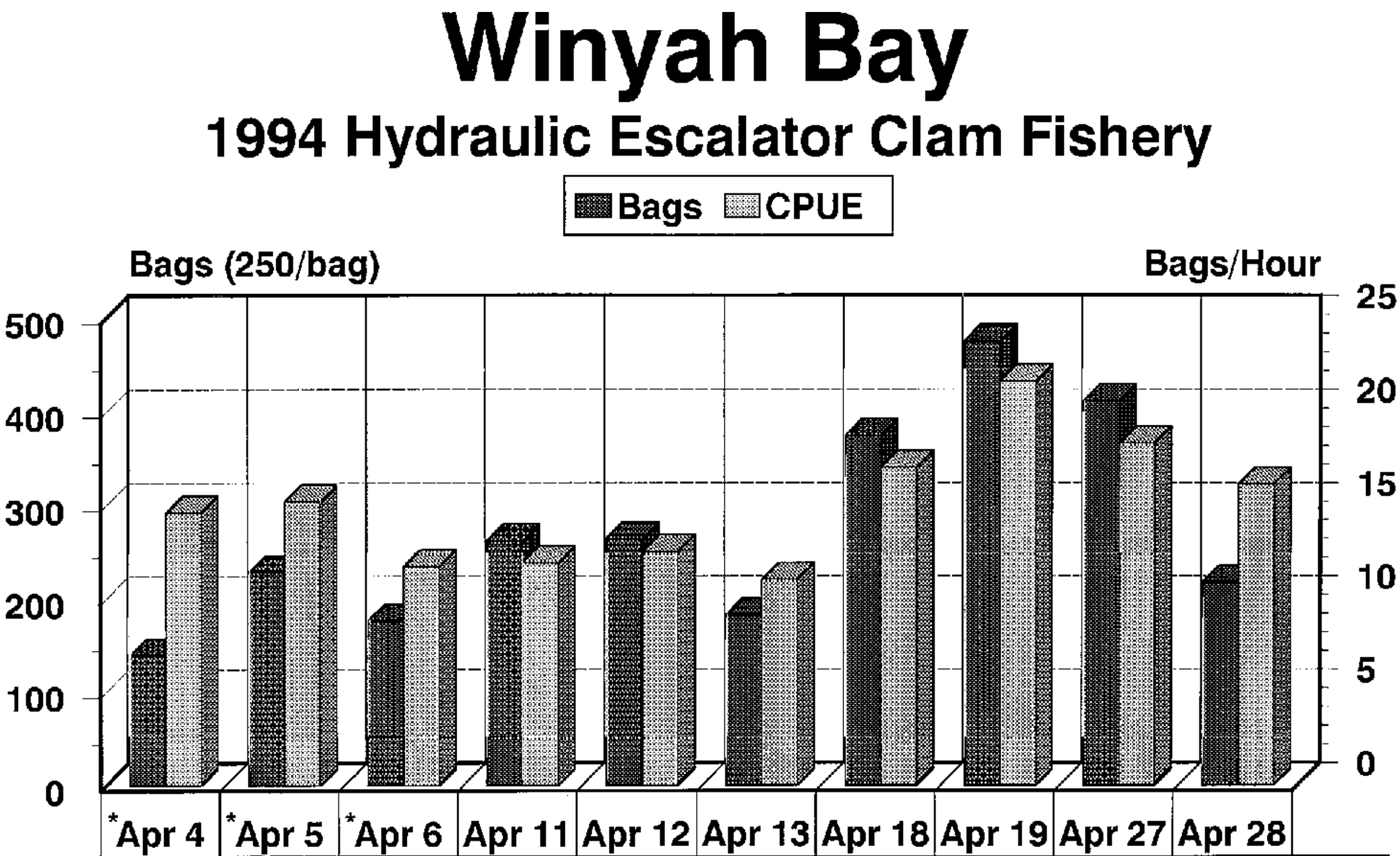

1 0 1 2
Nautical Miles
N
Ashley River
Cooper River
Stono R.
Wando River
Charleston
Mt. Pleasant
Charleston
Harbor
BREACH
INLET
Sullivan's Island
Isle of Palms
ATLANTIC OCEAN
SOUTH CAROLINA

Figure 2b.



Source: Office of Fisheries Management, Shellfish Management Program

Figure 2c.



	*Apr 4	*Apr 5	*Apr 6	Apr 11	Apr 12	Apr 13	Apr 18	Apr 19	Apr 27	Apr 28	
Bags	139	228	176	261.5	263.5	182	374	475	411	217	
CPUE	14.6	15.2	11.7	11.9	12.5	11	17	21.6	18.3	16.1	

Total = 2,727 bags x 250/bag = 681,750 clams

* Two harvesters fished on these days. Three harvesters fished thereafter.

SOURCE: Office of Fisheries Management, Shellfish Management Program

Figure 3.