AN ANALYSIS OF ECOLOGICAL CHANGE IN RELATION TO HUMAN SETTLEMENT PATTERNS AND ACTIVITIES IN ESTUARIES IN THE COFFS HARBOUR REGION

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This thesis is submitted as fulfilment of the requirements for the Degree of Master of Science by Research at the University of New England, Armidale NSW, Australia

December, 2002

DECLARATION OF ORIGINALITY

1. I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree.

2. I certify that any help received in preparing this thesis and all sources used have been acknowledged in this thesis.

Stephen M Sawtell

ACKNOWLEDGEMENTS

Firstly, I would like to offer my thanks to my supervisors, Dr. Steve Smith and Professor Rod Simpson.

Special thanks to Steve for the help with species identification and statistical analysis and review of the document.

I would like to thank Coffs Harbour City Council for the financial support, in particular their GIS Section, Ron Graham and Steve Bayliss for persevering with ideas and bringing them through into computer reality. Wendy Carter greatly assisted with charts and graphs.

Field sampling was assisted by Dr. Steve Smith, Scott Burton, Tamara Hinchey, Adam Davey and Karen Carter.

Early financial assistance was achieved from the Total Catchment Committee of Coffs Harbour. GIS database funding was also contributed by Coffs Harbour City Council.

Special thanks to Mr. Roger Dwyer for photogrammetric interpretations over many long hours.

With respect to onerous review of this hefty document I would like to thank Mike Rule, Liz Gerard, Gareth Hankinson and in particular, Dr. Steve Smith.

My personal and professional gratitude goes to Meg Bovis for the publication of this document and the professional guidance provided in making this a readable and useable document.

To Janine, Sam, Ali and Lewin, I thank you for your patience, encouragement and support, without which this research could not have been undertaken.

ABSTRACT

This study incorporates the needs, roles and responsibilities of government, community and academic sectors enabling "Science in Management". A new community based approach to management.

Estuaries are highly productive systems and have high ecological, recreational and commercial value. Agricultural, industrial and urban development together with the concentration of population in the coastal zone have resulted in increased loads of sediment, nutrient and other pollutants to estuaries. These impacts have led to significant changes to many estuarine habitats.

The aims and objectives of the study are: to provide baseline data on benthic communities, estuarine vegetation communities and human settlement patterns across the four major estuaries in the Coffs Harbour region; to examine the catchments of these estuaries and to compare and contrast the uses and activities in each catchment; and to determine if the human activities have had an impact on these estuaries through analysis of this data.

Benthic analysis was achieved by grab samples from a motorised punt whilst estuarine vegetation and human settlement patterns were analysed using photogrammetric techniques.

Univariate and multivariate analysis for macrobenthic data indicate differences in community structure within and between creeks across all time periods, that is, a high degree of spatial and temporal variation. Trends indicate a direct correlation between an increase in human settlement patterns and a loss of seagrass, saltmarsh and sedge/coastal heath and a direct relationship to increased mangroves across all creeks.

The analysis of benthic communities, estuarine vegetation communities and human settlement patterns are suggested as a more useful and accurate form of "core indicators" of estuarine health and ecosystem management. These indicators and all data have been incorporated on a Geographical Information System (GIS) and developed as an Integrated Management tool.

The need for Integrated Management in estuarine and ecosystem management, has been outlined and a new Integrated Management Model has been suggested.

Implications from this study are that further studies will need to incorporate updating the baseline data, chemical residue testing of biota and sediment and environmental audit of uses and practices in each catchment.

Science must produce data that can assist in achieving deliverable management outcomes for the benefit of the environment, otherwise resource management will relate only to resource deterioration.

Table of Contents

Table of Figures

Tables

1 INTRODUCTION

An estuary is a semi enclosed coastal water body which has a free connection with the open sea within which seawater is diluted with freshwater derived from land drainage (Roy, 1984). Middleton (1985) further adds that estuarine waters are typically brackish, that is, intermediate between fresh and salt. Naturally rich in nutrients, estuaries are ecologically highly productive and are important fish habitats (Zann, 1995).

Globally, estuaries have long been important to mankind either as places of navigation or for location of towns and cities on their banks (McLusky, 1989). Australia has 783 major estuaries, 415 in the tropics, 170 in the sub tropics and 198 in temperate areas (Zann, 1995). In Australia, estuaries were the principal sites of European settlement with the population and urban development continuing to grow along the Australian coastline (Adam et al. 1992)

Coffs Harbour, like other coastal areas, has experienced a dramatic population increase over the last 20 years, the major concentration of the Coffs Harbour population is along the coastal strip with only 10% of the population residing in the rural area west of the range (CHCC 2000). Increases in human settlement patterns and activities have consequent impacts on the land and estuarine systems.

1.1 OVERVIEW OF ISSUES FACING ESTUARIES

Estuaries are highly productive heterogeneous systems and usually have extensive communities of benthic and pelagic biota. Agricultural development throughout Australia and urbanisation and industrial development on the coastal fringe have resulted in increased loads of sediment, nutrient and other pollutants to estuaries which have led to significant changes to many estuarine habitats (Deeley and Paling, 1999).

Up until mid 1800 the effect of human activity was mainly silt erosion from agricultural areas and the disposal of human waste. Since that time the increased expansion of industry, production, use of power and manufacturing, transportation and intense fishing, together with the pressures of human population have increased and placed a diverse array of pressures on these waterways (Cronin, 1967; McLusky, 1989; Deeley and Paling, 1999).

Other issues facing estuaries include the progressive enrichment of estuarine waters with inorganic nutrients and organic matter which lead to changes in the structure and processes of estuarine ecosystems. Nutrient enrichment, particularly by way of fertilisers and sewage runoff may cause eutrophication, the excessive growth of algae. The resultant smothering of organisms depletion of oxygen, which may result in changes in community structure (Zann, 1995).

The agricultural and forestry industries have been present in Coffs Harbour since the mid 1800's. A higher level of horticulture has been experienced from 1940 through to the present, previously tomatoes and small cropping, now predominantly banana growing.

Changes in the catchment for land use and development purposes such as residential, rural residential, industrial and agricultural pursuits can create runoff issues and erosion and sediment problems. Runoff of nutrients, wastewater and contaminated waste also impact estuaries from time to time. Clearing or deforestation and the replacement of trees with built and paved surfaces that are non absorptive, also affect stormwater and hence estuarine systems. The piping of natural runoff channels and the use of herbicides and pesticides in and about waterways and drainage channels can have an impact on microbiota and benthic communities.

The addition of toxic materials includes such compounds as pesticides, heavy metals, petroleum products and toxic byproducts of industrial activity (Lacey, 1998; Deeley and Paling, 1999). These not only affect the resident species of an estuary such as fish, but can cause bio-accumulation in higher order species (McDougall and Dettman, 1989). Landbased application of chemicals for agricultural pest control have left residues of organochlorines and arsenic in soils (Sawtell, 1994). In the Coffs Harbour area, the application of chemicals (organophosphates) to the inter-tidal zones of estuaries for nuisance midge and mosquito control was conducted until 1987 (pers. obs. S. Sawtell). Human activities such as termite treatment under houses and pesticide use in bananas have led to chemical residues in fish (McDougall and Dettman, 1989) in a number of Coffs Harbour estuaries. In August 1998 Boambee Creek was subjected to a large fish kill which involved kilometres of creek and hundreds of fish.

No clear cause was found for this kill which ranged from tiny fingerlings to large flathead as well as pelicans.

Other issues such as overfishing, the introduction of exotic species, the construction of breakwaters, weirs and groynes, infilling for development and agriculture, dredging and siltation from catchment erosion can have detrimental impacts on both the flora and fauna of estuaries (Adam et. al, 1985; Zann, 1995).

Estuaries are overlooked as important ecological indicators of ecosystem health and environmental health, very little work or research has been done on benthic fauna and estuarine flora in the Coffs Harbour area. Without a sound database and appropriate core indicators, ecological change cannot be adequately assessed, particularly when analysing human activities on a catchment basis.

1.2 INCREASING PUBLIC AWARENESS

Media coverage of fish kills, public awareness of chemical residue issues and hazardous spills have all led to an increase in public awareness which, across a period of time, can create changes in the relevant legislation. Changes to the Environmental Penalties and Offences Act has tightened controls over development, new legislation such as the Protection of the Environment Operations Act (1997) sets new penalties for damage to the environment and runoff issues for the individual and the corporate sectors of society.

Recent changes to the methods of onsite wastewater management by way of changes to the Local Government Act in NSW has aimed to improve runoff from onsite wastewater systems (largely as a result of Wallis Lake oyster issues). New sediment and erosion control guidelines are endeavouring to stop large scale erosion of soil (pers. comm. G. Hankinson).

Litter campaigns such as “Clean Up Australia” have had their role in Public Awareness. Local campaigns, such as the Chemical Awareness Campaign from 1991 - 1993 had an impact on moderating the use of chemicals in the Coffs Harbour area. Movements such as Coast Care, River Care and Estuary Care and Estuary Watch endeavour to combine community membership with scientific expertise to try and manage the natural environment. The recent stormwater awareness programme by Coffs Harbour City Council, “Caring for our Creeks”, is a further example of a response to increasing community awareness.

An important point for Coffs Harbour estuaries is the recently (1997) proclaimed Solitary Islands Marine Park which brings a higher level of both awareness and investigation into development, pollution and runoff issues.

Agenda Twenty One, the international action plan to achieve sustainability of natural resource management, recognises the need for information to guide decision makers. It calls for the development of indicators which can measure sustainability and in this context, sustainable development takes on a much wider scope and application than the conservation of natural resources solely and focuses on the needs of people and of maintaining their quality of life. It is important to consider that sustainable development proceeds as an integrated relationship between social, economic and natural resource management. The OECD has developed environmental indicators which assess environmental performance, integration of policies and environmental accounting using a pressure, state response model. The Australian and New Zealand Environment Conservation Council has adopted the OECD model (ANZEC, 1998; Deeley and Paling, 1999). The Australian National System for State of the Environment (SOE reporting) was established as part of the national strategy for ecological sustainable development and seeks to provide key environmental indicators.

Scientific assessment of impacts is hampered by a lack of baseline data on macro-benthic communities, estuarine vegetation and human settlement patterns. Though these issues can relate to all estuaries, this study focuses on the NSW North Coast.

1.3 THE ESTUARINE ENVIRONMENT

The diversity in size, shape, salinity regime, circulation patterns and biota in estuaries is due to the interaction of a number of factors:

1. Inherited factors of a mainly geological nature (eg., bedrock, type, coastal morphology) that control the size and shape of the estuarine basin and the nature of the sediments within it.
2. Contemporary factors of a process nature (e.g, tidal currents, river discharge, ocean waves) that influence modes of sedimentation, estuary hydro-dynamics and the biota of the estuary (Roy, 1984).
3. Human factors such as infilling, dredging, construction of groynes, wharves and marinas.

Some estuaries lie in bedrock valleys which have been gradually infilled with terrestrial sediment over tens of thousands of years. During this time, they have also undergone multiple cycles of erosion and infilling with marine sediments in response to varying sea levels (Adam et al. 1992).

Estuaries can be classified into three groups (Roy, 1984). They are:

1. *Drowned river valley estuaries* - narrow, steep sided, riverine sand often collecting behind a sill of marine sand carried in by the tides.
2. *Barrier estuaries (estuarine lagoons)* - sand is deposited in the estuary to form large deltas and sand flats with long winding channels of water.
3. *Saline coastal lagoons* - cut off from the sea by a barrier of sand, non tidal and containing mainly marine sediment, also referred to as intermittently close/open lagoons (ICOLL's).

Barrier estuaries are characterised by narrow, elongated entrance channels within broad tidal sandflats, typical of Coffs Harbour estuaries (Figure 1-1).

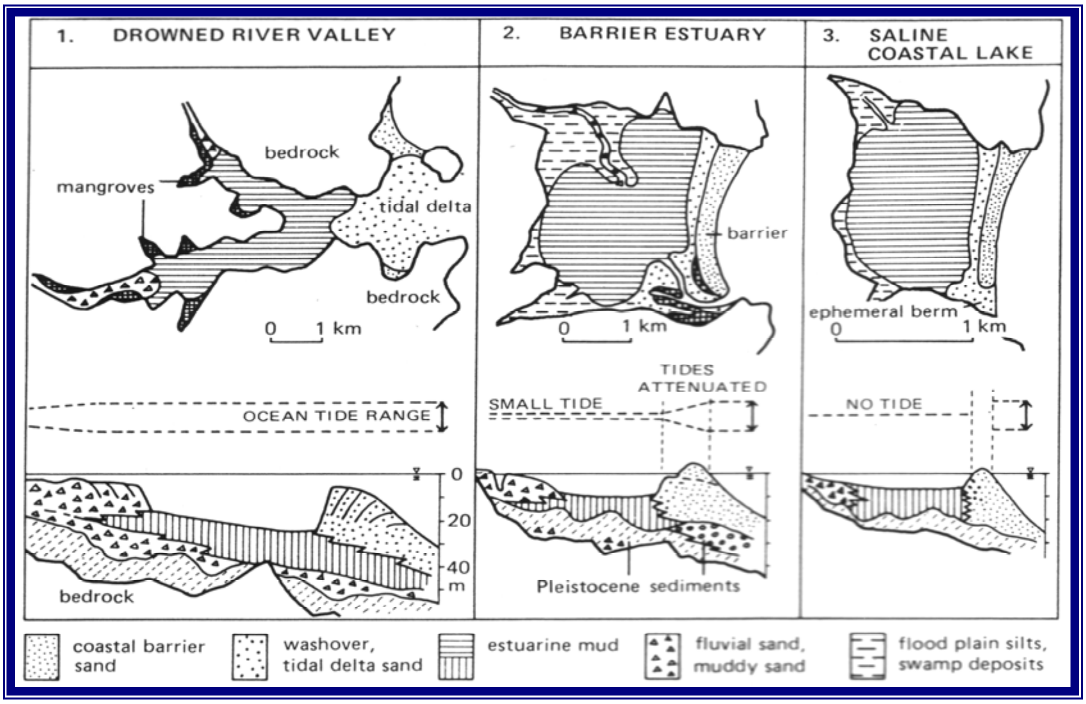


Figure 1-1 - Three main estuary types in NSW (From Roy, 1984)

indicating the different stages of maturity of estuaries reflecting the gradual infilling that has occurred over geological time scales.

1.3.1.1 PHYSICO-CHEMICAL PROPERTIES OF ESTUARIES

Sediment

Infilling has occurred from seaward with marine sand, and from landward with fluvial sand and mud and the accretion of calcareous and carbonaceous sediment, produced by biological processes within the estuary, e.g. plankton and molluscs (Roy, 1984; Adam et al. 1992). The size of the sediment particles is proportional to the speed of water flowing over the bottom, the faster the current often the bigger the grain size that is left behind as finer particles are held in suspension and washed away first. The rates of infilling vary as a result of the different size morphology, topography, coastal setting, geographical location, size of catchment and climatic conditions (Figure 1-2). Progressive estuary infilling over a geological time scale causes a reduction in water area and volume and average depth. (Roy, 1984).

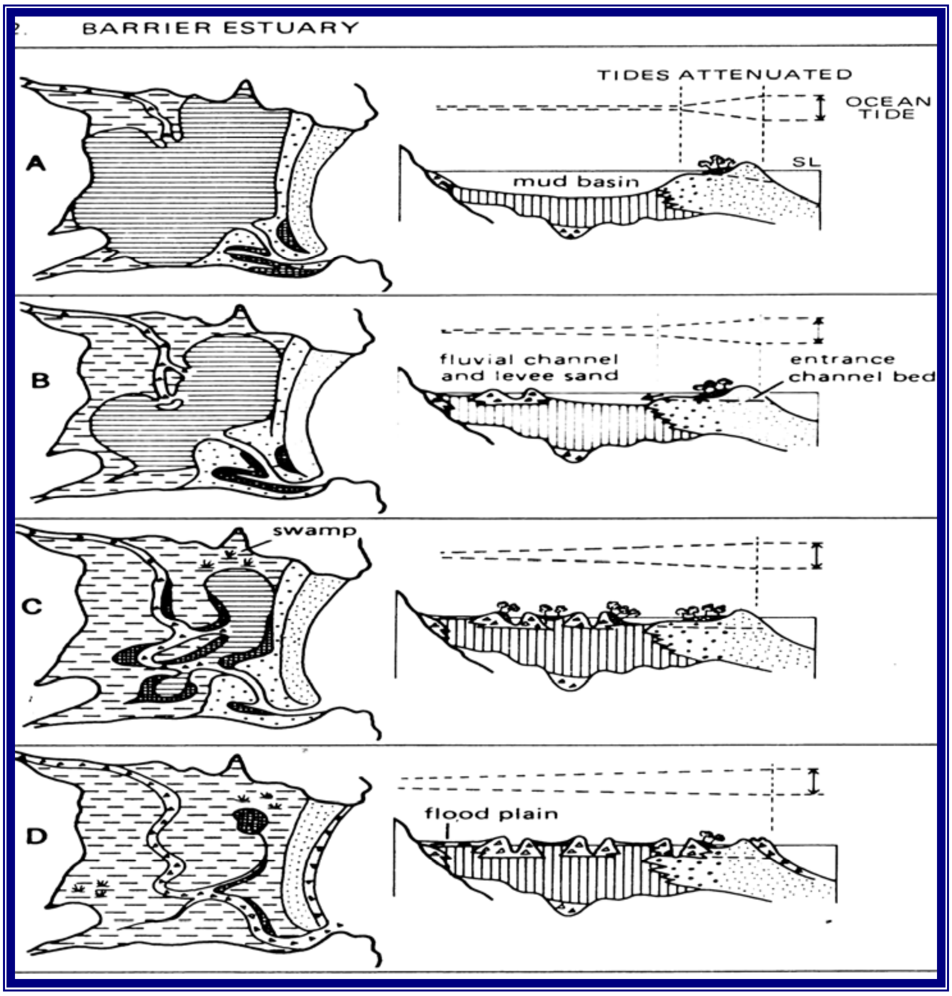


Figure 1-2 - Stages of infilling in the evolution of a barrier estuary (Roy, 1984)

A&B early stages of infilling
C: maximum shoreline complexity
D: estuary becomes channelised

Salinity and Tidal Flow

The pattern of salinity distribution within estuaries may also be used as a basis for their classification (McLusky, 1989) which results in three main types:.

1. Positive estuaries where fresh water runoff is greater than evaporation
2. Negative estuaries where fresh water runoff is less than evaporation
3. Neutral estuaries where fresh water runoff is equal to evaporation.

Positive estuaries, where freshwater runoff is greater than evaporation, (the most common type in temperate regions) can be split into four types depending on the tidal amplitude and volume of fresh water flow, based on the degree of saltwater mixing (Dyer, 1973).

1. Highly stratified or salt wedge
2. Fjords
3. Partially mixed
4. Homogeneous

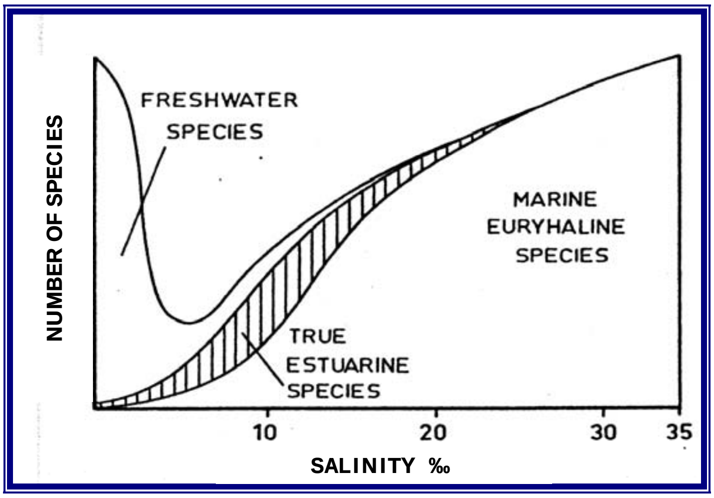


Figure 1-3- Salinity and estuarine species (From Nix and Elliott, 1975)
Variation in total number of species, and in the species representation of three different faunal components, in relation to salinity, within an estuary

The salinity regime within an estuary has a strong influence on the biota inhabiting different parts of the estuary. For example, a greater number of freshwater species inhabit the upper reaches where freshwater runoff is greatest. Marine species are clearly more evident in the lower estuary, subject to tidal influence and incursion of marine water. Figure 1-3 offers an interpretation of freshwater species richness relative to true estuarine species, and marine euryhaline species within an estuary, freshwater species diminish as salinity increases whilst marine species increase.

McLusky (1989) has classified estuarine plants and animals into the following categories:

1. Oligohaline organisms The majority of animals living in rivers and other fresh waters do not tolerate salinities greater than 0.5‰, but some, such as the oligohaline species persist at salinities of up to 5‰ and higher.
2. *True estuarine organisms* These are mostly animals with marine affinities which live in the central parts of estuaries, most are capable of living in the sea but are generally absent from the sea due to competition with other animals. These taxa are common at salinities of 5 - 18‰ with a range from 0 - 25‰.
3. *Euryhaline marine organisms*. These constitute the majority of organisms living in estuaries with their distribution ranging from the sea into the central parts of estuaries, each species has its own minimum salinity that it can live in. Many disappear by 18‰, but a few survive at salinities down to 5‰.
4. *Stenohaline marine organisms.* These are marine organisms which occur in the mouths of estuaries at salinities down to 25‰. (Figure 1-5).
5. *Migrants.* These animals, mostly fish and crabs, spend only a part of their life in estuaries and can adjust to variable salinities.

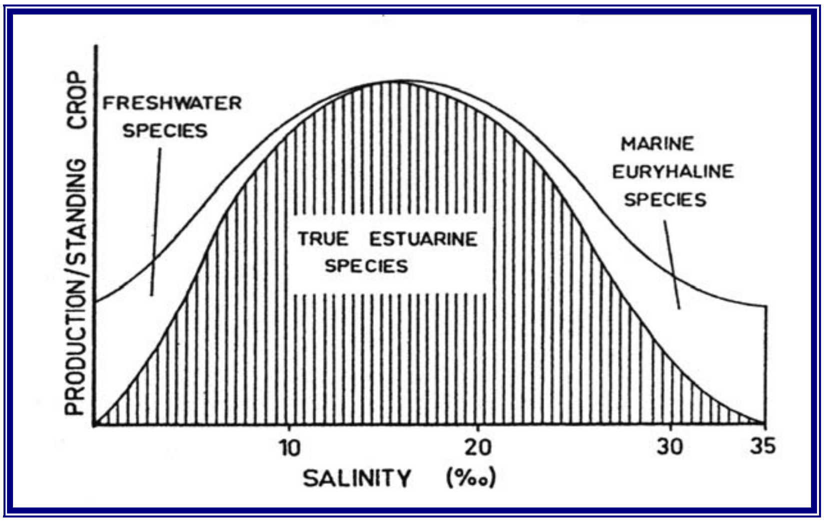


Figure 1-4 - Salinity and productivity (From Nix and Elliott, 1975)
Suggested qualitative form of variation in total production and/or standing crop and of the relative contribution to these quantities by three different faunal components, in relation to salinity, within an estuary. There are indications that this type of relationship is more applicable to the plankton and benthos of an estuary than to the nekton. The indication that production in fresh waters associated with an estuarine system is less than that in brackish waters should not be extrapolated to fresh waters in general (Nix and Elliott, 1975).

Salinity regimes also have an effect on the productivity of estuaries. True estuarine species produce a larger standing crop across a greater range of salinities (Figure 1-4).

Salinity, separate to depth, geomorphology and circulation patterns, is of primary importance in determining the distribution of organisms within estuaries and thus, the character of estuarine ecosystems (Hammond et al. 1994)

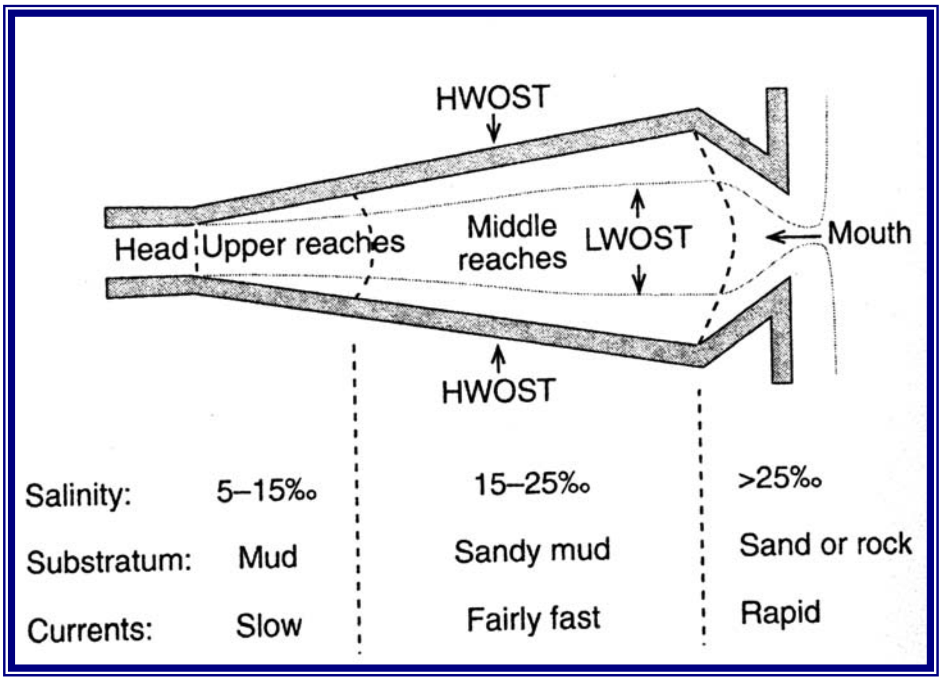


Figure 1-5 –Principal environmental characteristics of an estuary
An estuary is characterised by a gradient from low salinity near the upper reaches to high salinity near the mouth with the substrate similarly ranging from mud to sand and rock.
HWOST = high water line of spring tide
LWOST = low water line of spring tide (From Atlas and Bartha, 1993)

This salinity gradient contributes to differences in community structure along the estuary (Figure 1-5).

NSW North Coast estuaries at times present salt wedges which have the effect of differentiating the water in the creeks into two layers, the upper layer of fresh water is consistently well aerated compared to the underlying salt layer. In salt wedge estuaries the input from the landbased runoff is largely relative to the tidal flow, freshwater flows out over the "wedge" of saltwater entering from the ocean (Underwood and Chapman, 1995).

Whilst salinity of the water column in estuaries is important for fish and planktonic organisms, it is of direct importance for the majority of animals that live buried within the muddy deposits.

Far more important for the benthic communities is the interstitial salinity (salinity between the mud particles) which varies much less than the salinity of the overlying water (McLusky, 1974).

1.3.1.2 NUTRIENTS

Estuaries can be described as nutrient traps. They benefit from the influences of both fresh and marine waters. Compared to fresh waters the increased salinity and depositional environment of the estuary can concentrate both excessive nutrients and pollutants in the underlying mud (McLusky, 1989).

The underlying geology of the catchment and estuary defines the basin and entrance conditions, which in turn influences salinity and mixing regime, influencing the biotic communities. These factors together with climate have a major influence on the biological communities supported by estuaries (Deeley and Paling, 1999).

1.3.2 ECOLOGY

Ecology is the science that explores the interrelationships between organisms and their living (biotic) and non-living (abiotic) environments (Atlas and Bartha, 1993). Ecologists attempt to understand:

- How energy and materials move between different groups of organisms and the natural environment and what factors affect this.
- How and why the population of a species may increase and/or decrease at different times.
- The relationships between different species.

An understanding of these basic concepts and their links assists in interpreting the complex interrelationships within estuaries. The ultimate source of animal food is plant life which acts as a potential energy store, it is clear that a plant may be eaten by one animal which in turn is eaten by another and this creature may be eaten by yet another and so on.

Such a sequence of events is termed a food chain (Phillipson, 1966). As no system exists in isolation, food chains interconnect and are then referred to as a food web. Organisms with similar feeding habits and diets have been grouped together as in an ecological pyramid and each grouping or feeding level is termed a trophic level (Phillipson; 1966). Energy continually enters and leaves each trophic level.

There are two basic food chains or webs present in the estuarine ecosystem:

- The grazing food chain consists of herbivores which feed on living plants, together with their predators, and
- The detritus food chain consisting of detrivores which feed on dead plant material with their associated predators and are dependent on microbial breakdown of the food particles.

Food chains and food webs form identifiable communities within which lies a diversity of species. (Begon et al. 1986).

1.3.2.1 ESTUARINE ECOLOGY

Estuaries and their associated wetlands provide a variety of habitats which support plants and animals in a rich, diverse and highly inter-related web of aquatic and terrestrial ecosystems (Adam et al. 1992). Estuaries play a role in protecting juvenile fish from predation and also provide the source of food for juvenile and adult fish alike together with their breeding areas. It is estimated that 70% of the commercial fish catch of NSW is at some time dependant upon an estuary (Pollard, 1976). Living organisms and their non-living environments are inseparably inter-related and interact with each other.

Two main themes are apparent in estuarine systems. They are:

1. Inter-relationships and
2 Interdependencies

The biotic community interacts with the physical environment creating a flow of energy which in turn produces clearly defined biotic structures. These structures induce the cycling of materials between living and non living parts creating an ecological system or ecosystem.

Hutchings and Recher (1974) identified the fact that estuarine food chains which begin with seagrasses and mangroves often terminate with birds, some being waders, visiting these estuarine systems as long distance migrants. These dependant animals are attracted by the rich food supply available to them such as detritus feeding invertebrates (polychaetes, molluscs or crustaceans). In estuaries the main source of organic material for higher order consumers is through detrital pathways derived in the main from leaf litter.

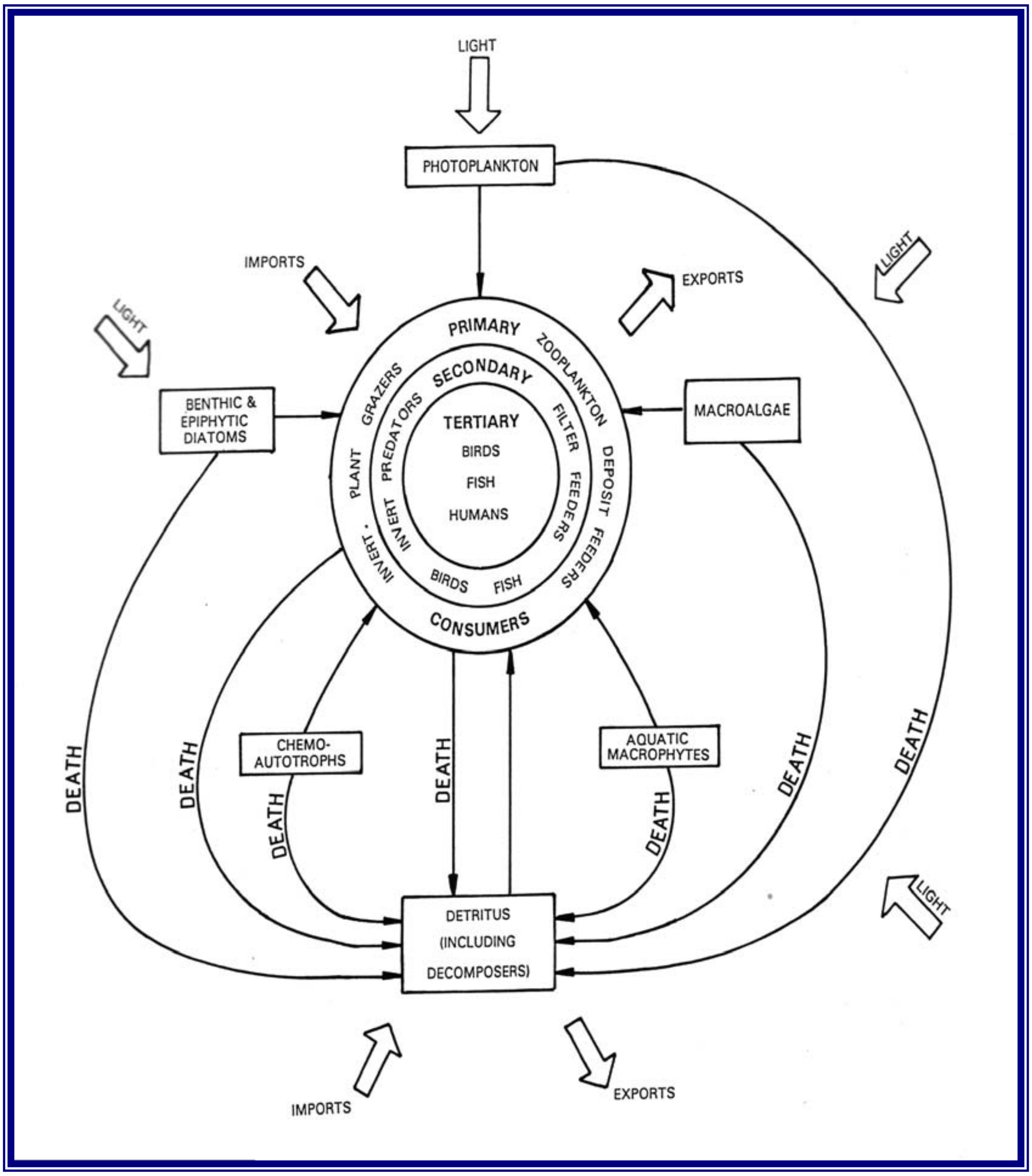


Figure 1-6 - An estuarine food web (Adam et al. 1992)

defines the pathways within which both the "grazing" and "detrital" food chains are involved in energy transfer throughout the estuarine system.

Primary consumers include zooplankton, deposit feeders, invertebrates and plant grazers, secondary consumers consist of invertebrate predators such as crabs and prawns whilst tertiary consumers include fish and birds which eat filter-feeders such as mussels and oysters and invertebrates such as prawns and crabs (Figure 1-6).

Plants are the primary producers of the ecosystem, about one half of the energy fixed by plants is used by plants themselves and the remainder is available to animals. Energy flows through plants to herbivores and through herbivores to carnivores. These animals are "consumers" and they form many food chains within a food web with each animal linked to others and ultimately to plants (Recher et al. 1986).

The study of estuarine ecosystems involves an understanding of energy flows and the detrital food chain, habitats, species diversity and abundance and the pressures which create change within the environment.

1.3.2.2 THE CYCLING OF ORGANIC MATTER

The organic matter within estuaries consists of material resulting from the excretion and decomposition of estuarine animals and plants, supplemented by fragments and dissolved organic material carried into the estuary (McLusky, 1989) (Figure 1-7).

Organic matter exists as either particulate or dissolved forms in aquatic ecosystems. Particulate organic matter (POM) includes living organisms varying in size from fish down to bacteria, as well as dead material (detritus). There are two forms of particulate organic matter, coarse particulate organic matter (CPOM) and fine particulate organic matter (FPOM). Most organic matter naturally derived from the breakdown of plant material occurs in the water column as dissolved organic matter (DOM) (Boulton and Brock, 1999).

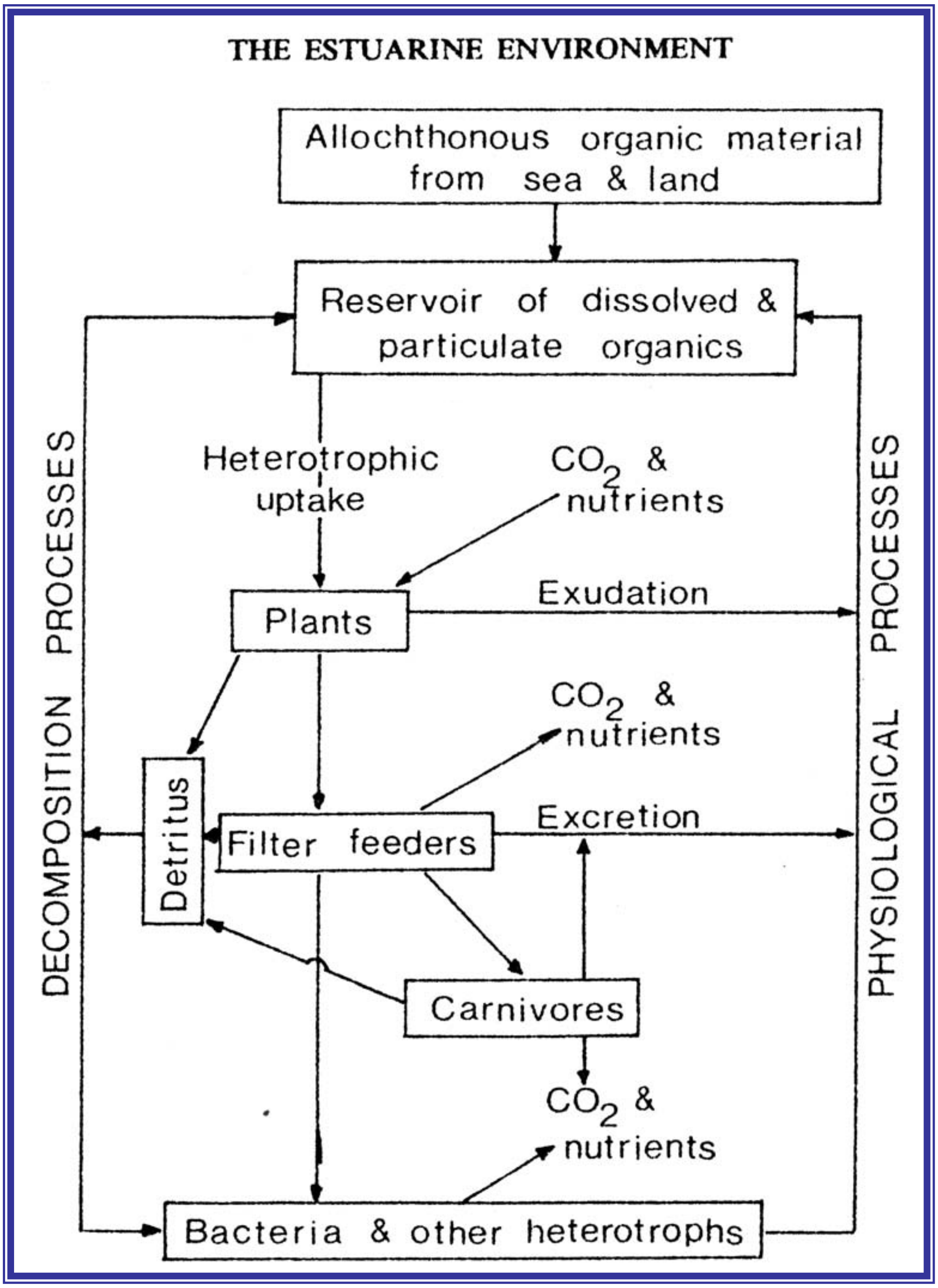


Figure 1-7 – Major pathways for the cycling of organic matter in estuary providing food web links between trophic matter and organic matter (DOM, FPOM, CPOM).

(McLusky, 1989 after Head, 1976)

Coarse particulate organic matter (CPOM) is broken down into fine particulate organic matter which may then reside in suspension and becomes accessible to plankton and filter-feeders. A further dissolved stage (dissolved organic matter [DOM]) is generally exported from that ecosystem first in colloidal or soluble form (Barnes and Mann, 1980).

1.3.2.3 THE DETRITAL FOOD CHAIN

Detritus consists of all non living organic matter, including waste products and the remains of dead organisms together with the associated microbial community (Day et al. 1994)

Mangroves, together with seagrass, form the basis of the detrital food chain. Litter (fragments of dead leaves, bark and fruit (CPOM)), falls from the mangrove or breaks off from the seagrass, soluble nutrients are leached out by rain and tides (DOM), the organic material is then colonised by microscopic fungi and bacteria simultaneously. The resulting decomposed material (FPOM) is eaten by small animals such as prawns and crabs (Barnes and Mann, 1980). These animals in turn excrete the undigested plant material (FPOM) which is then recolonised by fungi and bacteria (West, 1985; Recher et al. 1986). An example is shown in Figure 1-8 and Figure 1-9, for mangroves and seagrass respectively.

Mangroves and seagrass provide between 10 and 15 tonnes per hectare per annum of organic matter (detritus) to the estuary system (Recher et al. (1986); Adam et al. (1992); Underwood and Chapman (1995)).. (Table 1-1).

Table 1-1– Primary production of different plant assemblages in Botany Bay (From Underwood and Chapman, 1995)

Type of habitat	Area of habitat (hectares)	Annual production (tonnes ha $^{-1}$. yr^{-1})
Seagrasses with epiphytic algae	784	10
Mangroves	400	15
Saltmarshes	150	6
Benthic algae	200	3
Phytoplankton	4600	1.5

More complex food webs include the supply of food from the product of plant photosynthesis, invertebrates which feed on other invertebrates (predation) and less important groups such as planktonic animals (McLusky, 1974).

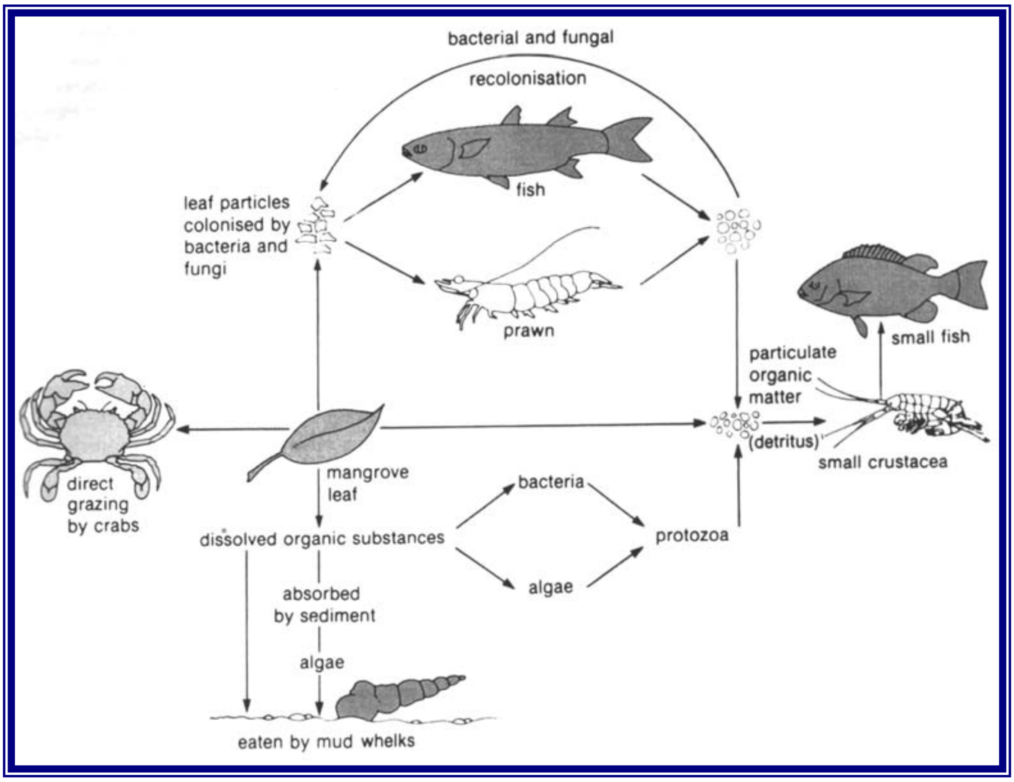


Figure 1-8 – The estuarine detrital food chain (from West, 1985)

Production based on mangrove leaves

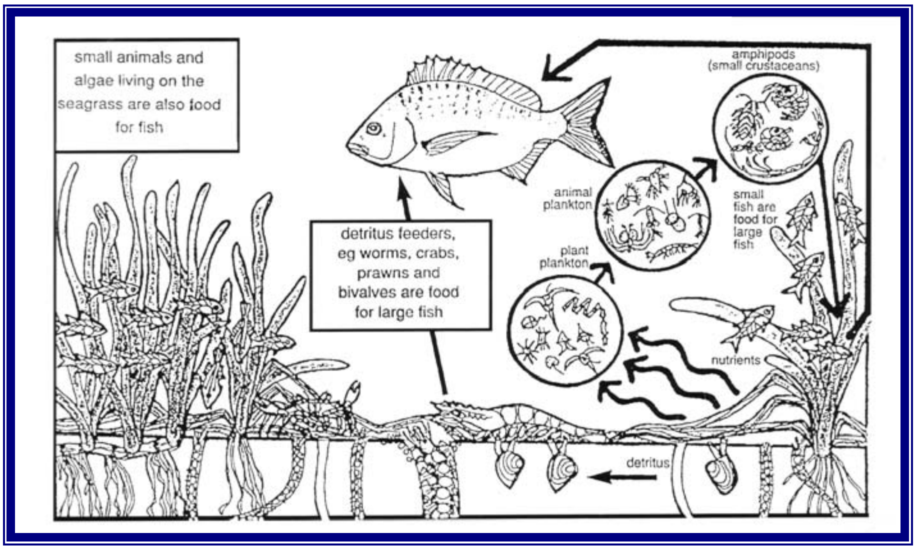


Figure 1-9 – A simplified foodchain in a seagrass community

(Smith and Pollard, 1997) Linking benthic communities with higher order consumers

Micro-organisms can account for as much as 90% of the energy flow through an ecosystem (Phillipson, 1966). Large populations of bacteria support populations of nematodes, ostracods and harpacticoids with a high proportion of the micro-fauna being omnivorous, feeding as browsers, scavengers and micro-predators. A large proportion of these micro-organisms are liable to be consumed by the many detritus feeding members of the micro fauna. Hutchings and Recher (1981) identified polychaetes, gastropods and crustacea as the most common macrofaunal species in the estuarine system.

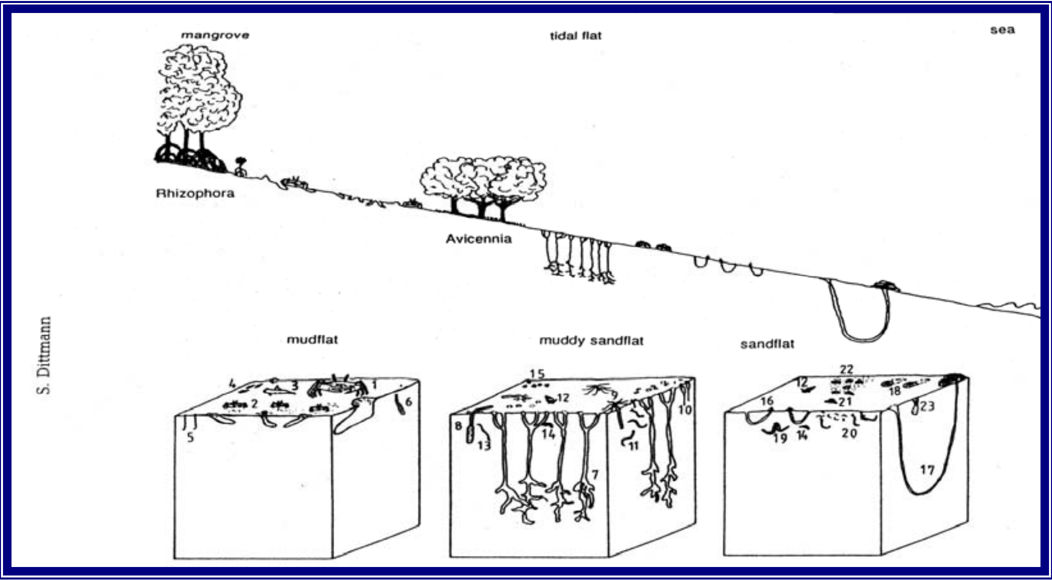


Figure 1-10- A generalised scheme of benthos communities in tidal flats of tropical northeast Australia (Dittman, 1995)

1: *Macrophthalmus* sp.; 2: *Uca* spp.; 3: *Periophthalmus* sp.; 4: Cerithsnails; 5: *Heteromastus* sp.; 6:Sipunculida indet.; 7: *Callianassa australiensis* (Dana); 8: Echiurida indet.; 9: *Loima* sp. (terebellid polychaete); 10: *Liguala anatina*; 11: small polychaetes *(Glycera, Nereis, Magelona, Prionospio)*; 12: *Nassarius pullus;* 13: Nemertinea indet.; 14: Amphipoda indet.; 15: *Clithon oualensis*; 16: *Paracaudina* sp. (Holothurid); 17: Enteronpneusta indet.; 18 *Arachnoides placenta*; 19: Nereis indet.; 20 small polychaete (*Armandia, Ancistrosyliss,* Syllidae, *Glycera*, Eunicidae); 21: *Polinices* sp.; 22: *Mictyris* spp.; 23: Tellinidae indet.

Dittman (1995) in Figure 1-10 identifies a generalised scheme of benthic communities in tidal flats of tropical north east Australia, of importance is the range of polychaetes and their relative depth of penetration with respect to the cross sectional profile of the tidal flat. Crustacea, bivalves, polychaetes, amphipods and isopods are a few representative benthic species within the macrofauna classification, these animals are relatively immobile and can be used as indicators for the assessment of local disturbance effects (Dittman, 1995).

Thrush (1999) identified a further variable of community structure, that is predation, and stated that predation structures communities by many complex and indirect interactions that are often difficult to predict and generalise, and that many of the predators in soft sediment communities are generalists, there is usually a lack of competitive exclusion. Thrush further states that the lack of simple negative effects and absence of major changes in community structure apparent in many studies, implies one or more of the following is happening:

1 Predation is not generally an important process directly structuring soft sediment communities
2. Complex interactions are common in these systems, and or
3. We are using inappropriate or incomplete study techniques.

1.3.3 ESTUARINE BIOTA

Estuaries are characterised by their varied plant communities (Figure 1-11), ranging from seagrass and mangroves in the tidal range through salt marsh into sedge/coastal heath.

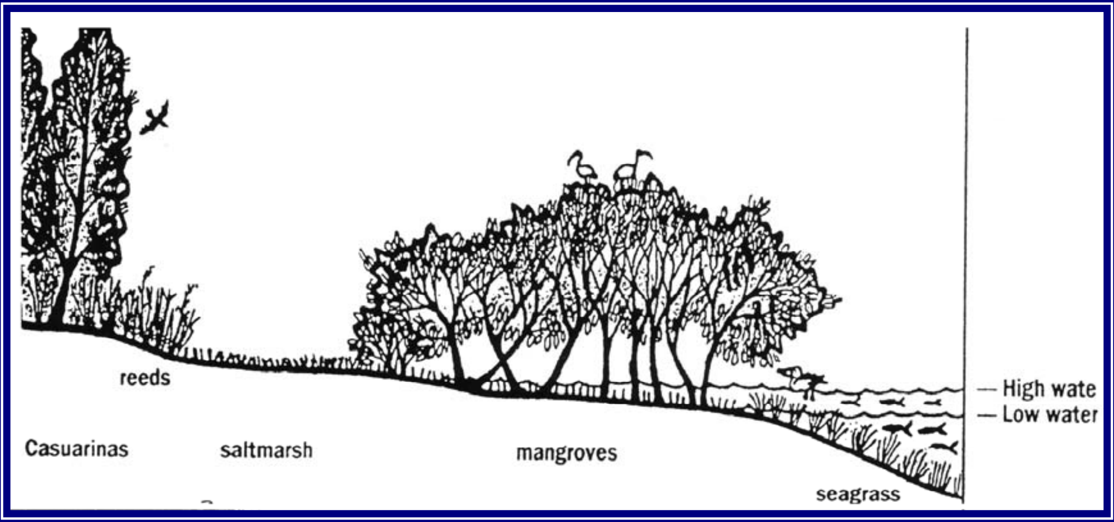


Figure 1-11 – Estuarine habitats (Adam et al. 1992)

Depicts three vegetation types typical of an estuary. From landward; saltmarsh, mangroves then seagrass. Sedge/coastal heath are generally located above saltmarsh

1.3.3.1 SEAGRASS BEDS

Seagrass are true grass (rhizomateous angiosperms) adapted to life in shallow, sheltered coastal environments (Zann, 1995). Seagrass generally occur in the intertidal and subtidal zones of relatively shallow estuaries and inshore bays. Seagrass beds contribute large amounts of organic matter to the estuarine food chains and act as baffles for silt functioning as sediment traps (Middleton, 1985). In NSW seagrass beds also provide food and shelter for many aquatic animals such as prawns, molluscs and other shellfish, fingerlings and small fish. Seagrass are generally of the species: *Zostera capricornii, Posidonia australis, Halophila sp*. and *Ruppia* sp. Typical fauna associated with seagrass include: polychaetes, crustacea, amphipods, fish, whelks, cockles and periwinkles (Smith and Pollard, 1997). The fauna of seagrass beds are observed in higher numbers and diversity than other estuarine habitats (Connolly, 1999). As depth and the turbidity of water play an important role in the local extent of a seagrass meadow, the broader issues of erosion and sediment runoff can then become impacts. The distribution of seagrasses is influenced by light intensity which is required for photosynthesis, light intensity decreases with depth and with increased turbidity.

Depending upon species, seagrass can provide between three and twenty tonnes of leaf matter (detritus) per annum per hectare (Adam et al. 1992).

1.3.3.2 MANGROVES

Mangroves like seagrass are true plants with roots, stems and leaves adapted for life between the tides on sheltered shores, estuaries and tidal creeks (Underwood and Chapman, 1995; Zann, 1995). They are classed as land builders and occupy the fringe of the intertidal areas between the land and the sea and also provide habitat and shelter for fish, crustacea and molluscs. Mangroves have developed unique mechanisms for salt tolerance, aeration and seed dispersal, and that have adapted to a harsh environment overcoming factors of unstable and low oxygen levels and high concentrations of salt, adaptations include: pneumatophores roots that extend above high tide in order to breathe; the mechanism of concentrating salt in leaves, then dropping them from the plant containing concentrations of excess salt (Middleton, 1985)..

Mangroves offer a habitat or shelter for many plants and animals and the soil or sediment in this environment may be sand but is more often a rich mud high in nutrients and essentially anaerobic (West, 1985, Adam et al. 1992). Mangroves occupy the upper tidal reaches of creeks and may be present as dense forests in tropical areas. The number of species declines at lower latitudes and there are only two species in the Coffs Harbour region, the grey mangrove *Avicennia marina* and the river mangrove *Avicennia corniculatu,* both of these species occur seaward of salt marshes and are subject to regular tidal inundation (Adam et al. 1992). Typical fauna include: crabs, isopods, amphipods, prawns, whelks, fish, polychaetes and oysters (Underwood and Chapman, 1995).

1.3.3.3 SALTMARSH

Coastal saltmarshes are an intertidal plant community complex dominated by herbs and low shrubs (Zann, 1995). Saltmarshes are dominated by plants such as saltwort (*Sarcocornia quinqueflora)*, rushes (*Juncus*), sand couch (*Sporobulus virginicus)* and the common reed (*Phragmites*) (Adam et al. 1988; Underwood and Chapman, 1995). These generally occur between tidal areas and dry land and help maintain water quality by trapping and recycling nutrients and filtering silt and pollutants from upland runoff (Adam et al. 1992). Saltmarsh are also efficient land builders (Barnes, 1974). They also provide organic matter for estuarine food chains and habitat for aquatic organisms such as juvenile fish.

Typical fauna associated with saltmarsh include: crabs, snails, slugs, mosquito and midge larvae, isopods, spiders, fish, wading and wetland birds and casual mammalian visitors such as kangaroos and wallabies (Underwood and Chapman, 1995).

1.3.3.4 COASTAL HEATH/SEDGELAND

This classification of vegetation relates normally to swamp forests. These are generally located adjacent to wetland areas above saltmarsh and represent the most inland habitat directly connected to an estuary. The dominant species of this area includes the paperbark (*Melaleuca ericofolia and Melaleuca quinquenervia)* and the swampoak (*Casuarina*) but can also include trees such as swamp mahogany and banksia. These forests also support numerous terrestrial animal species (Adam et al. 1992).

The different types of vegetation and changes that occur with development can have considerable impact. For example, an estuary that supports mostly saltmarsh with only a narrow mangrove fringe will have a different primary productivity base than one with extensive mangrove forest or seagrass beds, which in turn will be reflected in the distribution, type and abundance of consumer organisms.

1.3.4 RESPONSE TO ESTUARINE STRESS

Organisms within estuarine ecosystems are subjected to a variety of stresses and environmental pressures such as changes in water quality as a result of changes to pH, DO, turbidity, salinity, temperature, nutrients and depth, together with human factors such as pollution, runoff and clearing. For each species there is a range of abiotic and biotic factors within which it can survive, this is the zone of tolerance which has at either end a point beyond which it cannot survive whereby the population can enter a state of decline (Roberts, 1971).

Organisms can respond to stressful conditions in one of three main ways:

1. Migration to a more favourable environment
2. Adaption, or
3. Death

These responses can then affect species diversity and abundance. Estuarine systems have been found to be poor in species diversity but rich in abundance (Barnes, 1974). McLusky (1989) further depicts the pathway of changes which can occur to estuarine animals as a result of stress. (Figure 1-12)

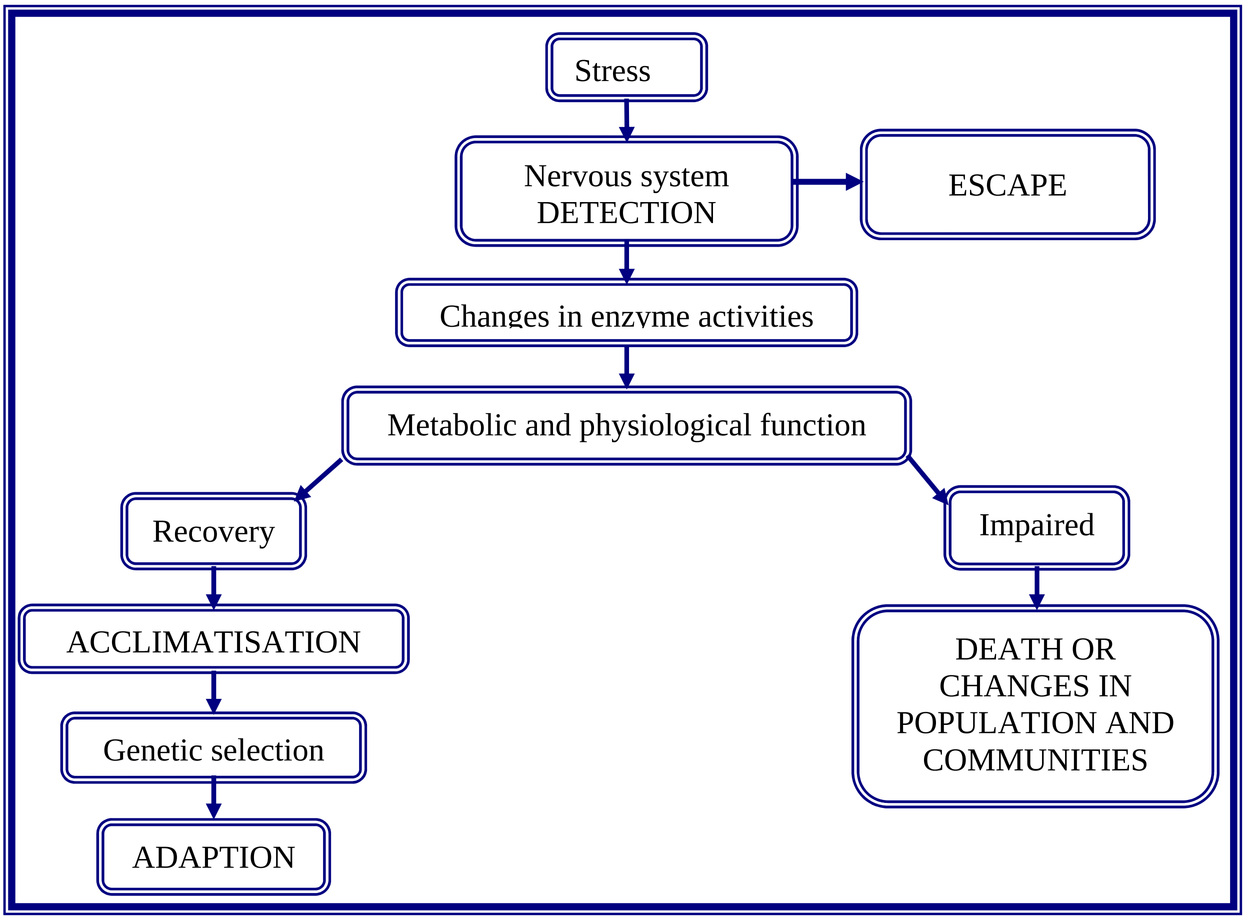


Figure 1-12 – Schematic sequence of the affects of environmental stress on estuarine animals (McLusky, 1989 after Blackstock, 1984)

Communities and therefore organisms that are subject to stress eventually change. The term "stress" refers to any physical or chemical factor (s) that restricts recruitment, growth or survival of individuals or populations of species which then affects the overall composition of the macrobenthic community (Dauer et al. 1992).

Estuaries are high stress environments where the additional stress from human activity can lead to large impacts on estuarine organisms. Human settlement patterns are an indicator of human activities and by interpretation can relate to human impacts.

1.3.5 HUMAN ACTIVITIES AND CHANGES IN THE ESTUARINE SYSTEM

Human impacts on estuaries have been documented worldwide and there are cases that have resulted in the complete loss of biota. Proximity of settlement and the philosophy that estuaries represent an unlimited drain system has now been demonstrated as unacceptable and as the range of anthropogenic factors known to affect estuarine ecology become better researched, there is a commitment and a need to reverse the trend of degradation.

Middleton (1985) attributes pollution, land reclamation, clearing and flood mitigation as adding to the destruction of estuarine habitats. In areas where a decline of saltmarsh has occurred, pressure from agriculture, reclamation and urban development have been the main causes of such destruction (Smith and Pollard, 1998).

Nutrient enrichment from domestic and organic waste creates change in fauna and sediment of the system, species diversity is reduced as organic enrichment increases (Pearson and Rosenberg, 1978; Gray, 1981; McLusky, 1989). As species diversity decreases the abundance of the remaining species increases (Pearson and Rosenberg, 1978) (Figure 1-13).

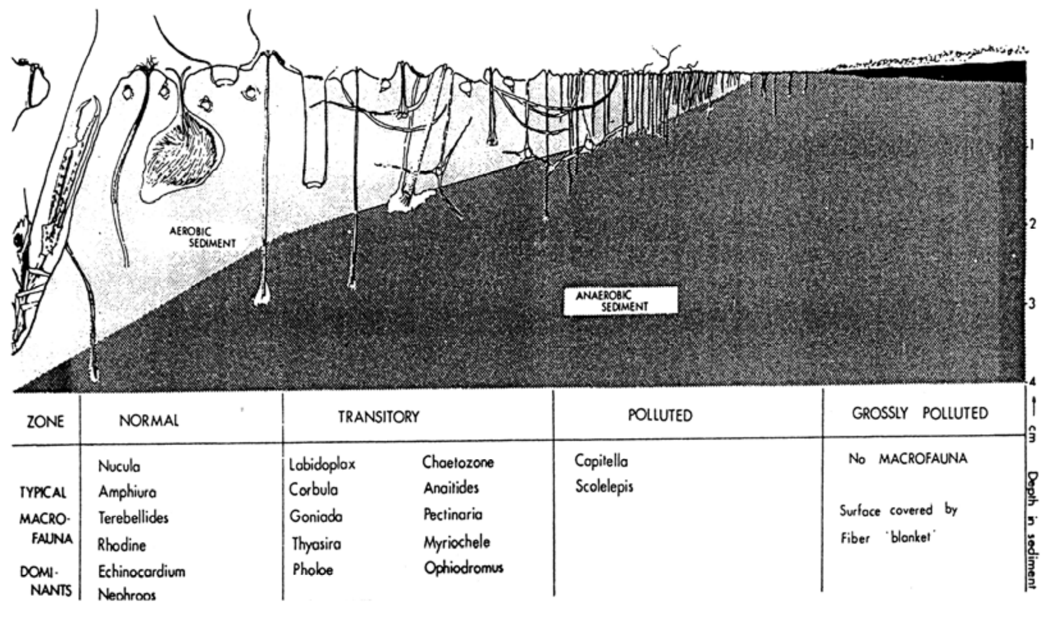


Figure 1-13 – Diagram showing the changes in fauna and sediment structure along a gradient of organic enrichment (Pearson and Rosenberg, 1978)

Human settlement and activities such as impacts from housing, construction and occupation, clearing, roads and industry, increase in sediment and erosion runoff, nutrient pollution and chemical residues are issues of major importance. Both point and non point sources of pollution can provide contaminants and pathogens derived from humans and animals, both bacterial and viral, into urban creek systems. As urban development increases in the catchment, corresponding increases in nutrients entering a water body can have a far reaching impact on water quality, plant growth and animal life, eutrophication and consequences of fish kills resultant from a lack of dissolved oxygen can occur. (Department of Urban Affairs and Planning; Circular F13, 1995).

More diffuse input to the catchments arise from non-point source pollution.

Cullen and O'Laughlin (1982) offer some basic characteristics of non point source (diffuse) pollution as:

1. Water draining. Any catchment carries dissolved and particulate material.
2. Some of these materials will be contained in base flow, but substantial increase in non point pollutants are likely following overland flow or near surface flow.
3. Consequently, substantial proportions of the non point pollutants are derived from uncontrollable rainfall events.

Urbanisation results in changes in runoff sediment yields and river channel stability. Other impacts include increased nitrogen loads from fertiliser based applications in a catchment which in turn leads to increased nutrients entering waterways with outcomes of eutrophication and algal growth. These in turn can create oxygen depletion in waterways (McClelland and Valiela, 1998). Some examples are:

Rural Runoff**:** Agricultural pursuits such as cropping, grazing and chemical usage all contribute water pollutants in the form of sediment, pesticides and nutrients and wastewater runoff and soil chemical residues.

Industrial Runoff: Industrial activities at times incorporate hazardous and toxic processes and residues with potential pollutants such as polluted runoff, residues and emissions. Runoff in these areas is intensified as a result of large areas of hard surfaced pavement materials.

Urban Runoff: Development of land for rural and urban purposes at times disturbs soil and alters the land surface and drainage patterns. Pollutants associated with urban runoff are litter, coarse sediment and fine suspended material or oil, tar, nutrients, pesticides and oxygen depleting materials such as grass clippings (Coffs Harbour City Council, 2000). Wastewater runoff and overflows are further issues associated with human settlement.

Water which becomes polluted in this manner becomes deoxygenated and turbid, aquatic life can disappear and nuisance species of exotic plants can thrive.

Anderson (1995) states there is increasing evidence that modern agriculture is beginning to saturate soils with nutrients as well as increasing soil erosion and hence nutrient loss. Other impacts such as pathogens, faecal coliform and nutrient contamination do not occur solely from human waste.

Smith (1994), in a study relating to problems with dogs, estimated that of the 500,000 dogs in Sydney the production of approximately 100 tonnes of excrement per day occurs and quantities of this are then washed off into estuaries with rainfall.

Land, water, vegetation, fauna and other natural resources are all interrelated and interdependent. The activities in the catchment are reflected by the health or otherwise of the receiving waters in the catchment this is reflected in this study by the estuarine systems. The concept of catchment management recognises the fundamental principles that "no component of the environment exists in isolation" (Department of Urban Affairs and Planning; Circular F13, 1995). Estuaries are the receiving point of all landbased runoff.

Some of the effects that drains and outfalls have on estuaries and seagrass are nitrification, an increase in turbidity, temperature increase, siltation and release of toxic products and heavy metals (West, 1989). These effects together with eutrophication and consequent dissolved oxygen (DO) depletion can have major impacts on estuarine ecosystems such as: seagrass bed destruction, changes in benthic community composition and depletion of fish species.

Estuarine environments are both periodically and permanently affected by human induced habitat modification and pollution. The degree and level of impact of these disturbances is not yet fully understood and requires comprehensive collection of baseline data to allow reasoned and informed scientific interpretation. Changes in species diversity and dominance patterns, possible defaunation, a breakdown in eco-system stability and an obvious increase in some opportunistic species (such as some algal and polychaete species) may result (Warwick, 1993). Kennish (1992) indicates that estuaries have at times been used as dumps, the disposal of organic pollutants also has been achieved in the past as a result of input matching the receiving systems capacity to assimilate, disperse or dilute the pollutant in question due to tidal flushing.

Burchmore et al. (1992) notes there are a number of human activities that have the potential to severely impact on estuarine habitats, of these; infilling, dredging and extractive operations; diffuse and point source pollution; waterfront developments and canal estates; road and bridge construction; which are all activities that lead to impacts in the catchments of this study. What continues is the runoff problem from erosion and lack of sedimentation control in respect to urban development, civil works and open agricultural cropping.

These trends are not limited to Australia. Neilsen and Cronin (1981) identified impacts occurring in Chesapeake Bay, like many estuaries world wide, experiencing deterioration of water quality from nutrient enrichment, sediment inputs and high levels of contaminants resulting in anoxic and hypoxic conditions which result in a decline in the associated living resources.

Poor water quality has affected up to 64% of NSW estuaries and loss of habitat has caused decline in estuarine fisheries with up to 21% of estuaries in NSW impacted in this way (Zann, 1995). Up to 50% loss has occurred to the seagrass species, *Zostera* in New South Wales estuaries. Many major estuaries have lost as much as two thirds of their seagrass beds in the last 30 – 40 years. For example, the Clarence River has lost up to 60% of its seagrass beds (Zann, 1995). Seagrass in Botany Bay has declined by up to 50% over the last 50 years (Underwood and Chapman, 1995). Zann (1995) further identifies pollution impacts, such as nutrients, oil, heavy metals, pesticides and sewage as serious problems in estuaries within developed catchments. (Figure 1-14).

Report Card

Subject: State of major coastal ecosystems and habitats

(A: excellent, to D: poor)*

Ecosystem	Pressures, Sources	State
Estuaries, coastal lakes (developed)	Serious eutrophication and pollution from elevated nutrients and contaminants from poor inland waterquality, developed run-off, sewage, industrial and shipping discharges.	C-D
Estuaries, coastal lakes (undeveloped)	Localised eutrophication and pollution from increased sedimentation and elevated nutrients from catchments, erosion, fertilisers, animal wastes and sewage. Most severe in cultivated catchments. (6,42)	A-C
Saltmarsh (developed)	Locally serious losses from reclamations, drainage, stormwater, weeds, dumps.	C
Saltmarsh(undeveloped)	Localised losses from draining, grazing, weeds etc.(7)	A-B
Mangroves (developed)	Locally serious losses from reclamations, alteration of estuaries, dumps.	C
Mangroves(undeveloped)	Localised losses from reclamations, ports.(8)	A-
Seagrasses(developed)	Widespread, serious die-back of temperate seagrasses from elevated nutrients and sediments.	C-D
Seagrasses(undeveloped)	Locally serious die-back of temperate seagrasses in many areas; locally serious die-back of tropical seagrass in several areas.(10,42)	A-C
Shores (rocky, soft) (developed)	Widespread serious overfishing and collecting in metropolitan areas; local pollution.	C
Shores (rocky, soft) (undeveloped)	Localised overfishing and collecting.(9,34,39)	A-B
Beaches (open, sandy) (developed)	Widespread serious littering; localised sewage pollution and poor bathing water quality.	C-D
Beaches (open, sandy) (undeveloped)	Widespread, light ocean and fishing litter; localised moderate to heavy beach litter in heavily visited areas.(40,47,101)	A-B
Coral reefs(undeveloped)	Significant losses of coral from crown-of-thorns starfish (Great Barrier Reef) and snails (Ningaloo) threats from elevated nutrients, overfishing, tourism, oil spills.(12,69,70,73)	A-B
Temperate reefs(developed)	Locally serious overfishing and collecting; introduced species; pollution. Status not well known.	B-C
Temperate reefs(undeveloped)	Localised overfishing and collecting. Status not well known.(11,31,48)	A-B?
Shelf seafloor communities (developed)	Overfishing of some species; effects of trawling; increased sedimentation rates; localised sea dumping. Status poorly known.	B-C
Shelf seafloor communities (undeveloped)	As above. Status poorly known.(3,13)	A-B?

*Scores
A: EXCELLENT (no obvious effects of human activities)
B: GOOD (general slight effects, or few sites with moderate effects)
C: FAIR (general moderate effects, or some sites with serious effects)
D: POOR (general serious effects, or some very serious effects)
? : UNCERTAIN STATUS (insufficient knowledge)

Figure 1-14 identifies anthropogenic influences, pressures and sources of impacts on various coastal ecosystems (Zann, 1995). Note the pressure on estuaries, saltmarsh mangroves and seagrass in developed areas ranges from moderate to serious effects.

1.3.6 HUMAN IMPACTS IN THE COFFS HARBOUR REGION

Impacts from sewerage runoff at times occurs from diffuse sources by way of septic tank run-off and infiltration and direct point discharges through breakdown and sewerage system overflows. A study of stormwater outlets indicated faecal coliform counts of up to 90,000 per 100ml were taken in the Carrolls Creek, a tributary of Coffs Creek (Coffs Harbour, NSW) (Jelliffe, 1995). This indicates high level sewage contamination which can also mean increased nutrients (nitrates and phosphates) leading to potential eutrophication. Public Health impacts are also of concern when such levels are present in waters used for recreation. Bioaccumulation and biomagnification are evident in the food chain of some Coffs Harbour estuaries (McDougall and Dettman, 1989). Results of pesticide sampling in fish up to 1989 indicated that:

- Coffs Creek: dieldrin residues were present in all fish samples from Coffs Creek. Most of the fish tested at that time had dieldrin residues exceeding the Maximum Residue Limit (MRL). Other chemicals present were DDT and Heptachlor (McDougall and Dettman, 1989).
- Moonee Creek: Low levels of dieldrin and chlordane residues were found in the fish samples (McDougall and Dettman, 1989).

Estuarine systems have the potential to respond following the removal of pressures. For example, chemicals ranging from organochlorines, used from 1960 to organophosphates from 1970, were applied to the intertidal zones in the major estuaries in Coffs Harbour area for the control of the Biting Midge (Sawtell, 1988; Sawtell, 1989). Pesticide trials assessing the chemical “Abate” on non-target intertidal organisms indicated high mortality rates of the *Mictyris* crab species (Sawtell and West 1988 un-published) following application. This raised the issue of consequent impacts on macro and micro fauna and possible destruction of larval and infaunal stages of species comprising the benthic communities. The application of chemicals to the intertidal zone of estuaries in NSW was banned in 1987.

Chemicals based on heavy metals were utilised in the catchments of the Coffs Harbour area from 1940 to 1960 in the form of lead arsenate and arsenic pentoxide (Sawtell, 1994). From 1960 organochlorines were utilised including DDT, dieldrin, chlordane, heptachlor and aldrin (McDougall and Dettman, 1989).

As a result of chemical residues, organochlorines were phased out from 1987 and organophosphates have been utilised since. Organophosphates though highly toxic are short term residual poisons (Sawtell, 1994).

Testing of soils for chemical residues has been required to comply with various statutes prior to building or development approvals in the Coffs Harbour area (Sawtell, 1994). The chemical residues of major concern in soils have been arsenic and dieldrin, though most areas tested have returned levels of dieldrin beneath the health investigation thresholds. However Reish et al. (1995) refer to an historical account of marine arsenic research on a global basis, where arsenic occurs in many different forms in the marine environment, including arsenite, arsenate, methyl arsonium, dimethylarsinic, trimethylarsene. The bio-transformation of these arsenical compounds is of concern when considering the potential for bioaccumulation and biomagnification.

Thoms and Thiel, (1995) states that sediment derived from urban areas may have a longer impact on estuaries as they are frequently associated with toxic materials, especially heavy metals at concentrations well in excess of background levels. Bioavailability of these chemicals can at times be delayed or suspended as a result of sediment overlay and the creation of anaerobic conditions, this then decreases the chemicals bio-availability.

On 17 August, 1998 a large fish kill occurred in the Boambee Creek (Coffs Harbour, NSW). For a number of kilometres along the creek bank either side of the confluence of the two arms, dead and dying fish were evident on the bank and in the water. These consisted of freshwater perch, mullaway, sand whiting, silver bream, flathead, silver biddies, whitebait and mullet. As the photos indicate (Plates 1.1 to 1.5) destruction across the ecosystem occurred ranging from small fingerlings up to very large fish (for example, flathead 1 metre long), the kill also included fish eating birds, such as a number of pelicans.

Plate 1-1 -Juvenile bream (dying) Boambee 1998

Plate 1-2 -Juvenile flathead (dead) Boambee 1998

Plate 1-3

Plate 1-4

Examples of range of species and size of fish affected by the fish kill Boambee 1998 (large flathead approximately 1m long)

Plate 1-5 -A pelican (dead) after the fish kill - Boambee 1998

Laboratory testing did not find organochlorines, organophosphates or heavy metals at levels that would create such a fish kill, although levels of aluminium, iron and zinc were above normal levels, acid sulphate impacts were also ruled out. Laboratory diagnosis identified deterioration of the fish gills and livers which indicated, without firm conclusion, that the method of death could have been pyrethroids, due to their high toxicity to the marine environment at very low levels of exposure. The gut of the larger fish evidenced many small fish. Similarly two pelicans adjacent to high watermark were found dead.

Soil works adjacent to the waterway were carried out during roadworks in the Boambee catchment for some months prior to August 1998 (Plates 1.6 to 1.10). As sediment and erosion controls were in place, this demonstrates that human activities of soil works and roadworks cannot avoid having some runoff impacts.

Plate 1-6 -Runoff - Boambee Creek 1998

Plate 1-7 -Stormwater controls and gates - Boambee Creek 1998

Plate 1-8 -Water quality and turbidity- Boambee Creek 1998

Plate 1-9 -Bank works, runoff and water quality - Boambee Creek 1998

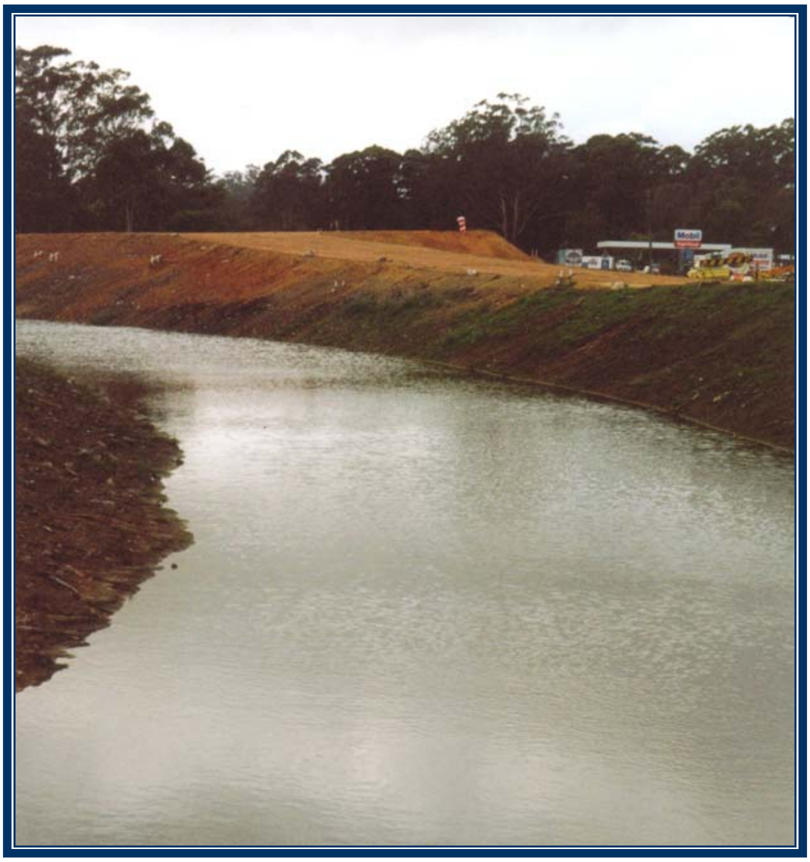


Plate 1-10 -Soil works reforming creek banks - Boambee Creek 1998

Consideration of impacts from human settlement patterns is imperative. For example Corbett et al. (1997) found that the change in runoff co-efficients between urban and forested catchments was quite significant. Runoff from urban areas can be up to 5.5 times higher than that from adjacent forested areas. As urban catchments were formed from forested catchments infiltration capacity of rain and rates of absorption decreases as rainfall intensity and duration increase. This creates an increased runoff, increased non-point source pollution and higher sediment yields from urban water sheds, creating a higher velocity and more erosive overland flow. (Corbett et al. 1997).

It is estimated that there is a 14.5% higher runoff co-efficient from urban areas as that compared to forested areas. Further, in recent studies in the Coffs Harbour area Lyons (1993) indicated that the clearing of banana plantations with no replacement ground cover presents an extreme erosion hazard, up to 338 tonnes of soil per hectare across a month (April, 1989 in the wet season) can be lost. Soil loss figures can be up to 31.8 tonne/hectare/per annum with an average loss of 22.4 tonne/hectare/per annum while tracks can loose the equivalent of 110 tonnes/ hectare/per annum.

Up to 29.5 tonnes per hectare was lost following recent banana planting, directly contrasting to those areas that were trialled with a cover crop treatment, which in turn lost only .97 tonne per hectare. This took place across a nine month field trial (Lyons, 1993).

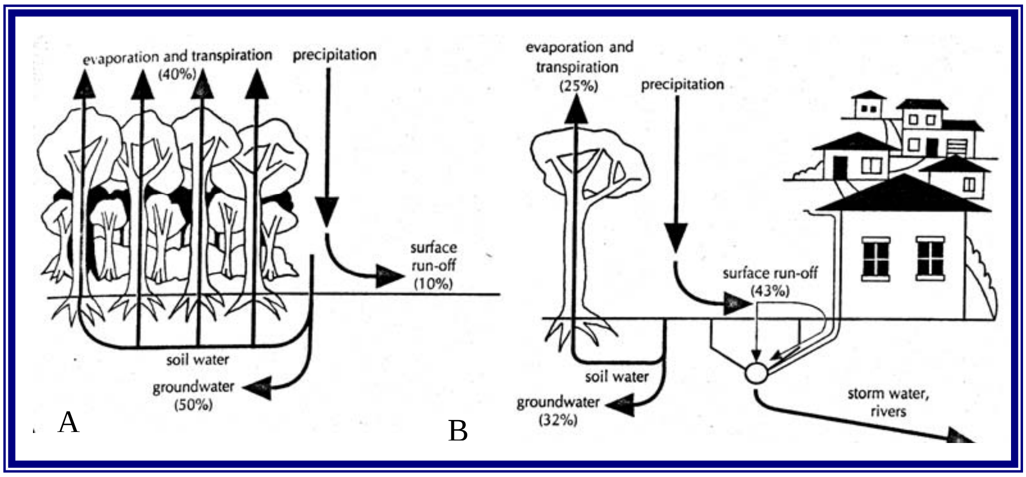


Figure 1-15 Cities affect the water cycle.

In a forest only 10% of the precipitation ends up as run-off (A). The houses, roads and pavements in urban areas reduce the amount of rainwater soaking down to the watertable, but increase the surface run-off (B) (Day et al. 1994)

This is further supported by Day et al. (1994) Figure 1-15 showing how urbanisation can reduce the amount of rain that percolates down to replenish groundwater and at the same time surface runoff usually increases from 10 to 43%; this water is often contaminated.

This introduces the importance of sediment loss and runoff controls and considerations of soil loss throughout previous historical uses of timber getting and agriculture which has occurred since the mid 1800's. Thus changes to human settlement and activities in the catchment can grossly affect not only the runoff, but the sediment carried in the runoff, which can eventually be deposited within an estuary. Figure 1-16 portrays typical human activities which can lead to impacts on the estuarine system. Nutrients or chemical pollutants on the land can become mobile and find their way into creek systems and eventually into the sea. This includes waste water runoff, nutrients and chemicals from agriculture (Figure 1-16). Time lags between pollutant input and the environmental response of larger aquatic systems due to inherent buffering make detection, assessment and management of the impact of wastewater and other pollutants difficult and expensive (Deeley and Paling, 1999).

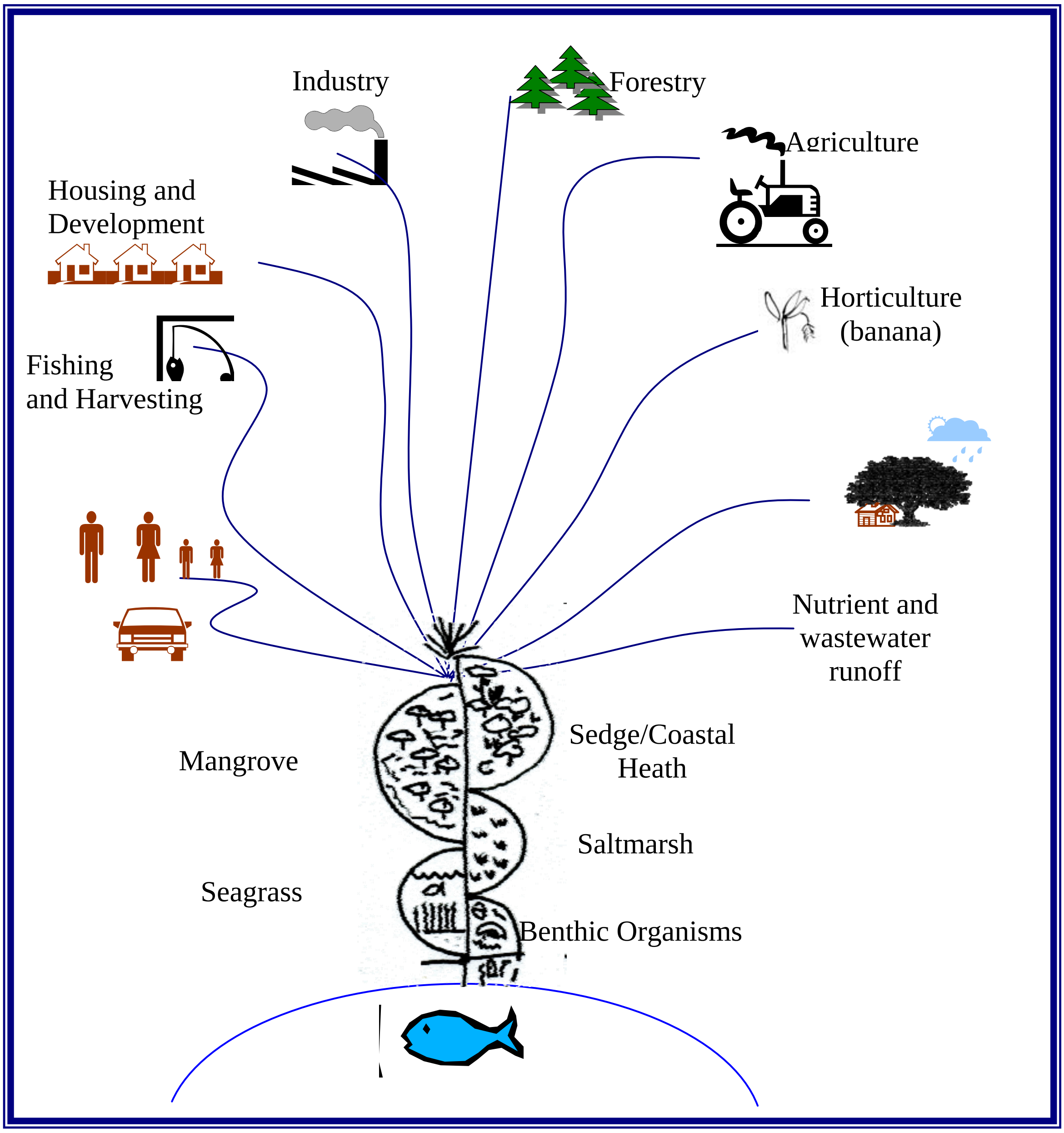


Figure 1-16 - Summary of a catchment with typical activities producing runoff and impacts on the estuarine system as a result of water movement through the water cycle. Inputs to catchment runoff are portrayed together with the linkage to the various estuarine habitats.

Maintaining biodiversity (Department of Environment Sport and Territories; 1993) has become a Federal Government commitment. The operation of Total Catchment Committees indicates a further commitment to the need for correct and adequate planning considerations, particularly considering that when changes in the structure of communities induced by human activities are evident things have gone too far.

Thrush et al. (1994) confirmed the need for broad, large-scale studies noting that many aspects of environmental degradation can only be detected and accurately assessed when there are sufficient data to distinguish long-term trends to short-term fluctuations. Without a long-term perspective, natural fluctuations may be mistakenly attributed to human impacts. Impact studies should thus document density changes and demonstrate causality (Thrush et al. 1994; Underwood and Peterson, 1998).

In evaluating benthic communities in Chesapeake Bay, Dauer (1993) determined that ecological stress from any source is best measured by multiple analyses or methods with different assumptions so as to avoid unacceptable misclassifications associated with a single method or analysis.

1.4 THESIS STATEMENT

The thesis statement is "An Analysis of Ecological Change in relation to Human Settlement Patterns and Activities in Estuaries in the Coffs Harbour Region".

1.4.1 AIMS AND OBJECTIVES

1. To provide baseline data on estuarine vegetation, human settlement patterns and benthic communities in four catchments in the Coffs Harbour Region, being Bonville Creek, Boambee Creek, Coffs Creek and Moonee Creek

2. To examine the catchments of four estuaries and to compare and contrast the uses and activities in each catchment.

3. To determine if human activities have an impact on the estuaries through an analysis of estuarine vegetation, human settlement patterns (HSPs) and benthic communities.

In this study, it is argued that the benthos is responsible for a large and predictable part of total system metabolism in estuaries. It is also argued that food is an important limiting and structuring factor in benthic communities, in this case detritus derived from estuarine vegetation.

It is intended, through analysis of physical, geochemical and biological processes controlling benthic and vegetation communities, to facilitate the interpretation of community characteristics, spatial distribution and temporal changes of benthic and vegetation communities in the four estuaries of the study.

The evaluation of the consequences of anthropogenically induced changes in the system includes the possible responses of benthos. These responses could include presence or absence of species, changes in densities and community structure within creeks that may reflect anthropogenic influences.

Green (1979) points out the interpretation of the results of a sampling exercise will be only as clear of objectives of the study. Further advice is given that before a sampling program can be designed efficiently all the questions that need to be addressed must be stated clearly and explicitly.

The specific questions addressed in this study that were initially considered follow:

- Are the estuaries characterised by certain macro-benthic species?
- Do these macro-benthic species change within or between creeks, both temporally and spatially?
- What are the vegetation communities in the estuaries?
- Are there differences in vegetation within or between the creeks and the catchments, as a result of different human settlement activities, patterns and impacts?
- What is the association of estuarine vegetation relative to the benthic communities?
- Are there changes in estuarine vegetation such as mangroves, seagrass, saltmarsh and is there any fragmentation or incursion into new areas in the period 1954 to 1994?
- What are the factors that create this change, for example, impacts in the catchment such as chemical usage, clearing, infilling urban development?
- What are the human settlement patterns in the catchments of these estuaries?
- What is the association of human settlement patterns, changes and activities in relation to estuarine vegetation and macro-benthic communities?

2 THE COFFS HARBOUR REGION

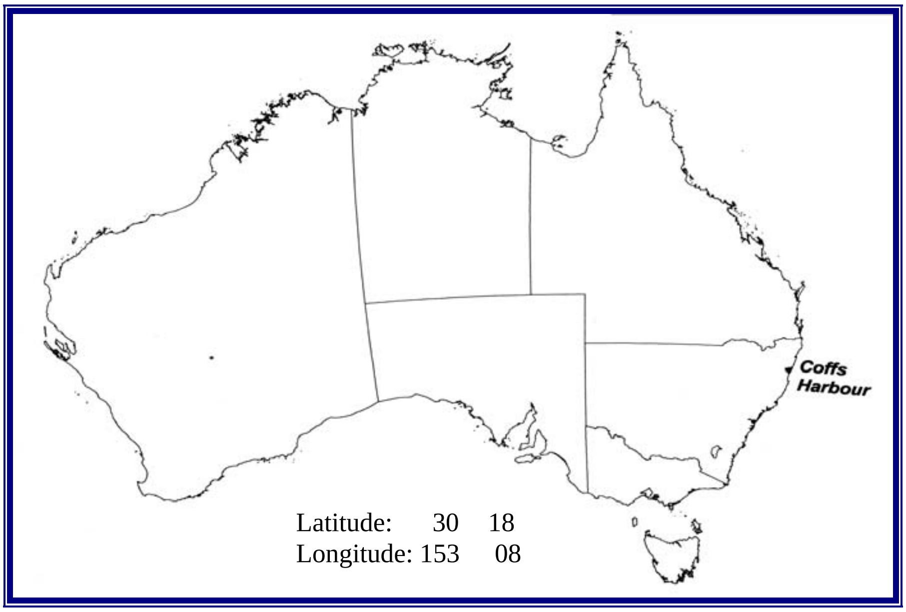


Figure 2-1 - The location of Coffs Harbour

Coffs Harbour is located on the mid north coast of New South Wales, 554 kilometres north of Sydney and 427 kilometres south of Brisbane. The Local Government area covers approximately 954 square kilometres, 47% of which is National Park or Forestry.

2.1 TEMPERATURE

Coffs Harbour experiences a moderate climate, classified as humid to sub-tropical. The highest recorded temperature is 42ºC and the lowest is minus 3ºC (CHCC, 2000).

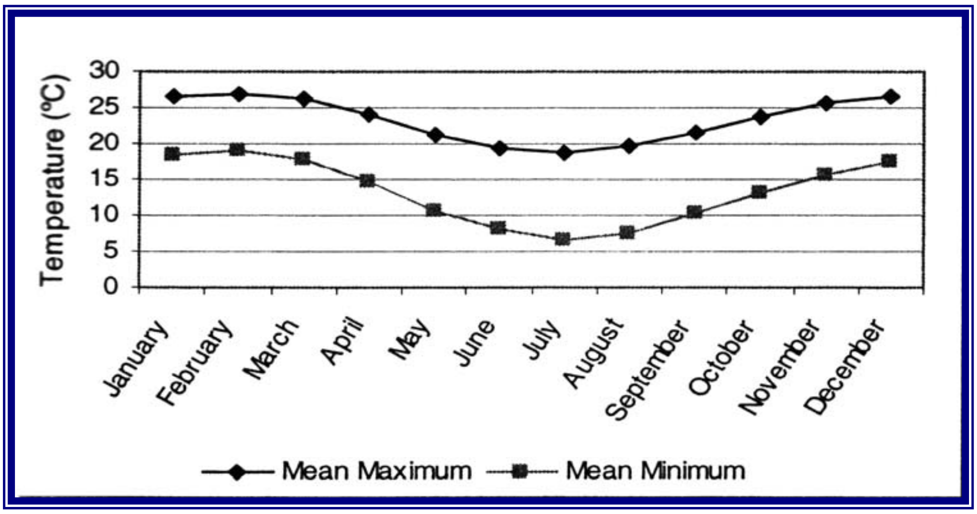


Figure 2-2 – Mean temperature chart depicting seasonal fluctuations (max, min) (CHCC 2000)

The topography of the area produces significant micro-climates. Northern and eastern facing slopes receive highest insolation and therefore record the highest temperatures.

Low-land hollows, particularly in sheltered valleys retain the cold air moving down from the coastal ranges and therefore experience the lowest temperature (NSW PEC, 1980).

2.2 PRECIPITATION

The area experiences high rainfall, averaging 1760 mm per annum, with most rain falling in late summer and early autumn (Figure 2-3). Low rainfall with frequent dry periods is common from October to April (CHCC, 1997).

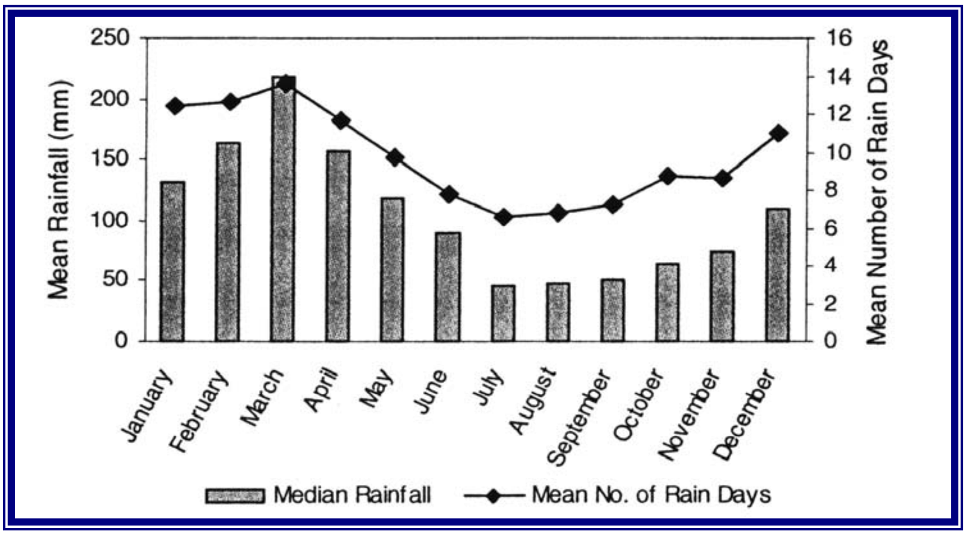


Figure 2-3 – Mean rainfall and mean no. of rainy days indicating "wet" and "dry" periods (CHCC, 2000)

The extremes of landforms exert a strong influence on rainfall within the area. Higher rainfall occurs east of the coastal range due to the orographic effect of the moist maritime air rising over the land, which can at times result in high intensity rain storms. The Coffs Harbour area has one of the highest rainfall erosivity levels in NSW (Coffs Harbour City Council, 1997) and this factor has considerable influence on sediment runoff issues within local estuaries. As the catchments are relatively small the critical rainfall duration that produces flooding is also short.

2.3 EVAPORATION

Evaporation is influenced by factors such as temperature, wind speed and atmospheric pressure, which in turn affect soil moisture and hence the volume of precipitation which is able to infiltrate the soil.

Evaporation is greatest during the warmer summer months (Figure 2-4).

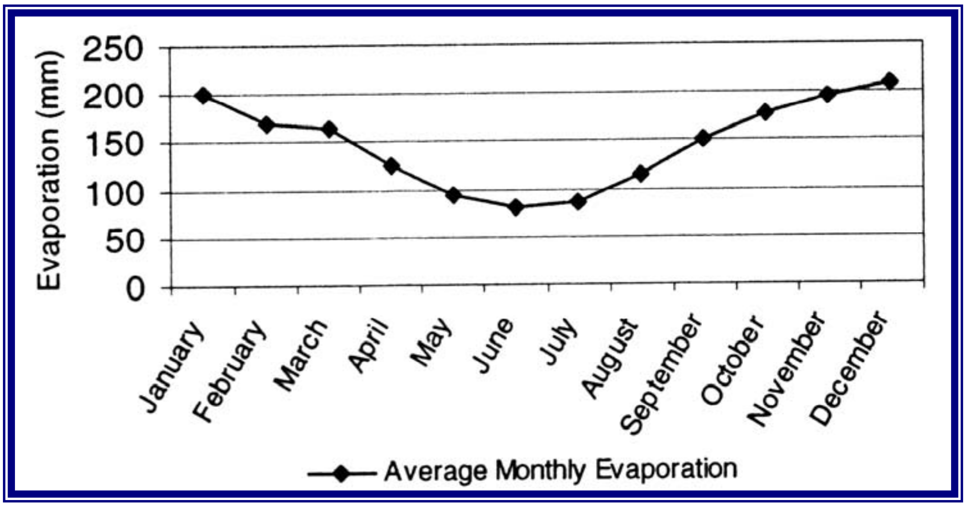


Figure 2-4 – Mean monthly pan evaporation rates

2.4 GEOLOGY AND TOPOGRAPHY

Topography is important to runoff considerations and stormwater issues. Steepness of slopes is a contributing factor to the high velocity of stormwater runoff typical of the Coffs Harbour coastal catchments which is characterised by a narrow coastal plain running inland to the steep coastal range.

The regional geology of the Coffs Harbour area consists of a sequence of sedimentary and metamorphic rocks with minor igneous intrusions known as the Coffs Harbour Block. This block is divided into three main lithological units.

1. Mooball silt stone
2. Brooklana formations
3. Coramba beds

The lithology is associated with mudstone and sandstones deposited on the ocean floor between 280 and 350 million years ago and is made up of materials commonly referred to as greywacke, argillite and slate (CHCC, 2000). The urbanised catchments in Coffs Harbour are characterised by the Brooklana formation and the Coramba beds. The beach/dune barriers and tidal deltas are composed of marine sand, estuarine muds and fluvial muddy sands of terrestrial origin coming from the Holocene deposits. (Stephens and Roy, 1979; CHCC, 2000).

Holocene sequences have been emplaced on a substrate of late Pleistocene estuarine sands and clays and pre-Quarternary bedrock.

The late Pleistocene sands and clays form the low flat "heath plains" which are particularly well represented in Boambee Creek, Coffs Creek and Moonee Creek behind the beach dunal system (Stephens and Roy, 1979). These are referred to as coastal heath sedgelands in the study. The height of these estuarine deposits show that they accumulated during a period when sea level was 2 to 4 metres above the present.

2.5 POPULATION

The population of the Coffs Harbour local government area has experienced a high growth rate since 1971 and in the 30 years from 1966 to 1996 the population has grown from 14,625 to 59,555, this represents a fourfold increase. Population distribution is unequal throughout the local government area with major concentrations along the coastal strip, with populations in the catchments of the study varying from 1176 in Moonee to 17,870 in Coffs (Table 2-1).

Table 2-1 Population in the urban catchments (CHCC, 1997)

CATCHMENT	URBAN POPULATION (1997)	CATCHMENT AREA (ha)
Moonee Creek	1,176	4,213
Coffs Creek	17,870	2,510
Boambee and Newports Creek	6,288	5,074
Pine and Bonville Creeks	8,680	11,627

2.6 RIPARIAN VEGETATION

The riparian zone is any land that adjoins, directly influences or is usually influenced by a riverine body of water. It is an ecotone that combines the elements of both the adjoining aquatic and terrestrial ecosystems (Boulton and Brock, 1999). Riparian vegetation relates to the trees and other plants within this zone. It is important to aquatic habitats and provides:

- Shade and shelter
- A source of nutrients and detrital matter through leaves and other organic matter that falls into the water
- Protection of stream banks against erosion
- A buffer between the waterways and adjoining land uses.

The percentage vegetated stream length for each creek varies considerably. (Table 2-2).

Table 2-2 - Vegetated stream length including indigenous and exotic vegetation (: CHCC, 2000) percentage vegetation is not dependant on creek length but may relate to the degree of development

CATCHMENT	VEGETATED STREAM LENGTH (%)
Moonee Creek	83.5
Coffs Creek	64.8
Boambee and Newports Creek	72.0
Pine and Bonville Creek	86.1

2.7 COFFS HARBOUR ESTUARIES

Bonville, Boambee, Coffs Harbour and Moonee are typical barrier estuaries and range between salt wedge types and those that are partially mixed. The four estuaries are the largest estuaries in the Coffs Harbour local government area and have a range of human activities, from agricultural and rural pursuits through to urbanised and industrial activities, within the catchment. Each creek has its own runoff issues and potential impacts.

2.7.1 BONVILLE CREEK AND CATCHMENT

The catchment boundary of Bonville Creek is portrayed in the attached diagram outlined in red, identified as Creek Catchment Boundary.

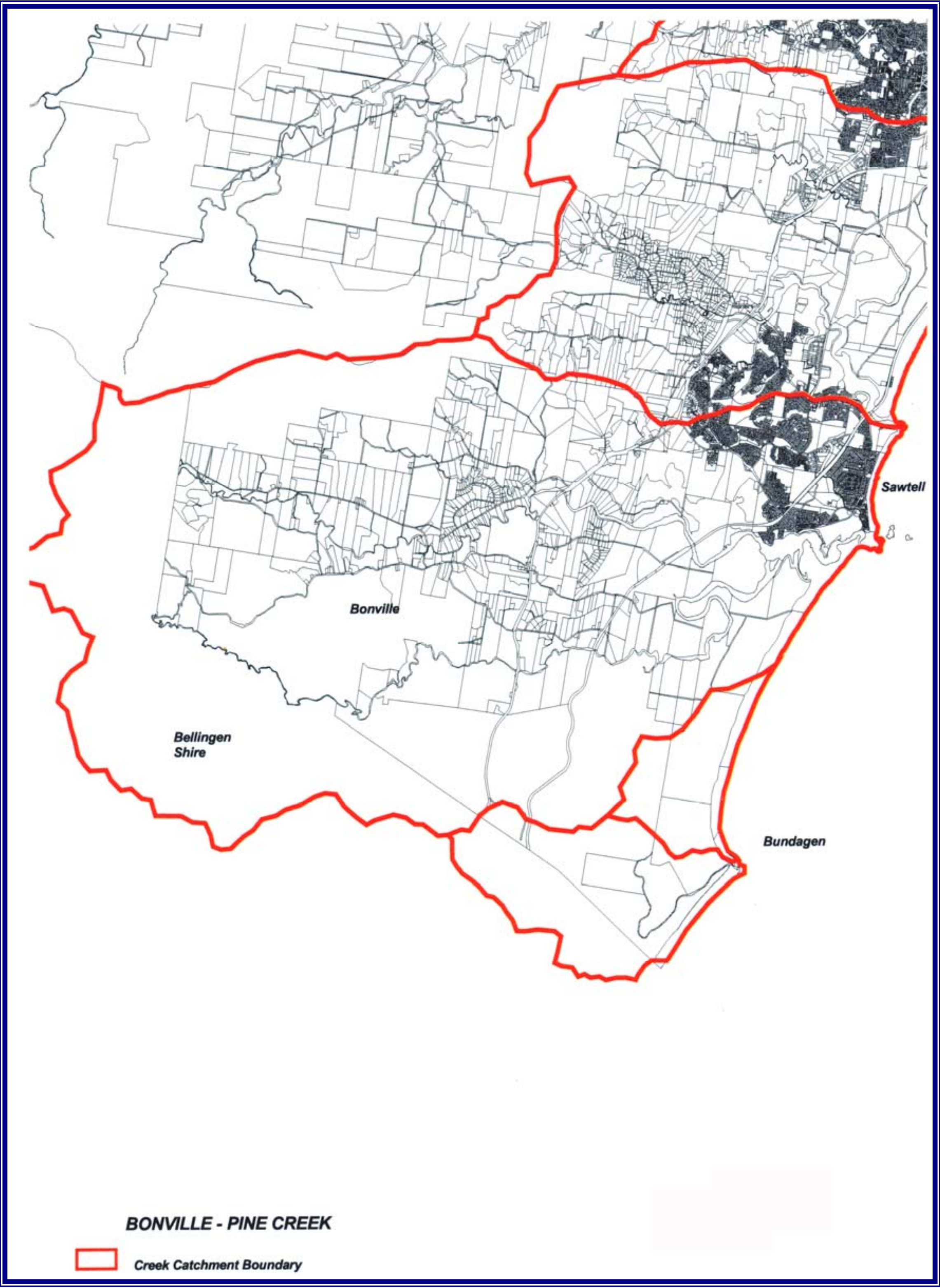


Figure 2-5 – Bonville Creek Catchment
Catchment boundaries, position of creek and property boundaries are depicted, indicating density of settlement

Table 2-3 - Coastal Creek Catchments detailing catchment area relative to creek length (metres) to tidal limit

BONVILLE/PINE CREEK	Catchment area		11,627 ha
	Entrance	Tidal Limit	8,846 m
	Pine Creek	Tidal Limit	7,963 m
BOAMBEE/NEWPORTS CREEK	Catchment area		5,074 ha
	Entrance	Tidal Limit	6,155 m
	Newports	Tidal Limit	5,586 m
	Cordwells	Tidal Limit	1,217 m
COFFS CREEK	Catchment area		2,510 ha
	Entrance	Tidal Limit	5,970 m
MOONEE CREEK	Catchment area		4,213 ha
	Entrance	Tidal Limit	7,141 m
	Skinners Creek	Tidal Limit	1,622 m

Table 2-4 - Coastal Creek catchment areas and primary uses. Total area in hectares (ha) relative to primary uses such as rural to urban (CHCC, 1999)

NAME	CATCHMENT AREA (HA *)	PRIMARY USES
Moonee	4,213	Rural, Residential, Bushland
Coffs	2,510	General Urban, including Residential, Industrial and some Bushland
Boambee	5074.9	Rural, Industrial, Residential, Bushland
Bonville	11627.7	Rural, Residential, Bushland

Table 2-5 - Estimated Areas and Nutrient Loads in Coastal Catchments (CHCC, 1999)
Projected loading of nitrates (N) and phosphates (P) with estimated areas of agriculture, urban and forestry pursuits.

Catchment	Total Area km^2	Estimated area, ha			Estimated runoff t/a	
		Agriculture	Urban	Forest	N-Load	P-Load
Moonee	42	1890	210	2100	18	1.0
Coffs	25	1250	1125	125	19	1.7
Boambee	51	2550	1020	1530	30	2.1
Bonville/Pine Creek	120	1680	720	9600	33	2.2

The Bonville/Pine Creek catchment area is 11,627 hectares, with a creek entrance to tidal limit of 8,846 metres (Table 2-3). The primary uses of the coastal creek catchments in area are: rural (including agriculture), residential and bushland (Table 2-4) (CHCC, 1999). Table 2-5 provides the area of use (in hectares) and an estimated nutrient runoff loading (tonnes per annum) with respect to catchment size which is an important consideration in determining catchment impacts.

Of particular importance is the cross sectional profile of the catchment which indicates heights of up to 550 metres, 30 kilometres from the coast, dropping rapidly to a flat coastal plain, this has significance with respect to stormwater and runoff (Figure 2-6).

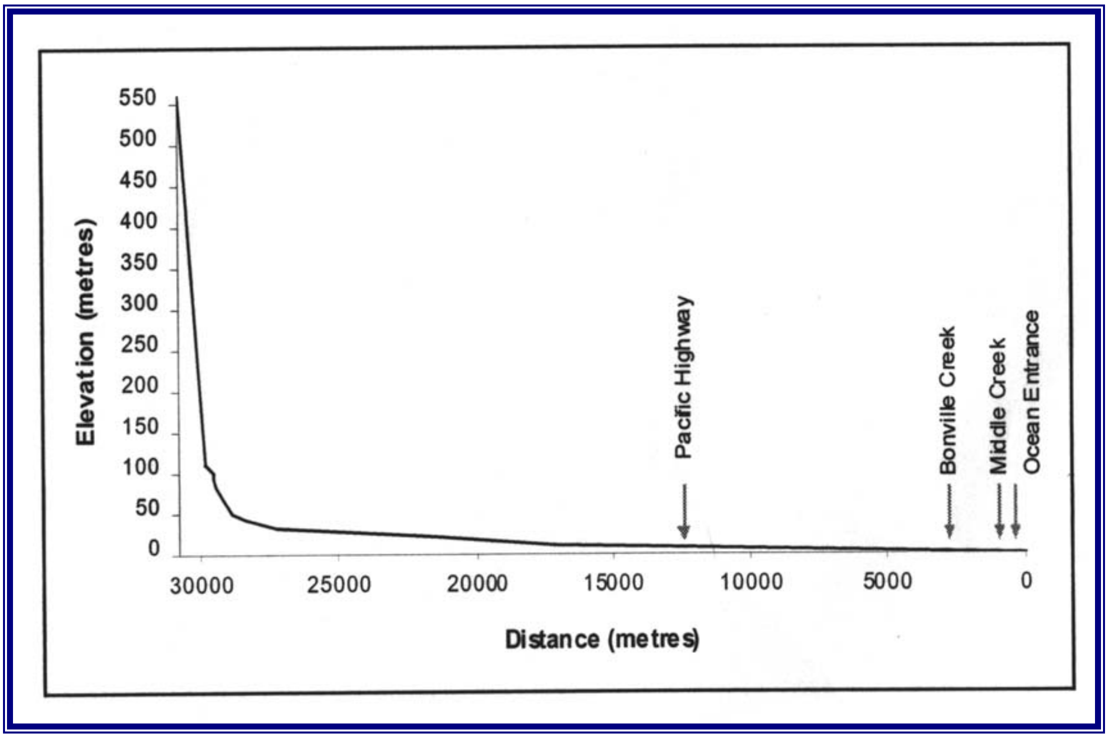


Figure 2-6 - Bonville catchment cross sectional profile (CHCC, 2000)
The steep drop off from the Great Dividing Range to the coastal plain is quite evident. This catchment evidences the largest coastal plain with the coastal range the greatest distance from the sea.

2.7.2 BOAMBEE CREEK AND CATCHMENT

The Boambee Catchment is outlined in the attached diagram highlighted as Creek Catchment Boundary.

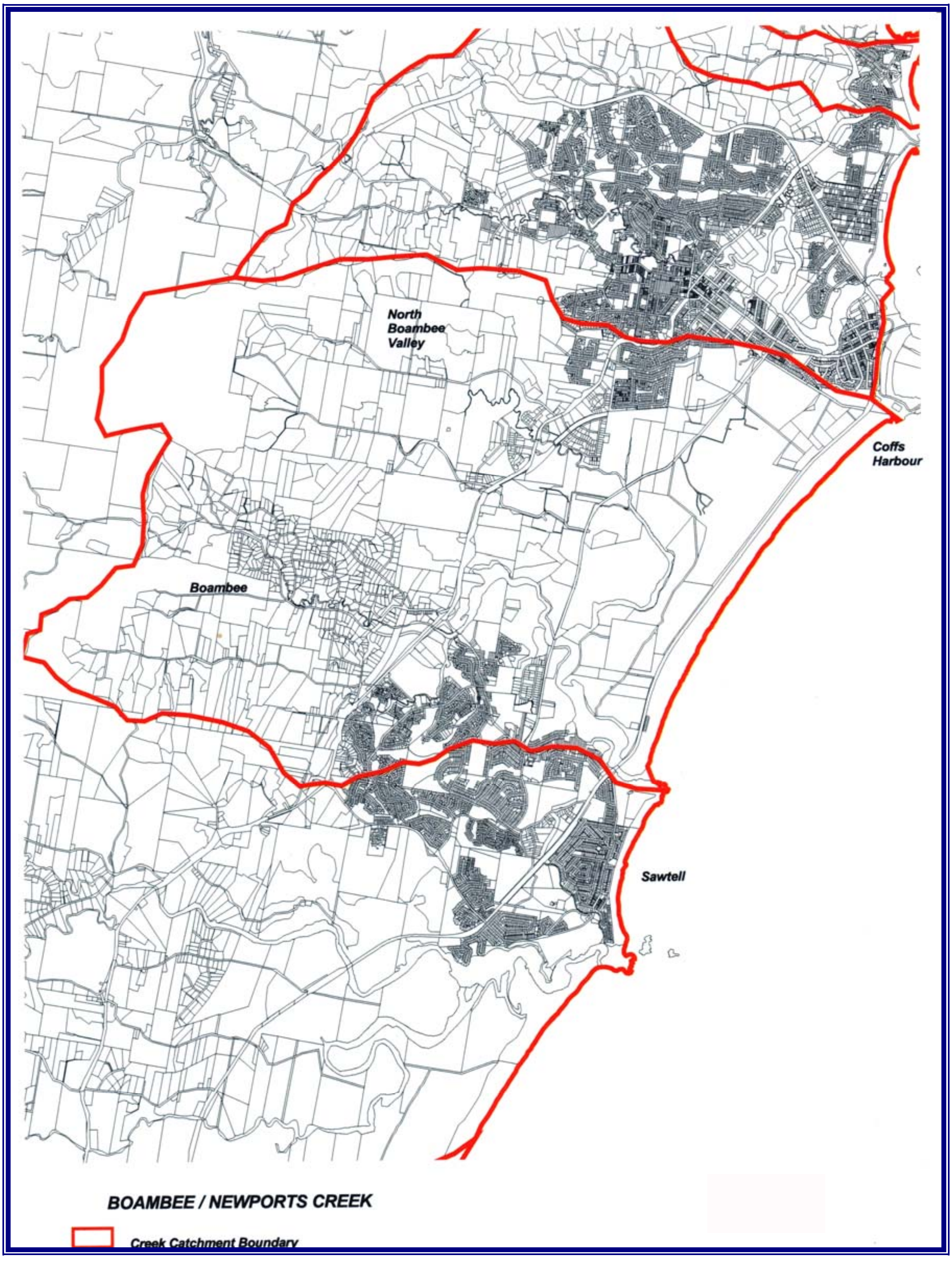


Figure 2-7 – Boambee Creek Catchment
Catchment boundaries, position of creek and property boundaries are depicted, indicating density of settlement.

Boambee catchment has an area of 5,074 hectares with an entrance to tidal limit of 6,155 metres (Table 2-3). Boambee has four primary uses - rural, industrial, residential and bushland (Table 2-4) equating to: 2,550 hectares of agriculture, 1,020 hectares of urban use and 1,530 hectares of forestry in the year 2000 (Table 2-5)

The cross sectional profile is not quite as steep as Bonville, dropping from 200 metres height at the catchment boundary, approximately 15 kilometres from the coast, down to a narrow flat coastal plain, again with significant impacts on stormwater and runoff (Figure 2-8).

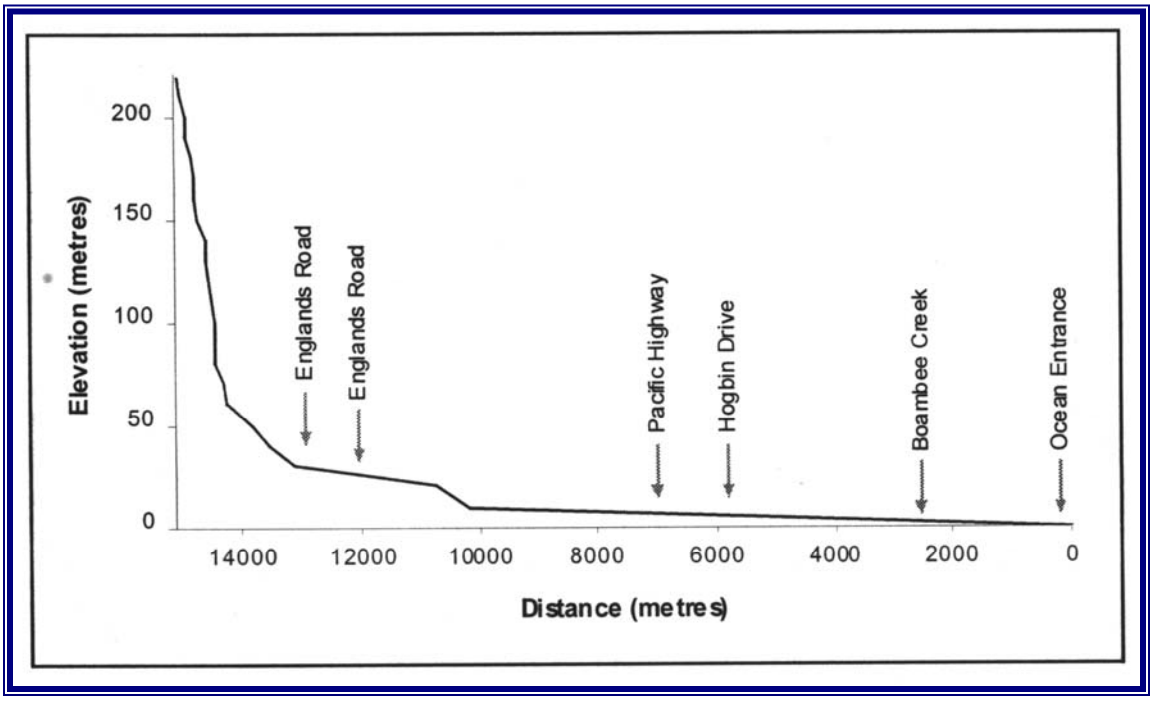


Figure 2-8 - Boambee catchment cross sectional profile (CHCC, 2000). The drop off from the Great Dividing Range to the coastal plain is clearly depicted.

2.7.3 COFFS CREEK AND CATCHMENT

The extent of Coffs Creek catchment is identified in the adjoining diagram outlined in red as Creek Catchment Boundary.

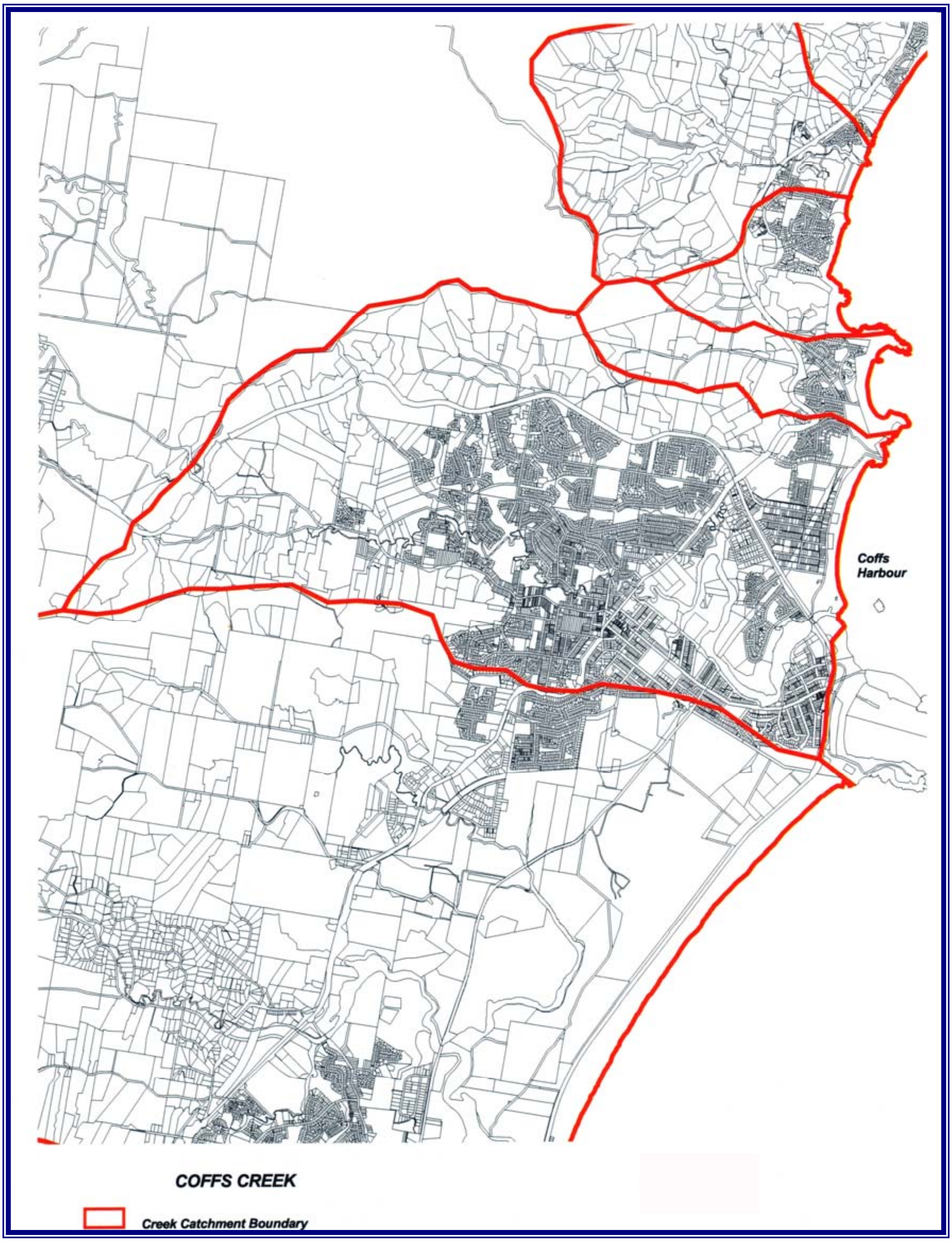


Figure 2-9 – Coffs Creek Catchment
Catchment boundaries, position of creek and property boundaries are depicted, indicating density of settlement

Coffs Creek catchment area is smaller than the other catchments, with a total area of 2,522 hectares and an entrance to tidal limit of 5,970 metres (Table 2-3). The primary uses as identified in Table 2-4 relate to agriculture 1,250 hectares, urban 1,125 hectares and forestry 125 hectares (Table 2-4 and Table 2-5).

The cross sectional profile indicates a height of 200 metres 14 kilometres from the ocean with a similar profile to Boambee, dropping down sharply into a flat coastal plain having significant impacts on stormwater and runoff (Figure 2-10).

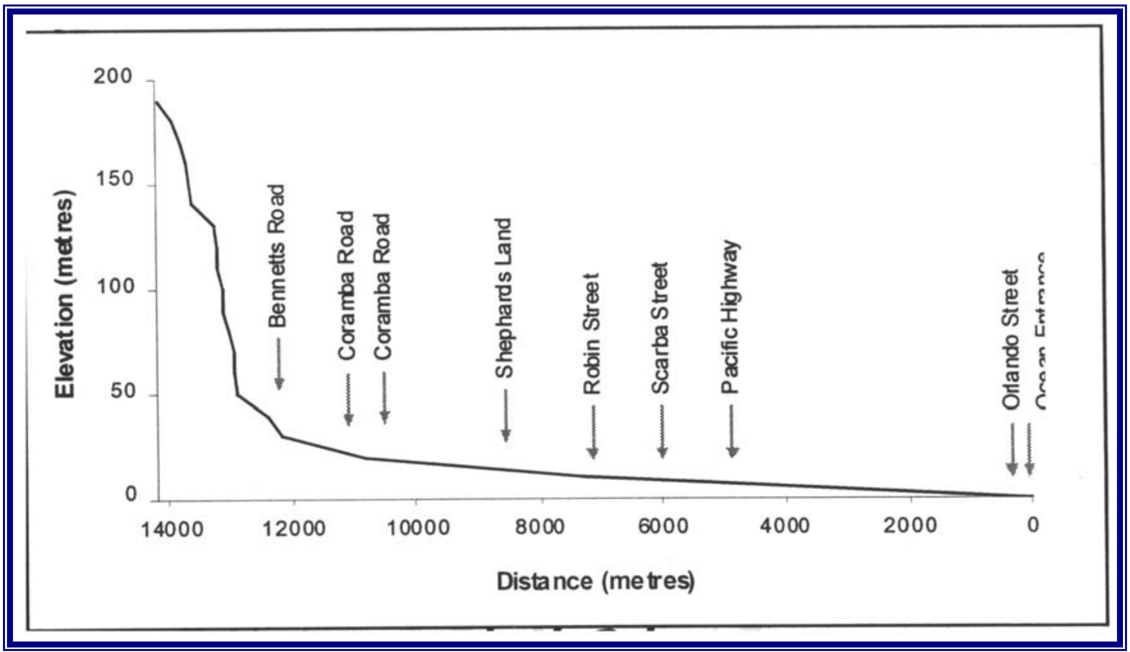


Figure 2-10 Coffs catchment cross sectional profile (CHCC, 2000)
The steep drop off from the Great Dividing Range to the coastal plain is quite evident.

2.7.4 MOONEE CREEK AND CATCHMENT

The catchment boundary is identified in red in the following diagram.

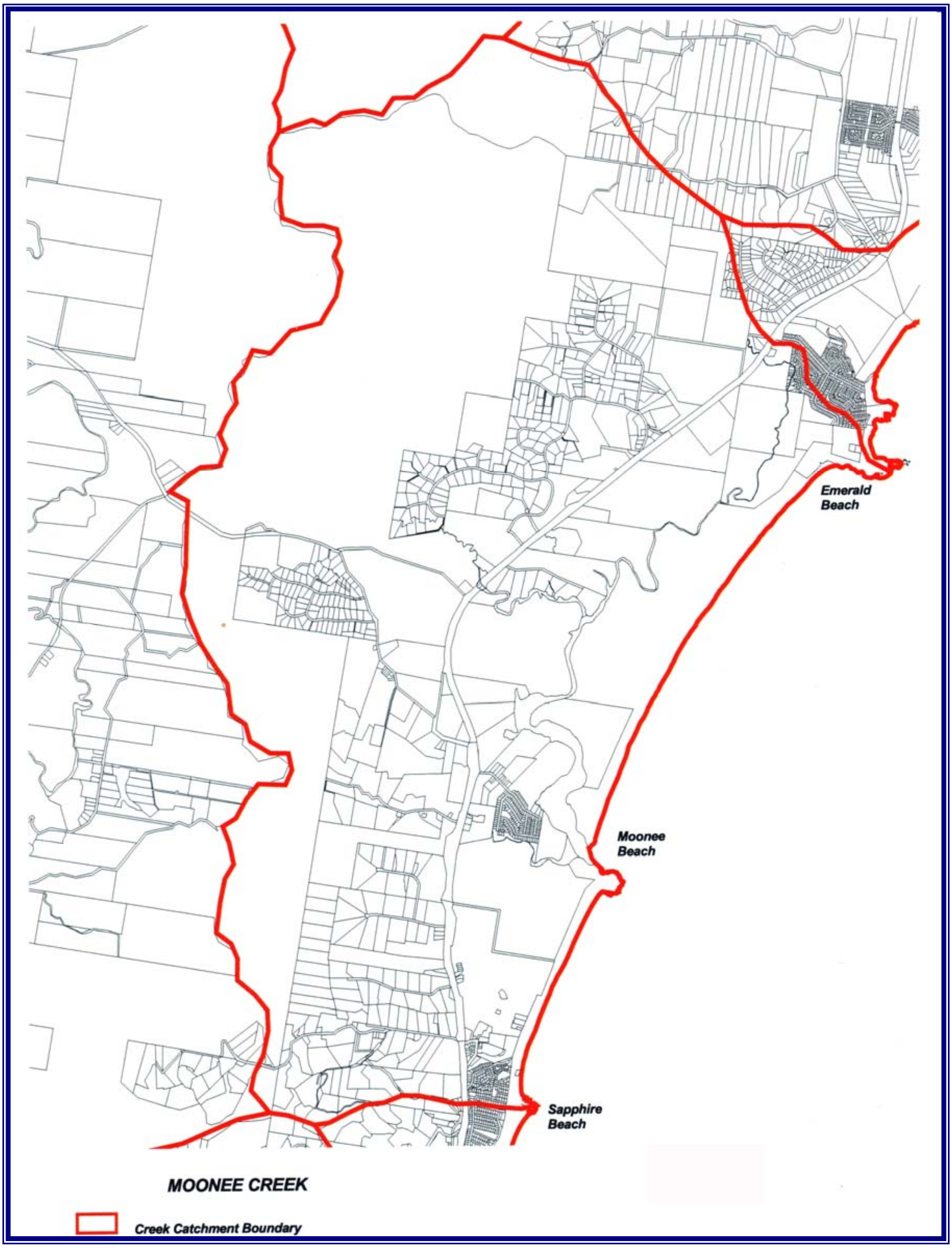


Figure 2-11 – Moonee Creek Catchment
Catchment boundaries, position of creek and property boundaries are depicted, indicating density of settlement.

Catchment area of Moonee is 4,213 hectares. Entrance to tidal limit is 7,141 metres ((Table 2-3). Primary uses as indicated by Table 2-4 are rural, residential and bushland with estimated areas and nutrient loads relating to 1,890 hectares pf agriculture, 210 hectares of urban and 2,100 hectares of forestry (Table 2-5)

The cross sectional profile of the catchment is less steep than Coffs and Boambee, still in excess of 200 metres in height, approximately 14 kilometres from the coast, dropping rapidly into a narrow coastal plain (Figure 2-12).

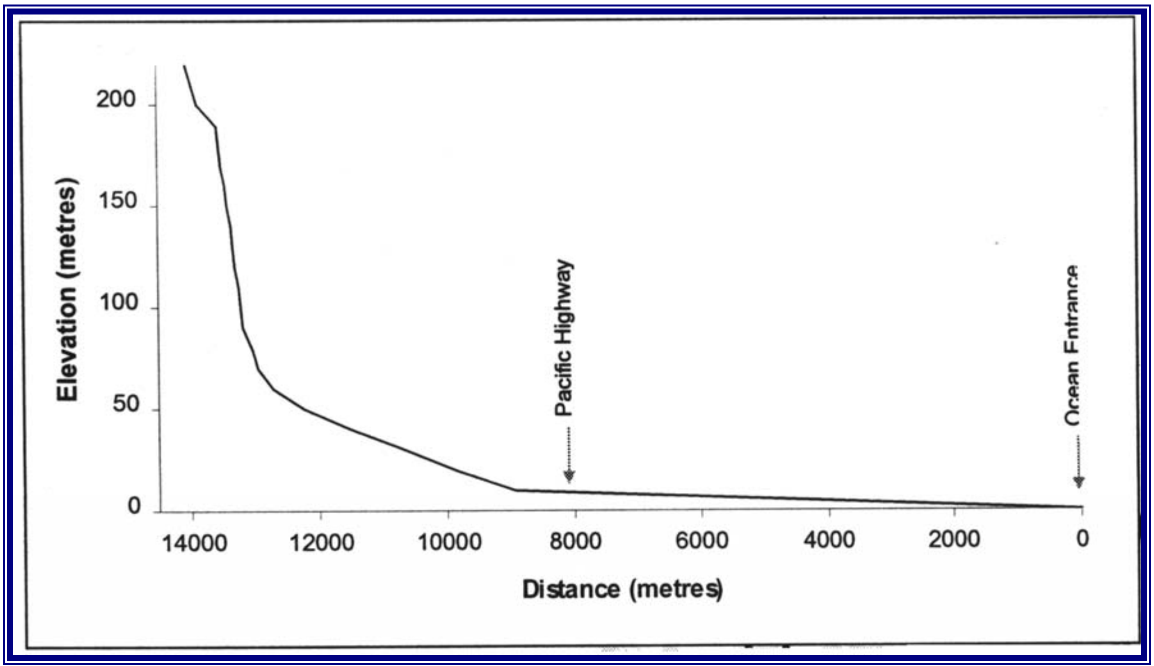


Figure 2-12 Moonee catchment cross sectional profile (CHCC 2000)
The drop off from the Great Dividing Range to the coastal plain is clearly evidenced though closer to the coast and less steep than other catchments.

3 ESTUARINE MONITORING AND RESEARCH

3.1 COMMUNITY ANALYSIS

3.1.1 COMMUNITY STRUCTURE AND COMPOSITION

Two main themes are apparent in estuarine systems which are:

1. Inter-relationships and
2. Interdependencies

The biotic community interacts with the physical environment creating a flow of energy which in turn produces clearly defined biotic structures. These structures induce the cycling of materials between living and non-living parts creating an ecological system or ecosystem (Recher et al. 1986).

The study of estuarine ecosystems involves an understanding of energy flows and the detrital food chain, habitats, species diversity and abundance and the pressures which create change within the environment. Begon et al. (1986) explains diversity within communities as a result of:

a) there being no homogenous environments within nature

b) then most, perhaps all, environments contain within them gradients of conditions (spatial or temporal), or of available resources, and

c) which then allows existence of one type of organism in an area which immediately diversifies it for others.

Luh and Pimm (1993) indicated that the creation of models of community assemblage takes static food web structures or a sequence of food web structures then adds population dynamics to the structure and so create models of community composition. Ecological communities do not spring into existence fully formed, rather they develop through a process that is called community assembly. A community is an assemblage of interacting animals which share a common environment with the boundaries of the community being limited to species living together in the same place at the same time (Recher et al. 1986).

The aim of community ecology is to explain the patterns of natural assemblages of organisms. Patterns can be detected by making comparisons among features of natural communities within or between those systems (Ardisson et. al. 1990).

Species richness, diversity and relative abundance will be primary factors in the analysis of data in this study.

Of relevance to this study is the question: does species composition of a community persist or does it cycle, and if so, through what recognisable states or through what complex sequence that may appear superficially random? Issues of perturbation and impacts introduces the concepts of “K” dominant species which are long-term or older organisms compared to “r” dominant species which relate to short-term, at times opportunistic species such as *Capitella.*

Benthic communities, in broad terms are the assemblage of bottom dwelling species at a particular place and time. Benthic community structure can be influenced by many variables, such as the nature of substrata, physical, chemical and environmental processes, localised disturbances, recent evolutionary history of the community, recruitment and settlement dynamics (Deeley and Paling, 1999).

Community ecology considers groups of populations of different species in one area. Whereas populations have properties such as size, birth rates and death rates, which are not properties of individuals, communities have properties such as species diversity, which are not properties of populations. Community ecology focuses on interactions among populations.

Hutchings (1999) found that the spatial distribution of benthic macrofauna is generally patchy, the spatial scales and species composition together with the local distribution of benthic macrofauna relate to other physical factors such as currents, wave actions and sediment characteristics, salinity and depth. Also chemical factors such as dissolved oxygen and biological factors such as predation and competition come into play. Deeley and Paling, (1999) further state that the distribution of the macrobenthos in the sediment column relates to the successional development of the benthic community, that is a continuous process of recruitment, population growth, predation and death.

In the marine environment concerted effort has been directed to the study of infaunal macrobenthic communities because:

1. The organisms are sedentary, thus reflecting local conditions;
2. The lifespan of many species allows community structure to integrate and reflect sources of stress over time;

3. Many species reside at the sediment/water interface where many pollutants concentrate; and
4. These communities are taxonomically diverse consisting of species that exhibit different tolerances to stress (Dauer et al. 1992; Dauer, 1993).

Though each of these generalisations is likely to be compromised to varying degrees in different habitats and by specifics of program design (sieve mesh size, degree of taxonomic resolution, sample size, sample frequency, etc.) the description of macrobenthic community structure remains an integral part of many environmental assessment schemes (Jones et al. 1986; Jones, 1987; Edgar et al. 1994; Jelliffe, 1997).

A macrobenthic community, for example, subject to increased organic loading, either spatially or temporally will exhibit:

1. A decrease in species richness and an increase in total number of individuals as a result of the high densities of a few opportunistic species.
2. A general reduction in biomass, although there may be an increase in biomass corresponding to a dense assemblage of opportunists (for example, *Capitella*).
3. A decrease in body size of the average species or individual.
4. A shallowing of that portion of the sediment column occupied by infauna.
5. Shifts in the relative dominance of trophic guilds (Pearson and Rosenberg, 1978).

The term “stress” refers to any physical or chemical factor (s) that restricts recruitment, growth or survivorship of individuals or populations of species, thereby affecting the composition of the macrobenthic community (Bilyard, 1987; Dauer, 1993). Communities and therefore organisms subjected to stress eventually change (Bilyard, 1987).

Impacts on an estuarine system, particularly the macrobenthos, result from numerous sources, one of importance is organic enrichment. Sequential changes in benthic communities under the influence of progressive organic enrichment of the marine environment occur (Pearson and Rosenberg, 1978) and give rise to a change in the type of species and total abundance (Figure 3-1).

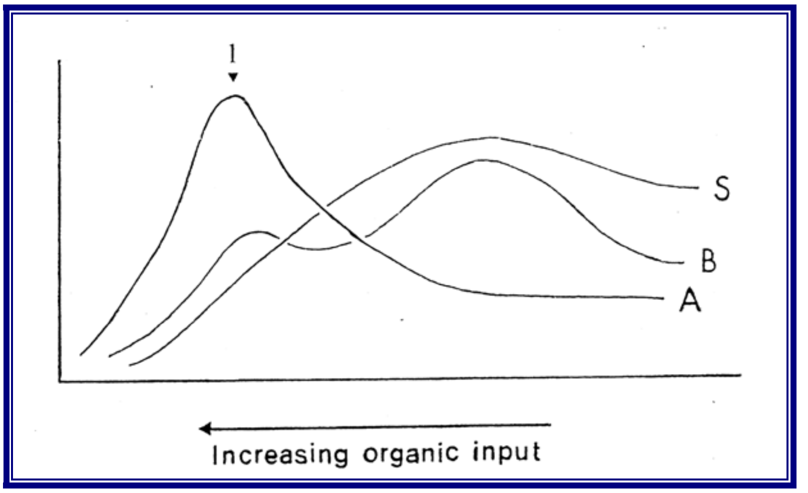


Figure 3-1 Generalised species-abundance-biomass (SAB) diagram showing the change along a gradient of organic enrichment.

In an organically polluted environment there tends to be a transient increase of abundance and a decrease in species and biomass. S. species number; A. total abundance; B. total biomass; 1, abundance contributed to by an increase in opportunistic species. Modified from Pearson and Rosenberg (1978)

Benthic organisms are very sensitive to habitat disturbance including organic enrichment of the sediments and contamination of the sediments by toxic substances (Pearson and Rosenberg, 1978). Their responses to sediment contamination facilitates the spatial definition of impacts (Gray, (1980) cited in Bilyard, (1987)).

Bilyard (1987) further explains that benthic infauna are superior to many other biological groups that could be monitored, eg., plankton, fish and marine birds, because they are sedentary and must adapt to environmental stress or perish. Monitoring of benthic infauna is necessary to establish the magnitude, spatial distribution and temporal distribution of anthropogenic impacts in the receiving environment.

Estuarine health is arbitrarily defined by prevailing community attitudes and values. The definition of estuarine "health", as modified by Nicholson and Mansbridge (1996 p.2) is used in this study; "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organisation as comparable to that of the natural habitat of the region as possible". Numerous indices are available to examine community structure. Most measure the aspects of abundance and species richness which are often highly correlated with changes in the total community.

Analysis of community structure can therefore be roughly divided into univariate methods (for example, diversity indices), graphical methods from which numerical indices can be derived visually, and multivariate methods (Deeley and Paling, 1999). For example, utilising non-metric multi-dimensional scaling (nMDS) (Clarke and Warwick, 1994).

It needs to be realised that in the design of any sampling program, despite the many and varied methods used, data collected will have two features in common.

1. All are subject to problems of inaccuracy and imprecision arising from the application of the sampling methods.
2. Ecologists are constrained by time and funding which restrict the placement and numbers of samples taken (Andrew and Mapstone, 1987).

The primary aim in determination of abundance is to estimate the number of organisms in one area and secondly to examine the differences between the areas.

Hutchings (1999) in relating to the history of Australian taxonomic research on marine benthic fauna of estuaries and marine protected waters, states that until the 1960's studies tended to concentrate on fish, larger molluscs and decapods with little attention being given to less conspicuous but very diverse groups such as peracarid crustaceans, smaller molluscs and polychaetes. In the 1960's an increasing environmental awareness led to the development of baseline and long-term monitoring programs based in the vicinity of capital cities (Hutchings, 1999). This trend has recently been turned around by the scientific investigation of ecosystems in Regional Australia.

The analysis of anthropogenic activities and their effects on estuarine health together with its contribution to shifting community structure, diversity and abundance is widely used for the detection and monitoring of impacted estuarine systems (Warwick, 1993). Monitoring at an ecosystem level is spatially, temporally, strategically and financially unattainable and thus community assemblages are used as an ecologically indicative study unit for practical purposes (Warwick, 1993).

These community studies usually aim at examining one component of the biota (eg. Waterbirds, fish or invertebrates), with assumptions made that the performance of that component is a general reflection of the system itself.

An analysis of the macrobenthic communities is important with respect to commercial dependencies of marine fish species and the overall vigor of the estuary.

From the available literature, it is obvious that the macrobenthic communities depend on the provision of detritus into the system, generally from sources of estuarine vegetation such as mangroves, seagrass and saltmarsh (West, 1985; Adam et al. 1992). It is thus logical to assume that any impact on this estuarine vegetation could impact on the macrobenthic communities. An analysis of human settlement patterns and any changes in the estuarine vegetation associated with these estuaries is therefore necessary for the interpretation of estuarine function.

3.1.2 SAMPLING OF SOFT SEDIMENT BENTHIC COMMUNITIES

Maher et al. (1993) indicates that in the review of environmental surveys and monitoring programs, financial and human resources have been wasted through the poor standard of professional practice in their design and implementation. They found that these studies are data rich and information poor. Jones (1997), provides a description of estuaries and sampling apparatus used for major comparisons. The different sampling devices have a range of applications with grabs having application across a range of depth (Table 3-1). Corers are generally used in shallow habitats unless SCUBA is used.

Table 3-1 Grabs/corers used in Botany Bay (Jones, 1997)

ESTUARY	CLASSIFICATION (Roy 1984)	STUDY	SAMPLING			SEDIMENTS	SALINITY ‰	DEPTH (m)
			DATES	APPARATUS	INTENSITY			
BOTANY BAY	open ocean embayment	Australian Museum 1993	*April'92 *July'92	Smith-McIntyre grab 0.05m^2	6 sites x 3 subsites x 2 times n = 5	mud⇒sand (range: 5-63% mud, mean = 22% mud)	marine	6⇒10
BOTANY BAY	open ocean embayment	Jones & Candy 1981	Nov'76 ⇓ Jan'77	corer 19cm diameter	9 sites x 1 time n = 10	mud⇒sand	marine	2⇒21
JERVIS BAY	open ocean embayment	Hutchings & Jacoby 1994 *(vegetated sites excluded)*	Feb'89 ⇓ June'91 (3-month intervals)	Smith-McIntyre grab 0.06m^2	6 sites x 9 times n = 5	muddy sand	marine	*12 *20
PITTWATER	drowned river valley	Rose 1994	*April'92 *Dec'92	Smith-McIntyre grab 0.05m^2	4 sites x 2 subsites x 2 times n = 4	mud (range: 50-95%, mean = 75% mud)	30 - 33	10⇒14

Description of estuaries and sampling used for major comparisons. (The arrows indicate a range of sediment grades and depths and sampling over a period of time rather than at specific months (as indicated by the *)

The acquisition of representative soft bottomed samples is the fundamental pre-requisite for much research in aquatic ecology and environmental science. McLusky (1974) states that a corer is most useful for quantitative studies of intertidal estuarine substrates, whereas a small grab (Figure 3-2) is vital for collecting animals from areas which are never exposed by the tide. The use of trawls, dredges, suction samplers, snap grabs (e.g. clam shell) of scoop design and corers of impact or hydrostatic type result in various degrees of semi quantative sampling only. In practice bucket grabs provide reasonably accurate quantative sampling of soft bottoms and achieve the most rectangular bite, particularly the Van Veen grab (Blomquist, 1991) (Figure 3-2).

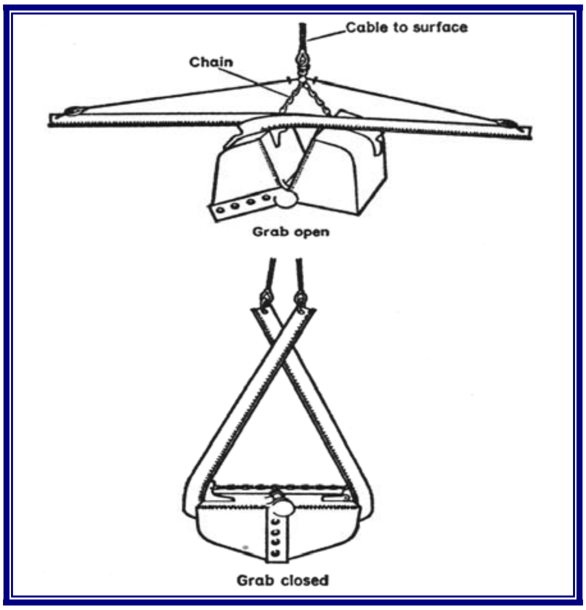


Figure 3-2 - Grab Sampler (McLusky, 1974)

The Van Veen grab was utilised from a boat and was purpose built, this made sampling from the middle of the creek possible at depth, SCUBA methods were not possible. Each biological sample in the study comprised 0.07m² Van Veen grab, all samples required retrieval from a depth ranging from 0.5 to 3.0m. Benthic macroinvertebrates are commonly defined by the sieve size on which they are retained and can be classified into micro (<0.38Um), meio (0.38Um - 500Um (0.5mm)), macro (0.5-200 millimetres) and megafauna (> 200 millimetres components) (Deeley and Paling, 1999).

For pollution studies, identification to family results in information comparable to that obtained from species level data (Smith and Simpson, 1993).

This immediately reduces the necessity for extensive and tedious identification to species level. While accurate community estimates are obtained using smaller mesh sizes (e.g. 0.5 millimetre), the cost and time taken to sample is increased substantially (Schlacher et al. 1996). When using a mesh size of 1 millimetre, animal retention is reduced compared to that of an 0.05mm sieve, this results in the loss of some information, however this information loss needs to be considered as a balance between desired accuracy, practicality and the cost effectiveness of sampling using a 1 millimetre aperture.

Material of the samples were retained on a 1 millimetre sieve, preserved in 10% formalin, thence 70% alcohol, with polychaetes, crustacean and molluscan specimens sorted, identified and counted under a stereomicroscope in the laboratory (Hutchings and Murray, 1984).

3.1.3 ANALYSIS OF SEDIMENT GRAIN SIZE

Sediment particle size is known to influence benthic community structure and its composition (Gray, 1981; McLusky, 1974). In linking sediment structure to community composition, granulometric analysis was carried out for each site in each creek, the aim being to achieve grain size similarities for all sites within the 4 creek systems. Whilst field sampling was undertaken sediment samples were also taken for grain size analysis. For each site 500g of oven dried sediment was weighed and placed in a series of sieves with apertures corresponding to the Wentworth scale (Table 3-2). One sample per site was taken on the basis that initial observations indicated that sediment characteristics were homogeneous within a site.

Standard methods were followed whereby the sieves were mechanically shaken for 10 minutes to separate the sample into distinct size classes. Sediment in each sieve was then weighed and calculated as a percentage of the original sample weight. The information was then graphed cumulatively in order to obtain sorting co-efficients which give an indication of grain size complexity (Table 2-1).

Percentage sediment to pass through the smaller sieve aperture (that is 0.063mm) was considered silt clay fraction and was not treated further. Mean particle size was then calculated using weighted means., this data provided an important single value which could be used in the calculations of environmental data for correlations with the benthic data. A series of six sieve sizes were used to process all sediment samples (<0.063; 0.063; 0.125; 0.25; 0.5 and 1mm).

Size is considered as the dependent variable, to this end the Wentworth Gray classification was utilised (Table 3-2). Using Australian Standard apertures which operate on the percentage retained, which is then categorised into various denominations of silt and clay to cobble.

Table 3-2 The Wentworth scale of grain size characteristics and description ($ø = -log_2$ of the particle size in mm)

GRAIN SIZE (mm)	PHI (ø) SCALE	SEDIMENT TYPE
256mm	-8	cobble
64mm	-6	cobble
16mm	-4	pebble
4mm	-2	pebble
2mm	-1	granule
1mm	0	very coarse sand
0.5mm	1	coarse sand
0.25mm	2	medium sand
0.125mm	3	fine sand
0.063mm	4	very fine sand
<0.063mm	5-14	silt and clay

3.2 PHOTOGRAMMETRIC DATA CAPTURE AND INTERPRETATION

Photogrammetry is the science of obtaining spatial data from photographs and is accepted as an alternative to traditional land survey techniques for many survey applications (per. com. R. Dwyer). Using modern stereo plotting instruments, broadscale topographic mapping can be undertaken, (usually at a significantly reduced cost) with accuracy comparable to that obtained using land survey techniques, that is, plus or minus 0.1 of a metre in plan and height (Hanslow et al. 1997). Many studies have utilised the interpretation of aerial photography for not only information, study or evaluation purposes, but particularly for high level information related to legislative reform or change. The data produced can be of relevance in many areas of ecosystem and environmental management.

The application of photogrammetry as an interpretive and data management tool has dramatically increased over the last 15 years. For example: West et al. (1985) provided “An Estuarine Inventory for NSW”; Adam et al. (1985) mapped SEPP14 wetlands; and Sawtell (1994) interpreted the previous banana agriculture areas for the Coffs Harbour City Council Contaminated Land Policy which identified areas requiring soil tests for chemical residues.

McTainsh et al. (1986) utilised the interpretation of aerial photographs to study changes in spatial and temporal patterns in mangroves for the period 1944 to 1983 in the South Queensland area, whilst Edgar et al. (1999) documented ecological and physical attributes, population and landuse in Tasmanian estuaries (this assessment relied heavily on aerial photographic interpretation with utilisation of a geographic information system (GIS). Bucher and Saenger (1994) utilised vegetation maps produced from aerial photographs to classify tropical and sub-tropical estuaries, whilst Saintilan and Williams (2000) utilised aerial photographs of the south east coastline to interpret decline of saltmarsh in south east Australia. Aerial photographs classifying land use based upon the degree of disturbance of natural vegetation and the intensity of agricultural usage were interpreted by Atkinson et al. (1981).

Wilton and Saintilan (2000) have outlined protocols for inventory and monitoring mapping, in particular of mangrove and saltmarsh habitats. These study protocols identified: a preferred scale of mapping relative to identification of habitat change; distortion, georectification and ground control points; and a classification system for mangrove and saltmarsh habitat delineation.

This study utilises stereoscopic photogrammetric interpretation of aerial photographs to assess changes in estuarine vegetation, in particular mangroves, seagrass, saltmarsh and sedge/coastal heath. The same technique was used to assess changes in human settlement patterns identify housing, roads, tracks, paved areas and agricultural areas for the period 1954 to 1994.

3.3 DESIGN OF THE STUDY

3.3.1 LAYOUT, STATISTICAL DESIGN AND ANALYSIS

The basic design of the study was guided by the work of Green (1979) which stated that in an environmental study there should be a logical flow: purpose → question → hypothesis → sampling design → statistical analysis → test hypothesis → interpretation and presentation of results. Green (1979) further states that proper statistical methods should be used but the biologically defined objectives should be dominant and utilise the statistics rather than the reverse. The reliability of data was considered in the light of work by Andrew and Mapstone (1987) who identified the need for accuracy and precision analysis, particularly giving guidance with respect to inaccuracy which could result from inappropriate design. As up to 80 separate samples were planned for each sampling period, estimates of abundance and relative abundance were important considerations.

The usefulness of an estimate is dependent on the precision as well as its accuracy. Accuracy can be interpreted as the closeness of a measurement/estimate to the true value of the variable being measured, whereas precision is the degree of concordance amongst the number of measurements or estimates for the same analyses. Precision increases as variability decreases. It has been found that natural populations, are spatially variant and generally not regularly or randomly distributed but aggregated (Andrew and Mapstone, 1987). This relates to considerations of the presence or absence of organisms relative to location, such as open sandy bottoms versus seagrass beds. Variation amongst the sample data depends upon the size of the sampling unit relative to the scale of aggregation.

Obviously as the size and number of replicates increases so too does the cost. Initial surveys should consider the cost benefit analysis with respect to the application of resources. The pilot study in 1996 utilised seven sites each with three replicates.

Andrew and Mapstone (1987) further states that apart from considerations such as ensuring sampling programs are appropriate to the questions being asked, there are two procedural questions which need to be addressed empirically if the sampling program is to be efficiently designed.

These are:

1. How big should each sample unit be, and
2. How many replicates are needed.

The analysis of pilot data can indicate relative accuracy and relative precision. It may indicate where best to apply resources and where not to waste resources. Again, the pilot study achieved 84 samples which took five days in the field to gather and over 150 hours to sort, process and identify. This provided the basis for feasibility and achievability.

All sampling designs and optimisation procedures require estimates of variances and all means before the main program has commenced. These estimates can be obtained from three sources:

1. Pilot Studies
2. Previous Studies
3. Published Data

In this case, no previous data were available and previous work in NSW used different methods, for this reason a pilot study was necessary. Once the data were achieved the pilot study utilised non metric multidimensional scaling (nMDS), similarities and dissimilarities were analysed using a similarities percentage (SIMPER) matrix. Decisions on sites, locations and replicates were then made which altered the methodology for the main sampling program. The outcome was four sites with five site replicates across four creeks based on the interpretation that all sites were dissimilar or different.

In general the study took on three facets, or three stages.

Stage 1 - Analysis of macrobenthic communities. Variables of interest generated by the data from the analyses were:

1. Univariate analysis - abundance (N), species richness (S), summary of common species, three way analysis of variance (3 way ANOVA) and multiple comparisons using least significant difference (LSD) were undertaken.

2. Multivariate analysis - this involved an analysis of community structure utilising a range of multivariate methods. These were: non metric multi-dimensional scaling (nMDS); analysis of similarities (ANOSIM); similarity percentages (SIMPER) and biological environmental variables (BIOENV).

Stage 1 followed the format of:

1. Field methods
2. Laboratory methods
3. Data analysis and interpretation

Stage 2 of the study utilised interpretation of aerial photography for areas of estuarine vegetation. The four parameters were Mangroves, Seagrass, Saltmarsh and Sedge Coastal Heath, total areas were mapped. These were then correlated within and across creeks and then cross correlated as a percentage of creek against human settlement patterns, based on percentage catchment coverage.

Stage 3 analysed aerial photography with respect to human settlement patterns. The parameters were: housing, horticulture (bananas), roads (sealed and unsealed), paved areas (industrial) and tracks, calculated as areas and percent catchment cover.

All photogrammetric data were manipulated on a Geographic Information System utilising Arcview GIS.

Stages 2 and 3 followed the format of:

1. Field methods
2. Photogrammetric interpretations
3. Data analysis and interpretation

3.3.2 CONTROLLABLE AND UNCONTROLLABLE FACTORS

Many variables can impact on the study program. An understanding of some of these follow.

3.3.2.1 CONTROLLABLE FACTORS

i) Sieve Mesh Size

There are obvious trade offs between precision, accuracy and practical feasibility all within cost restraints and the questions being asked as the basis of the study, as stated, 1 mm mesh size was used.

ii) Time

Depending at what time of the day the samples were taken will mean whether the same tidal regime is utilised. Daytime may allow predation of some organisms and the feeding may take place at night time.

iii) Tide

All samples were taken at full tide. This allowed for maximum access. The creek area travelled was up to six kilometres, therefore the flat bottom motorised punt allowed for accessability on both the rise and fall from high tide.

iv) Choice of Sampling Device

Blomquist (1991) identified the impacts on sampling devices or limitations. These can take the form of water flow through the device, whether core or grab samples and the following:

a) Disturbance of the sampling during closing of operations,
For example fouling by timber or rock

b) Depths of sediment penetrated.
The type of sediment: clay silty sediments are soft and light unconsolidated organic sediments as compared to consolidated shellgrit or detritus. Generally the samples in this study had a high component of sand.

c) Proximity of repenetration of the grab following failed grabs.
This was an operator dependent issue. Once a failed grab occurred the boat was moved approximately 5 metres.

v) Grab Size and Type of Sediment

This can determine penetration of the grab sampler. The volume of sediment retrieved by the grab can be determined by the softness or otherwise of the sediment to be penetrated, which in turn can affect depth of penetration and therefore the number of species and individuals captured in each grab.

vi) Proximity of Sites to Other Disturbances

Bonville Creek was once the subject of dredging and sand mining in the upper reaches, other creeks are the subject of increased human settlement patterns. Estimation of other disturbance can be very difficult, stormwater discharges and sediment and erosion controls are important.

vii) Proximity to Other Habitats

Closeness to seagrass beds determines the penetration or otherwise of the grab sampler. The grab samples were located away from seagrass beds, however there was considerable data on the proliferation or otherwise of benthic communities within and separate from seagrass beds.

viii) Seasonality

Recruitment can follow seasonal influences. Ideally sampling at each season throughout the year would gain great benefit, however, cost and time restraints would be considerable, this was controlled and affected by the choice of sample times.

3.3.2.2 UNCONTROLLABLE FACTORS IN THE STUDY

i) Estimation of Existing Human Impacts

The degree of human activity dictates the human impacts. For example agricultural activities affect the nutrient and sediment runoff and rainfall erosivity (eg impacting of soil works) adjacent to creeks.

ii) Time Scales

Aerial photography for the four creeks is only available from 1954 epoch for comparative analysis.

iii) Ratio of Creek Lengths

As creek lengths differ a ratio, based on a percentage of lineal length was calculated for the location of all sample sites (7 in pilot study, 4 in consequent sample periods). Some creeks are different in the overall length and therefore catchment size. Overall length was designated as 100%, sample sites were then distributed based on percentage of creek length enabling relativity between sites in different creeks.

4 MATERIALS AND METHODS

4.1 JUSTIFICATION

Estuarine systems are highly productive and as a result are economically and culturally important, especially in terms of the commercial and recreational fisheries which they support (Bucher and Sanger, 1993). An analysis of the macrobenthic communities is important with respect to these dependancies and the overall vigour of the estuary. These are good indicators of estuarine health due to the sedentary nature of the organisms, their life span, their residency at the sediment interface and the different tolerances to stress exhibited by different species, Dauer, (1993).

The initial concept for the study involved sampling design and layout utilising a control estuary, the only estuary which could be utilised as a control was the Wooli River. This catchment is, in the majority, National Park and has experienced less human impact as a result of very little residential, industrial or agricultural development. However, the sheer size of the Wooli River dwarfs the short, narrow coastal estuaries of the study of Moonee, Coffs, Boambee and Bonville, and as such was inappropriate for comparing and contrasting status, health and development. There were no other reference creeks or rivers suitable within the area of geographic interest and accessability.

4.2 SAMPLING TECHNIQUES

4.2.1 BENTHIC COMMUNITIES

Due to the distances to be covered along the four waterways of the study and the difficulties of access in the estuaries such as depth, sand build up, seagrass beds, it was decided to use a grab sampling device as the preferred method of capture for the samples.

As previously discussed a small (0.076m^2) Van Veen grab was considered the most appropriate method for sampling benthic communities (See Plate 4-1). The grab was deployed from a flat bottomed punt using a steel gantry and hand winch, the punt provided seating for rough sorting at the site and an assistant was required each sampling period.

Plate 4-1 Grab Sampler and Boat

The samples were rough sorted in the field through a 1 millimetre sieve with all organisms and residual detrital material in the sample returned to the laboratory for further processing and examination. The resulting fraction of detritus and animals were then preserved. Further sorting of animals was carried out after the whole of the samples had been fixed in the 10% formalin solution for a minimum of 72 hours. Formalin was later removed from all samples and replaced with 70% alcohol. This method results in well preserved specimens, examples of each of the species were compiled with a reference collection for the overall study.

All samples were sorted under a stereo dissecting microscope and, where possible, animals were identified to species level. Where this was not possible animals were identified to the highest possible taxonomic resolution and given a species code. For example, unknown fish species were given the code: Fish Species I. For the most part discrete species were readily identified, however the juvenile shells of *Velacumantus australis* and *Pyrazus* sp. were grouped together as “Family Potomodidae” as they can be easily confused, small capitellid worms were too small to distinguish as either *Capitella capitata* or *Notomastus estuarus* and were thus labelled “*Capitella*”.

4.3 EXPERIMENTAL DESIGN: PILOT STUDY; SELECTION OF STUDY SITES; SITE LOCATIONS AND DESCRIPTIONS

4.3.1 PILOT STUDY - MACROBENTHIC SAMPLING

The objective of the overall study was to determine if different creeks supported different communities and if so, could these be related to levels of human impact within the catchment. In order to ensure that an optimal design was used for the main study, a pilot study was conducted in July to September, 1996.

The main aims of this study were to determine the number of sampling sites required for the larger study and the number of replicates that were required for each site. One of the problems with assessing differences within and between creeks is the fact that the benthic community structure varies across both cross-sectional (i.e. from the bank to the middle of the creek) and longitudinal (i.e. upstream-downstream) gradients (Pearson and Rosenberg, 1978; McLusky, 1989), it is thus essential to standardise sampling across creeks for comparative purposes.

The objectives of the pilot study were to: i) explore the longitudinal variation and nominate specific sampling sites; and ii) to determine how many replicate samples should be taken.

In order to measure longitudinal variation seven sites were established at each of the four creeks. As creek lengths varied, it was not appropriate to use simple linear measurements between sites and instead, sites were established using standardised equivalent distances (Table 4-1). In this approach, the full length of the creek represents 100% and samples are established at the same percentage distances upstream or downstream for each creek. Reference points for measurements were the mouth of the estuary and the upper tidal limit. As Coffs Creek was the location where sampling was most likely to be constrained by available habitat, the equivalent distances were established for this creek first and then applied to the other creeks (Table 4-1). All creeks have different legnths from opening to tidal limit. (Table 2.3).

At each of the seven sites of the four creeks, three replicate Van Veen grab samples (0.076m^2) were taken during the period July to September, 1996.

All sampling was conducted in the centre of the estuary and in a depth range of 0.5m to 3.0m., in order to minimise the effects of cross-sectional variation, samples were taken at high tide. Samples were sieved through a 1mm mesh, sorted and identified to the highest possible level of taxonomic resolution. Standard taxonomic reference keys were used to identify those benthic organisms removed from the sediment (Hutchings, 1984). Data were then explored using a suite of multivariate methods in the PRIMER package (Clarke and Warwick, 1994). Specifically, analyses were conducted to determine: i) overlap between sites, ii) equivalence, similarities or dissimilarities between creeks; iii) the relative precision of the three samples from within each site (i.e. small scale patchiness).

Table 4-1 - Proportional distribution of sites along creek length

This table relates to the ratios applied to Coffs Creek. The percentage of creek was then reapplied to the other three creeks to achieve the proportional distribution along that creek of sample sites. Lower limit is creek entrance, upper limit is tidal reach. Data was drawn from scaled orthophoto maps.

SITE	LINEAL DISTANCE cm entrance to tidal limit.	PERCENTAGE DISTANCE %
1	4.5	10.97
2	8.5	20.73
3	17.0	41.46
4	23.5	57.32
5	29.0	70.73
6	32	78.05
7	37.0	90.2

Table 4-2 - Study Sites 1996 to 1997, 1999

Indicating grouping of similar sites to produce 4 new (dissimilar) sites

1996 Pilot Study		1997 and 1999 Study
Sites 1 and 2	→	Site 1
Sites 3 and 4	→	Site 2
Sites 5	→	Site 3
Sites 6 and 7	→	Site 4

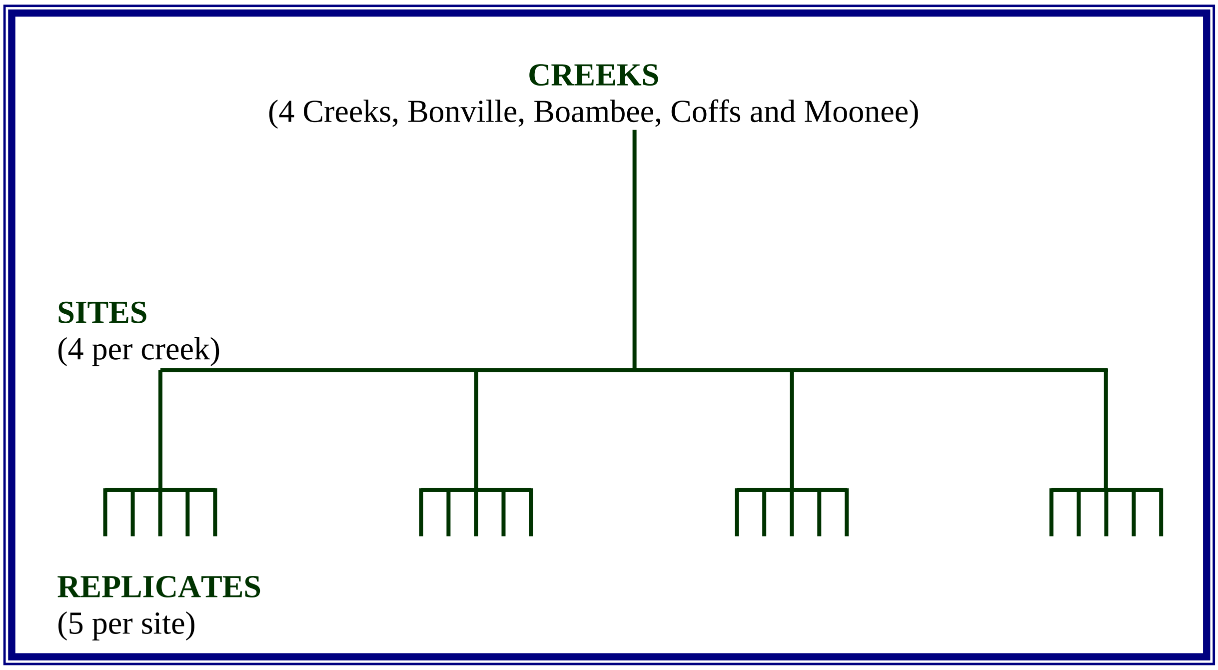


Figure 4-1 - Adjusted design for benthic sampling in 1997 and 1999

Interpretation of the results of the pilot study indicated that the sites at 1 and 2 were similar, as were sites 3 and 4, and sites 6 and 7, at most creeks. For this reason, new sites were established between each of these sites thus reducing the total number of sites to four for each creek (Table 4-2). Using precision analysis five replicates were needed to achieve a precision of $D \leq 0.2$ for total number of individuals (N) and total number of species (S) at most sites and so the number of replicates were increased from three to five for each of the new sites. The new sites were established on the basis of each site bing significantly different.

The new sampling design thus required four sites per creek with five replicates per site, resulting in a total of 20 samples/creek/time, a total of 80 samples per sample time (Figure 4-1). The relative position of sites used in the pilot study and in the subsequent samples in 1997 and 1999 are shown for each creek in Figure 4-2, Figure 4-3, Figure 4-4 and Figure 4-5.

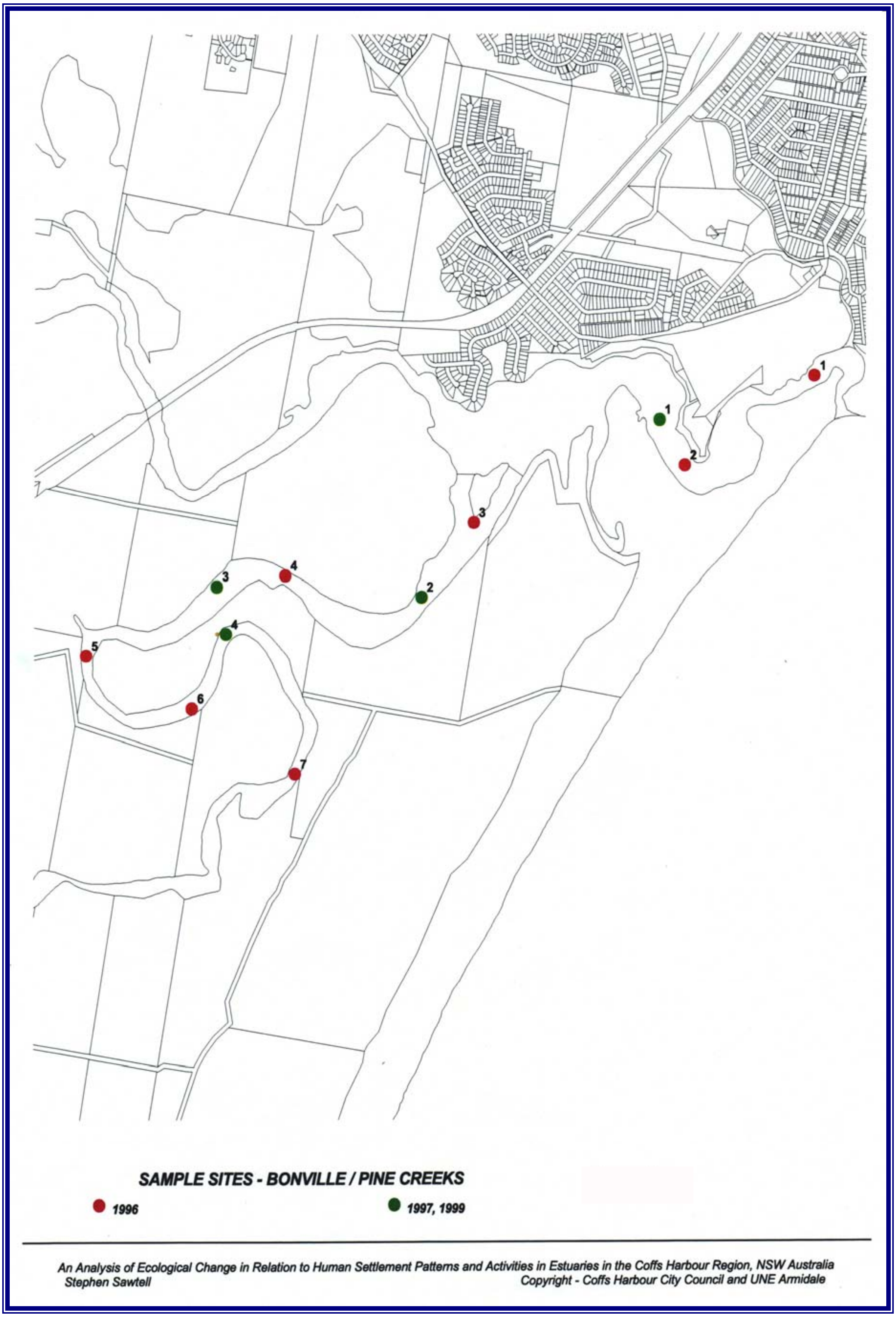


Figure 4-2 - Sample sites 1996, 1997 and 1999 - Bonville/Pine Creeks

Relative position of sampling sites in Bonville/Pine Creeks for the pilot study (1996) and subsequent sampling (1997/1999)

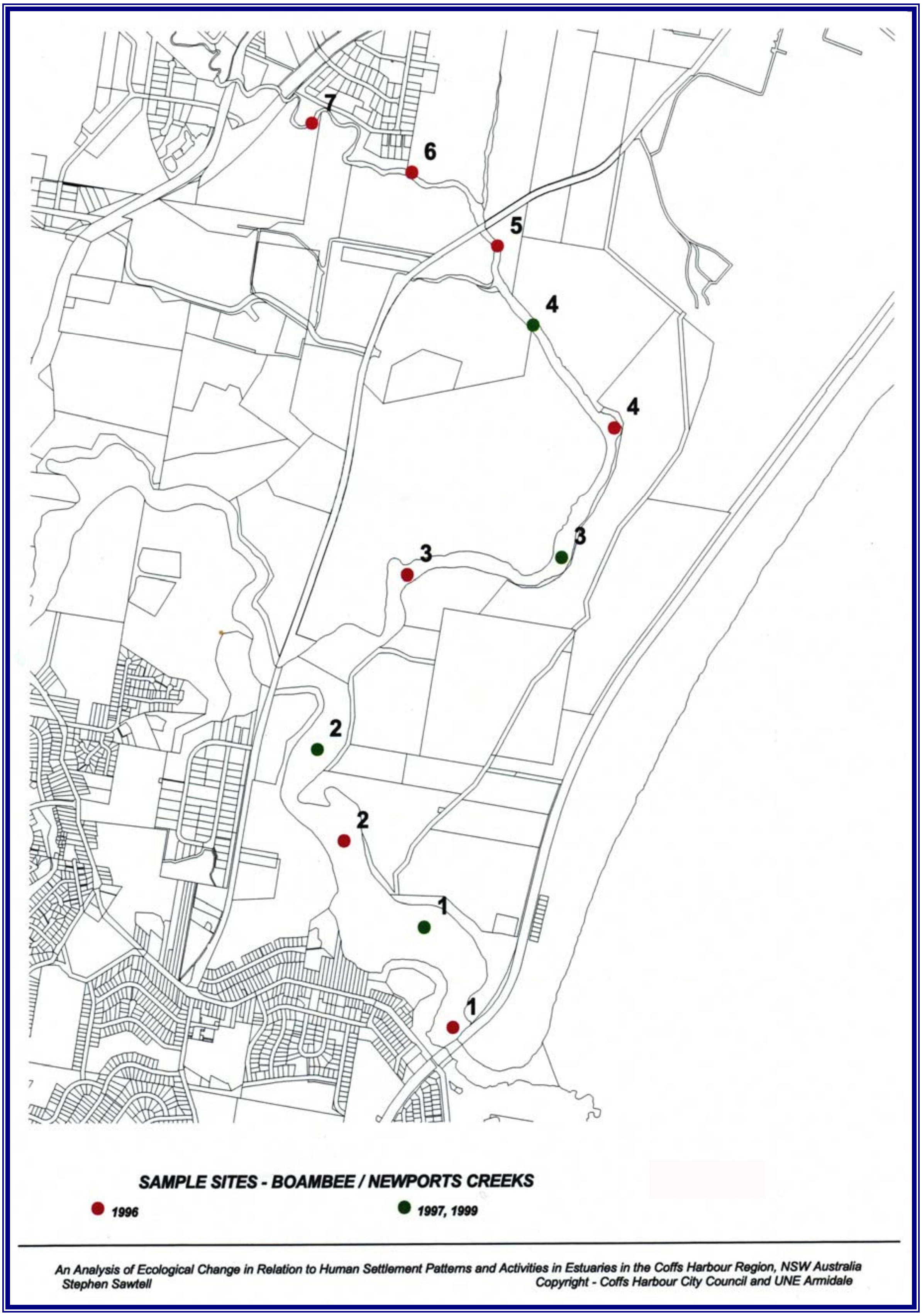


Figure 4-3 - Sample sites 1996, 1997 and 1999 - Boambeee/Newport Creeks

Relative position of sampling sites in Boambee/Newport Creeks for the pilot study (1996) and subsequent sampling (1997/1999)

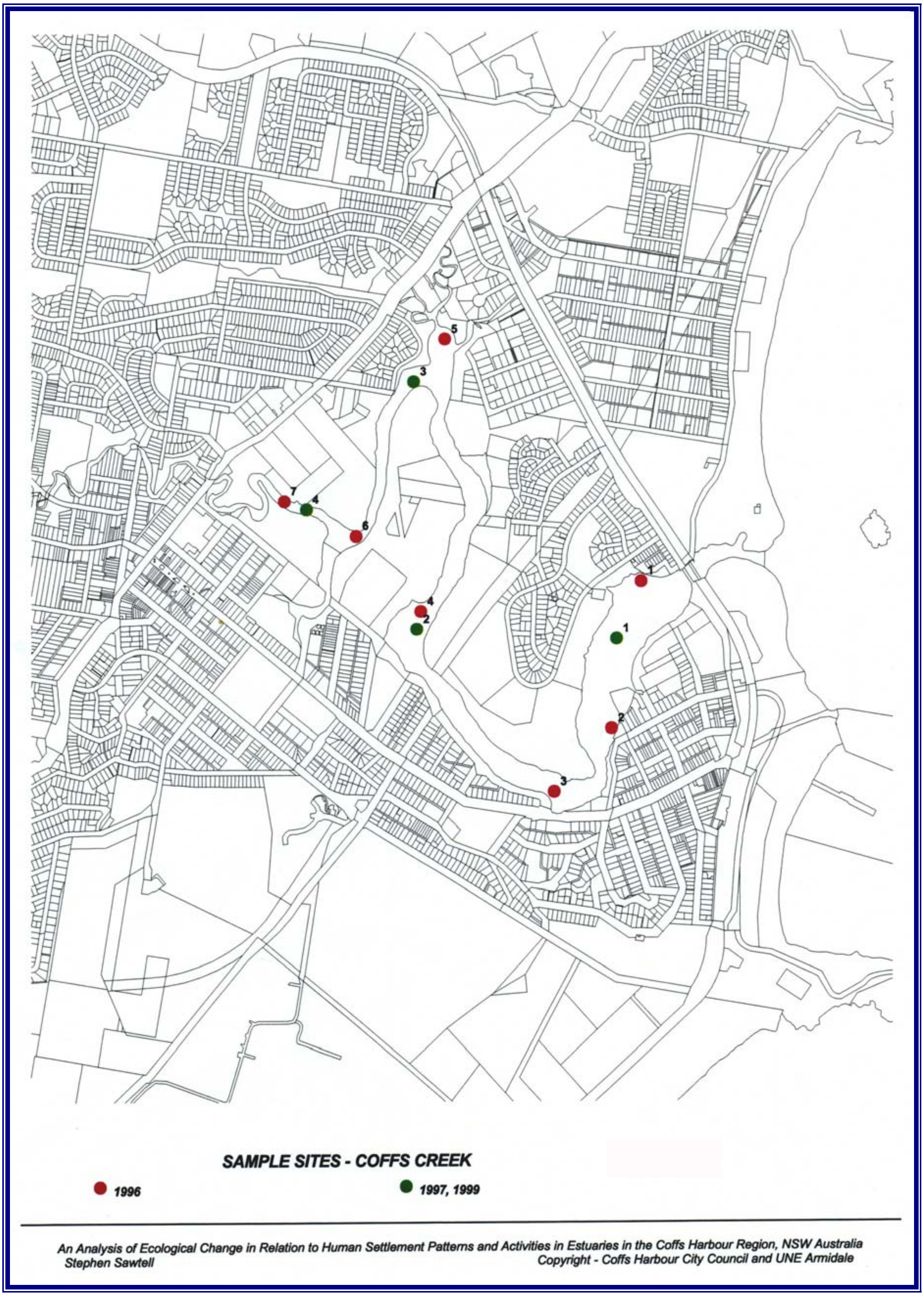


Figure 4-4 - Sample sites 1996, 1997 and 1999 - Coffs Creeks

Relative position of sampling sites in Coffs Creek for the pilot study (1996) and subsequent sampling (1997/1999)

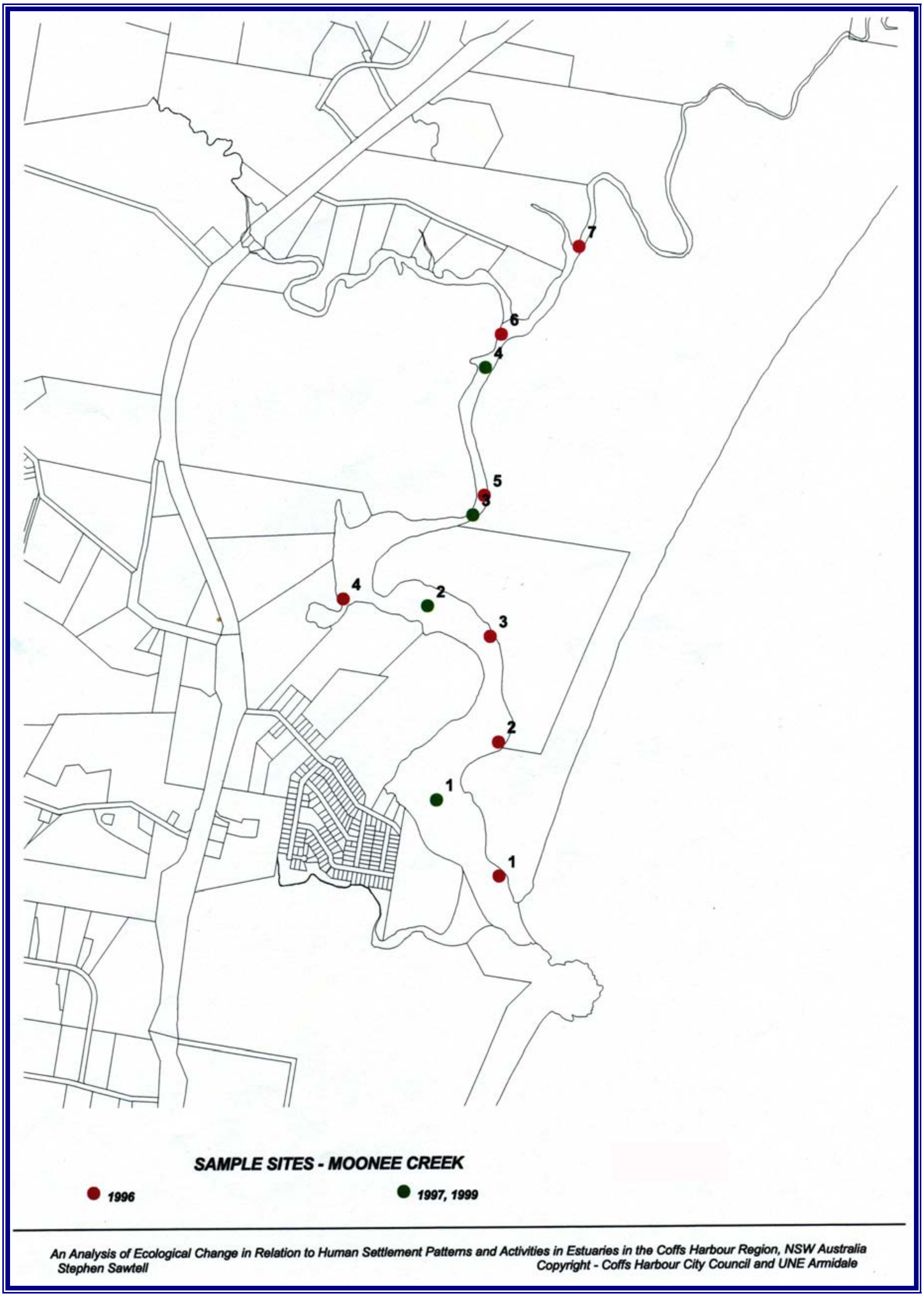


Figure 4-5 - Sample sites 1996, 1997 and 1999 - Moonee Creeks

Relative position of sampling sites in Moonee Creek for the pilot study (1996) and subsequent sampling (1997/1999)

4.4 METHODS FOR PHOTOGRAMMETRIC DATA CAPTURE AND INTERPRETATION

Based on the previous success of data capture in relation to banana cultivation areas in the Coffs Harbour region (Sawtell, 1994) and the research of West et al. (1985); Adam et al. (1985), the use of aerial photography would best capture data on changes to the areas of estuarine vegetation which included seagrass, saltmarsh, mangrove and sedge/coastal heath.

This decision was supported by the fact that historical aerial photography is available for some of the estuaries involved in the study (that is Moonee and Coffs Creeks) dating from 1943 to the present. However, as 1943 data was not available for all creeks, data interpretation for the study included photographs for the period from 1954, 1964, 1974, 1984 and 1994. Interpretation was easier from the larger photo scales (Plate 4.3) but adequate data were also reliably obtained from the smaller images (Plate 4.2) as these photos were flown using a variety of cameras of different formats and focal lengths and at a range of flying heights.

Different textures of vegetation, boundaries of estuaries and human settlement patterns of roads and housing become quite obvious from aerial photograph interpretation (Plates 4.2' 4.3 and 4.4).

Plate 4-2 Aerial photograph of Coffs Creek 1954 (CHCC)

Plate 4-3 - Aerial photograph of Coffs Creek 1994

Note: changes in vegetation adjacent to the estuary and changes in roads and housing. Camera, focal length, photoscale and lens calibration are important details affecting outcomes. Contact prints from the Coffs Harbour City Council photo library were used for the interpretation.

4.4.1 ESTUARINE VEGETATION: Textures and Profiles

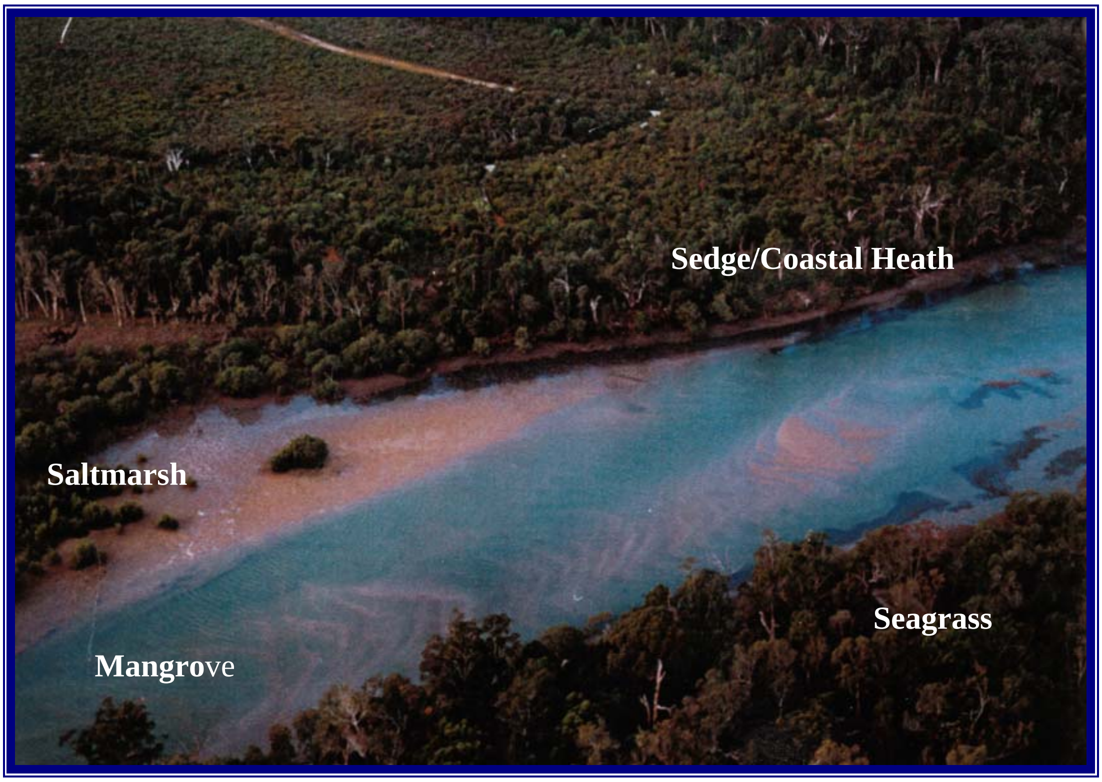


Plate 4-4 Textures of seagrass, saltmarsh, mangrove and sedge. Seagrass offers a very dark texture within the estuary margin. Mangroves straddle the High Water Mark (HWM) (Boambee Creek)

Different types of vegetation present a different texutre. This, together with proximity to the creek and the stereoscopy which provides depth assists in identifying areas of vegetation associated with estuaries (Plate 4.4 and Plate 4.5). These textures interpreted from aerial photographs are a result of the uniqueness of appearance of the actual texture of the vegetation type (Plate 4.6, Plate 4.7, Plate 4.8, Plate 4.9, Plate 4.10 and Plate 4.11).

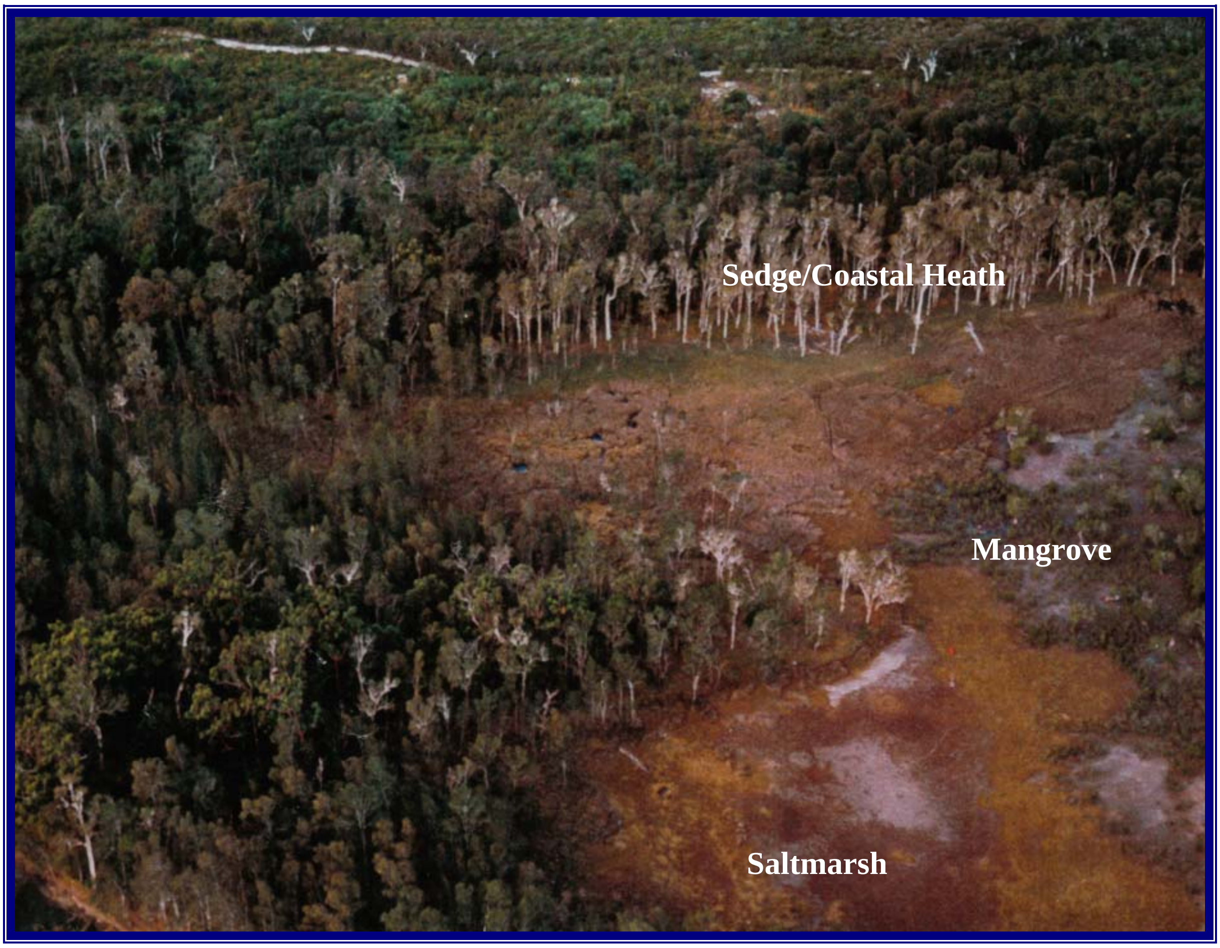
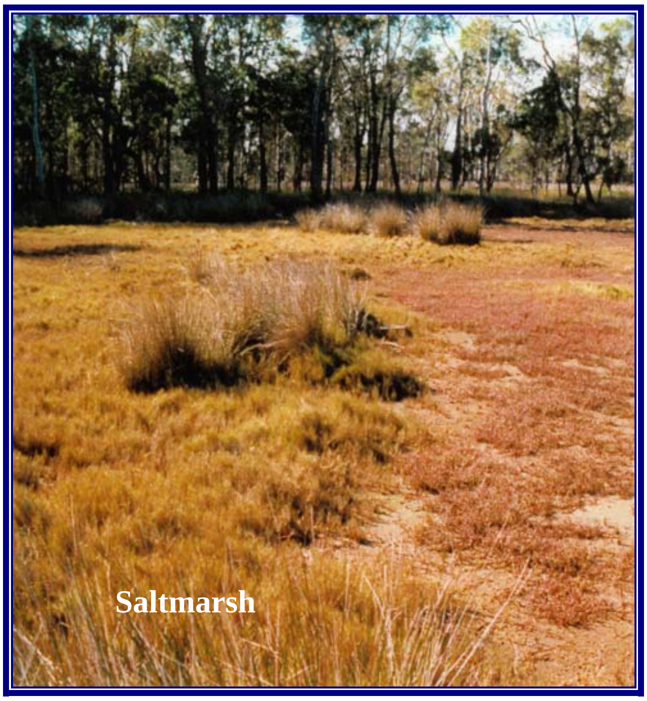


Plate 4-5 View of saltmarsh, mangroves and sedge/coastal heath. A transect profile from HWM would evidence a change from mangroves, through saltmarsh into sedge/coastal heath (Boambee creek)



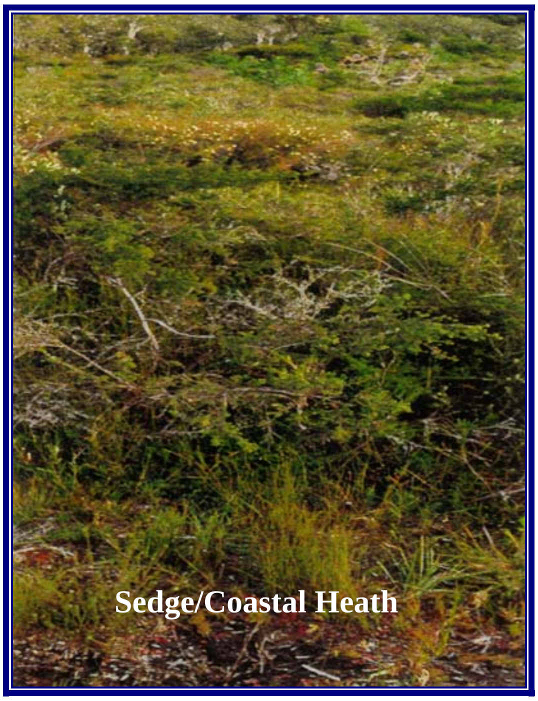


Plate 4-6 Saltmarsh and coastal heath. Note typical saltmarsh vegetaion of juncus. Sp. saltcouch and salt wort (Boambee Creek)

Plate 4-7 Mangrove incursion into saltmarsh. Note texutre of mangrove (midground) and salt couch (foreground) (Boambee Creek)

Plate 4-8 Human impacts in saltmarsh areas (trampling and tyre tracks) (Boambee Creek)

Plate 4-9 - Reed and melaleuca vegetation type (Boambee Creek)

Plate 4-10 - Typical sedge/coastal heath composed of Banksias, boronia and melaleuca. (Moonee Nature reserve)

Plate 4-11 - Typical profile of sedge/coastal heath, heavily slunted. (Moonee Creek)

4.4.2 HUMAN SETTLEMENT PATTERNS - Texture and Profiles

The parameters of interpretation where activities of housing, paved areas (industrial), roads; surfaced and non surfaced (sealed and unsealed), tracks and banana cultivation areas, again interpreted for time periods 1954, 1974 and 1994.

Photographs were examined stereoscopically and each vegetation type and human settlement pattern was digitised using a PG2/ANCO analytical stereodigitiser under eight times magnification. The photogrammetric procedures used are standard, long-established practices which are universally used for all mapping purposes from aerial photographs (R. Dwyer (pers. com.)). These procedures correct all distortions occurring in aerial photos whether caused by changes in relief, camera angle or lens manufacture (R. Dwyer (pers. com.)).

4.4.3 GEO-REFERENCING

The 1994 aerial photos were fully controlled with three dimensional ground control using the ISG Horizontal Datum and the AHD (Australian Height Datum) Vertical Datum, these ground control points are physical features identifiable on the photographs.

To ensure that the older photography was controlled, common datum points were identified on the older photos and stereodigitised from the 1994 photos, thus building up a file of three dimensional control points in ISG and AHD. The three dimensional view provided by the stereodigitiser allowed much better interpretation than simply viewing each photo monoscopically, the visible height of vegetation aided the separation of vegetation types.

The object of this pilot study was to provide initial field identification and orientation training, this then enabled the first phase of interpretation and digitising to be implemented. Following the pilot study further field surveys and ground truthing were carried out during April - July, 1997. With a better understanding of the task and the texture and nature of the vegetation, (particularly the sedge/coastal heath and differences related to the borderline between sedge and saltmarsh species), a second phase of interpretation was undertaken involving the review of earlier analysis and data correction where necessary. Phase 1 of the study was carried out in 1996 and 1997, Phase 2 of the study was carried out from 1997 to 2000.

This created the information database which was used to extract changes over time. The data were collected by one interpreter (avoiding any variation between operators) with more than 30 years experience in all aspects of aerial photo interpretation, stereoscopic digitising was carried out by R. Dwyer and Associates. Data were gathered for a total of 16 estuaries of the Solitary Islands Marine Park though only that data relating to Moonee, Coffs, Boambee and Bonville Creeks have been utilised in this study.

Capturing the data was a complex task which involved interpretation from the photos thence digitising into computer format and converting the data into square metre areas. This involved up to 768 calculations to verify and validate the data generated by computer in Geographic Information System (GIS) format.

4.4.4 GEOGRAPHIC INFORMATION SYSTEMS (GIS)

In order to explore the hypothesis that changes in estuarine vegetation were related to human impacts within the catchment, it was necessary to provide a measure of this human influence. The method chosen to do this was to analyse changes in human settlement patterns (HSP), also derived from the aerial photography, the types of human settlement patterns, the parameters of interpretation for human settlement patterns, or activities of housing, paved areas (industrial), roads - surfaced and non-surfaced (sealed and unsealed), tracks and banana cultivation areas for the time epochs 1954, 1974 and 1994).

The Arcview GIS System was chosen, this is a computerised mapping system which also offers a data management system which enables manipulation of that database. It generates calculations providing spatial relationships between data sets, in this case, estuarine vegetation types of saltmarsh, seagrass, mangroves, sedge/coastal heath and human settlement patterns. These can then be compared spatially within the creeks and catchments or temporally, from 1954 to 1994.

4.5 WATER QUALITY

In situ water quality tests were carried out at each sampling time using a Horiba U-10 Water Quality Meter at the same locations as the grab sampling sites. Readings were taken at surface and on the bottom. The measures made were of conductivity (COND), turbidity (TURB), salinity, temperature, dissolved oxygen (DO) and pH, depth was also measured at each site.

A second measure of water quality was also undertaken. Coffs Harbour City Council in fulfilling it's public health responsibilities take fortnightly water samples from each of the creeks of the study. The samples are taken from the recreational areas in the lower reaches of the creeks, some 300 metres from the creek opening and these samples are taken consistently at the same place. Upon investigation the sampling methodology was found to be inadequate as all samples were taken on the high tide, this then allowed considerable dilution of any contaminants which may be present. Following representation to the Coffs Harbour City Council in 1997 the sampling regime was changed with samples taken at low tide. Hence, sample results were utilised for the 1997 and 1999 years with a geometric mean taken across 26 samples for each year for parameters of faecal coliform and total coliforms.

4.6 SEDIMENT GRAIN SIZE

During the benthic grab sampling, one sediment sample was taken (per site) in order to determine sediment grain size (min. 500gm). (Section 3.2). Mean particle size was then calculated using standard methods (Buchanan, 1984) (Figure 3.4). The purpose of determining sediment grain size is to arrive at a single value which can be used in the calculations of environmental data for the correlations with the benthic data (BIOENV).

4.7 BIOLOGICAL - ENVIRONMENTAL VARIABLES (BIOENV)

Biological Environmental Variables (BIOENV) is a method which correlates physico-chemical and biotic data using rank correlation co-efficients. A harmonic weighted Spearman co-efficient was used to match the local rather than global structure of the biotic and abiotic patterns (Clarke, 1993). In this case, the abiotic factors which were correlated with patterns of community structure were: pH, conductivity, turbidity, DO, temperature, salinity, depth, geometric mean of both faecal and total coliforms and mean grain size.

BIOENV is a programme which systematically searches all variable components to find the optimal match between biotic and abiotic information (Clarke, 1993). .

4.8 ANALYSIS OF PATTERNS OF COMMUNITY STRUCTURE

The statistical analysis in the study followed the protocol outlined by Clarke and Warwick (1994) for community analysis and detection of pollution-induced stress in community data. Univariate statistical tests were conducted as an analysis of summary community variables. A 3-way Analysis of Variance (ANOVA) was used to look at the differences between times, creeks and sites. Abundance (N) and species richness (S) were also determined together with multiple comparisons utilising Least Significant Difference (LSD).

Multivariate analysis was conducted on all species/abundance data using the PRIMER (Plymouth Routines in Multivariate Ecological Research; Clarke and Warwick, 1994) for analysis of community structure. The raw data were fourth-root transformed and similarities between samples were calculated using the Bray-Curtis similarity measure. Non-metric multi dimensional scaling (nMDS) was used to display a visual interpretation of the similarities between samples.

Two way ANOSIM (analysis of similarities) were conducted. SIMPER breakdowns (similarity percentages) indicated the species responsible for differences between samples and only the species responsible for the top 50% of variation between samples have been presented in the results.

4.8.1 CONCEPT OF ANALYSIS OF ESTUARINE VEGETATION CHANGES AND CHANGES IN HUMAN SETTLEMENT PATTERNS.

Analysis-of-variance and regression analysis (R^2 correlations with correlation coefficients) were utilised in determining if any inverse (negative) or direct (positive) correlation occurred between increases or decreases in vegetation and the increases in the human settlement patterns.

All data were standardised as percentage catchment (HSP) and percentage creek (Est. Veg) then transformed to determine if there were any correlations between patterns for each type of estuarine vegetation and human settlement patterns. That is HSP data were correllated against catchment size as a percentage and all vegetation data were correllated against creek size as a percentage. The rationale for this approach is not a “standard” method but one which was derived for this study.

5 RESULTS

5.1 BENTHIC ANALYSIS

5.1.1 SUMMARY OF SPECIES

The three sampling periods yielded a total 71 different species across all creeks (summarised in Table 5-1)

Table 5-1 - Summary of taxanomic affiliations of estuarine macrofauna

TAXA	Nº OF SPECIES
Polychaetes	36
Amphipods	5
Decapods	7
Isopod	1
Mollusc - Bivalve	7
Gastropod	9
Fish	3
Animals (unknown)	3
	71

All raw data appear in Appendix 1. A full species list appears as Appendix 2.

The following plates (Figure 5-1 to Figure 5-8) depict some organisms from the taxa of amphipods, polychaetes and bivalve molluscs. A full photographic representation of all species identified from sampling is on the Interactive Data CD inside the front cover of this thesis.

Plate 5-1 - Hadziid sp. (Amphipod) (Actual size 15mm)

Plate 5-2 - *Notomastus estuarius* (polychaete) (Actual size 40 mm)

Plate 5-3 - *Lasaea australis* (bivalve mollusc) (Actual size 3mm)

Plate 5-4 - *Tellina deltoidalis* (bivalve mollusc) (Actual size 20mm)

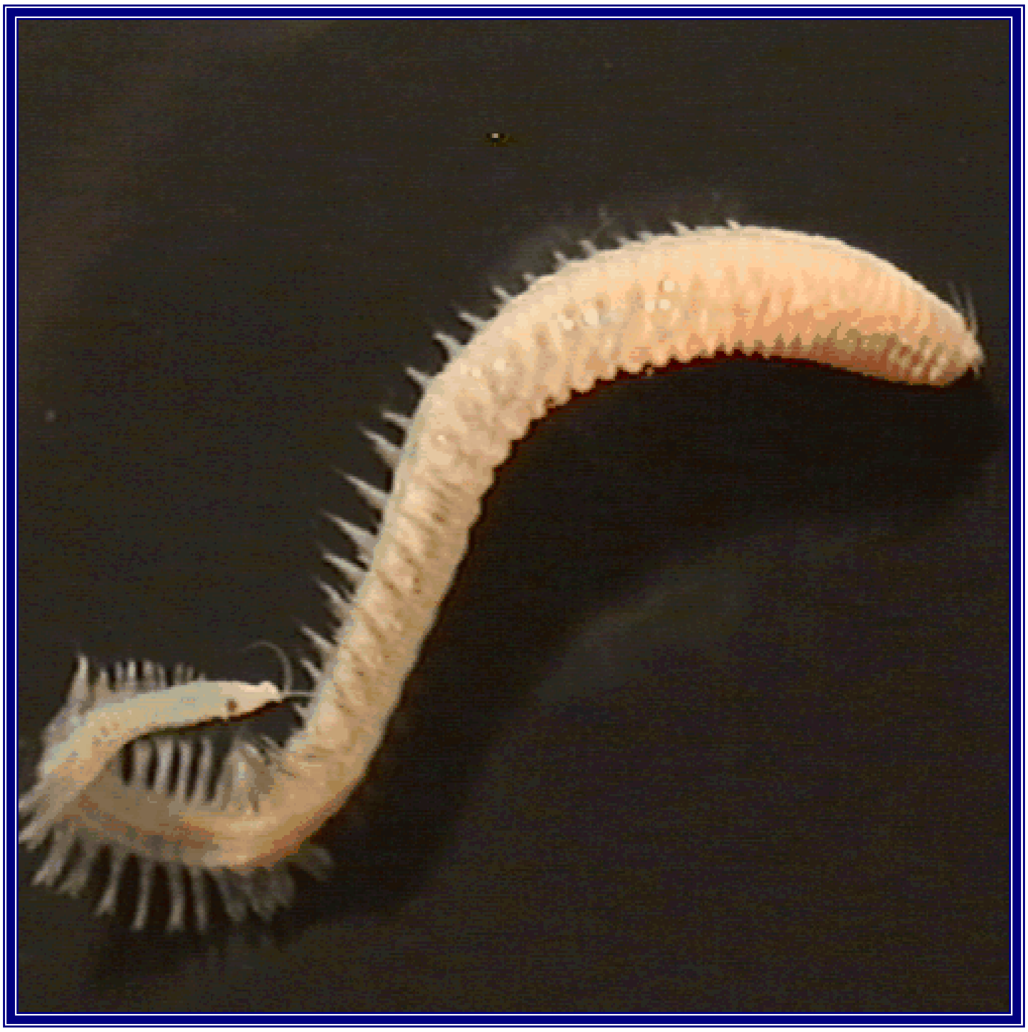


Plate 5-5 - *Australonereis ehlersi* (polychaete) (Actual size 60mm)

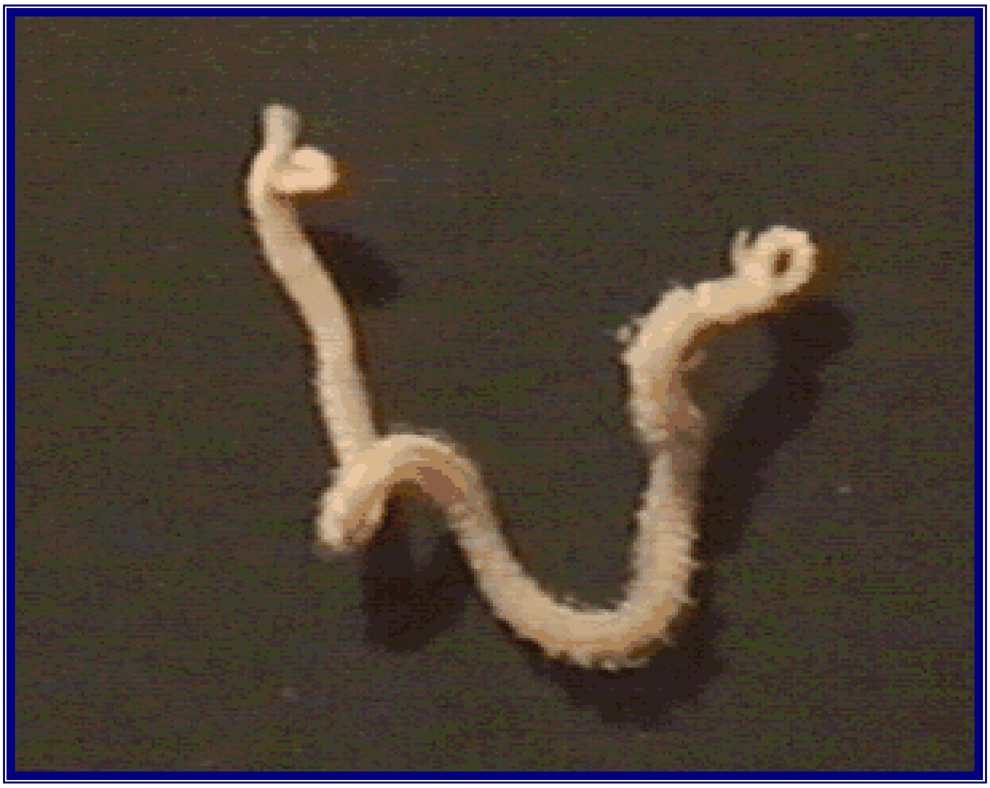


Plate 5-6 - Magellionid sp. (polychaete) (Actual size 40mm)

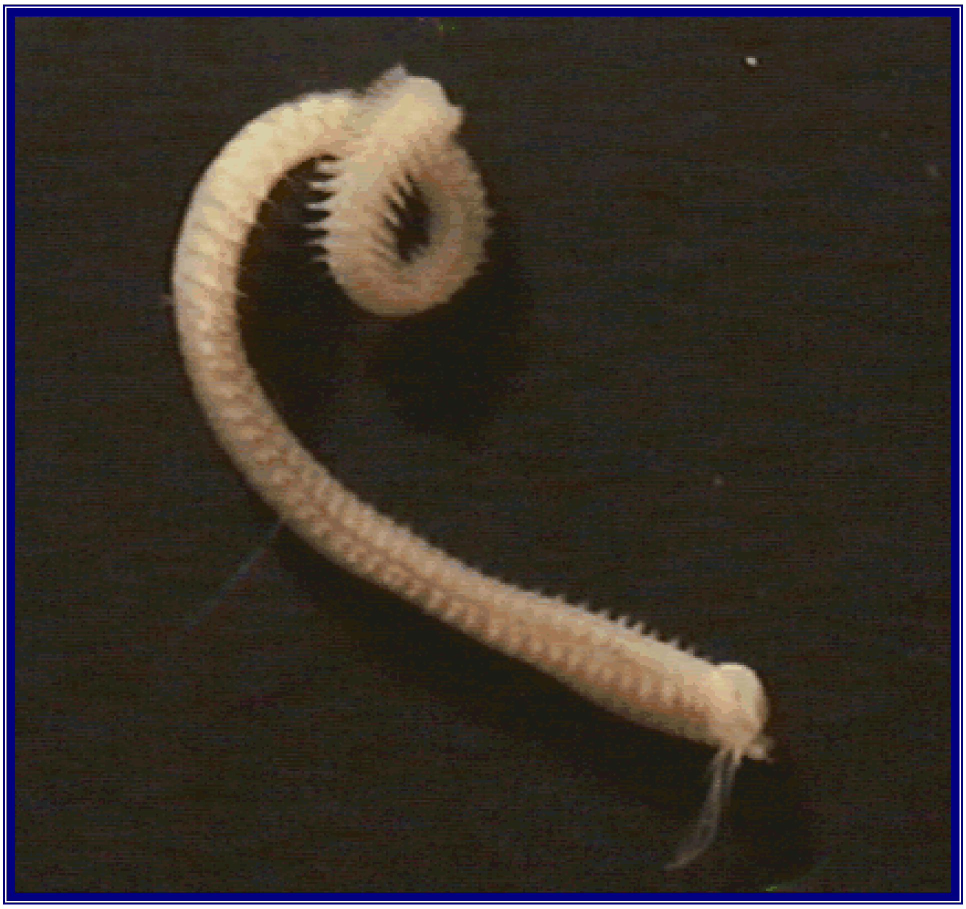


Plate 5-7 - Nereidid sp. (polychaete) (Actual size 50mm)

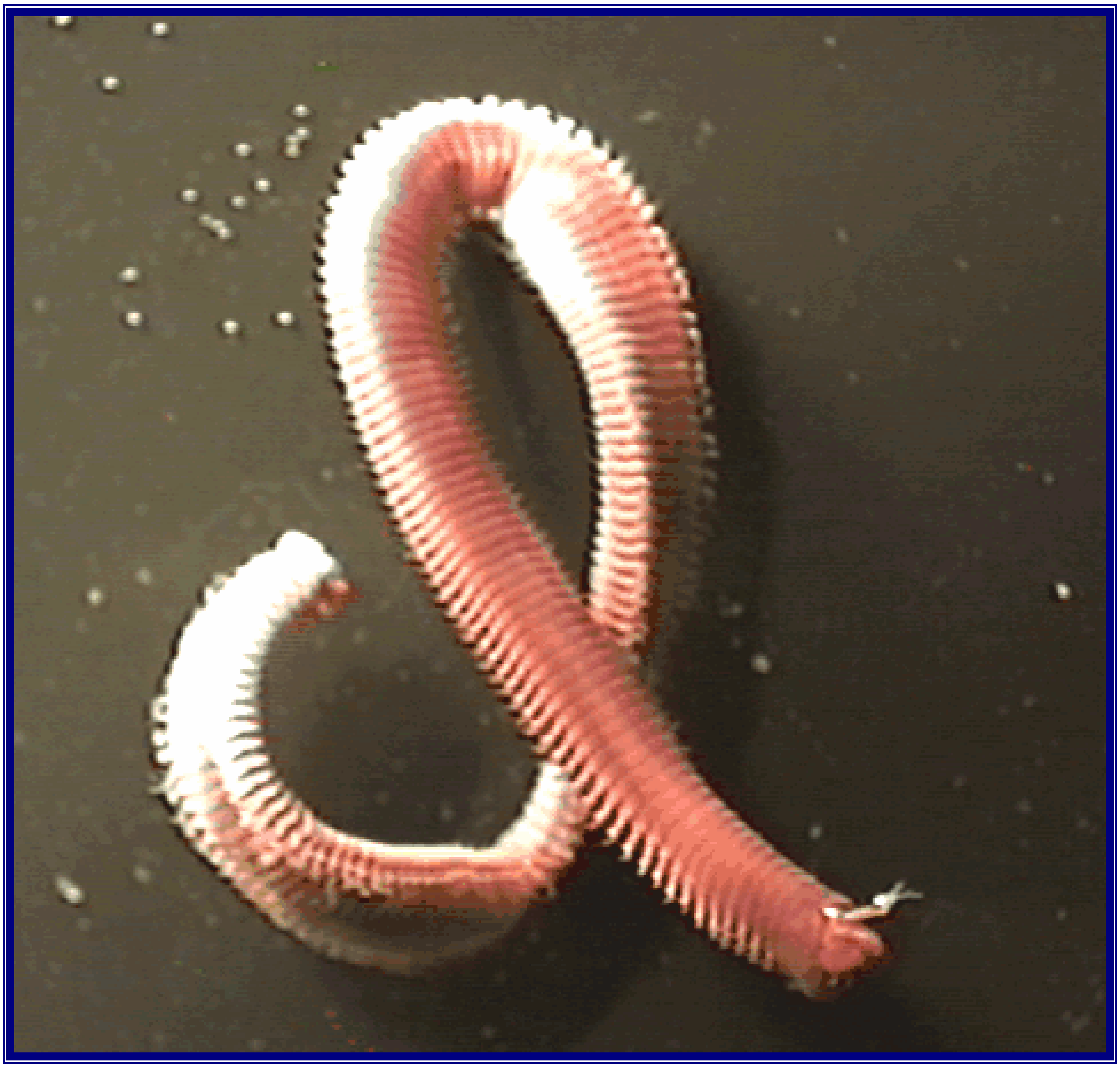


Plate 5-8 - *Marphysa* sp. (polychaete) (Actual size 60mm)

5.2 MACROBENTHIC DATA ANALYSIS - WITHIN CREEKS

5.2.1 COMMUNITY COMPOSITION - 1997 AND 1999 BONVILLE CREEK

To enable comparisons of results within creeks and between creeks and with other studies, abundance (N) and species richness (S) were calculated. Abundance (N) represents the total number of individuals and species richness (S), the number of different species present per sample. Mean abundance and species richness tables (with standard error) appear in Appendix 10.9.

Site 1 across all creeks presented the greatest number of zeros per site, i.e. no fauna in a number of replicates (grabs), and therefore Site 1 was excluded from the multi-variate analysis across all creeks. All data for Site 1 was interpreted from the 1997 and 1999 results separately.

5.2.1.1 DIFFERENCES BETWEEN SITES WITHIN BONVILLE CREEK

Similarity percentages (SIMPER) were used to identify species contributing to the differences between sites within the creeks. For this analysis, data from both sample periods were used to examine consistent patterns of community structure at each site.

The data displayed in the table of similarity percentages is transformed data and is averaged across the time periods 1997 and 1999. (Appendix 4).

Site One

Interpretation of the data from 1997 and 1999 indicates a clear dominance of the amphipod Urohaustorid sp. with high abundances of the bivalve *Tellina deltoidalis.* Some polychaetes were also present.

Site Two

Site 2 is dominated by the bivalve mollusc *Tellina deltoidalis.* The second most abundant species was the amphipod Urohaustorid sp. followed by *Scoloplos simplex.* The gastropod *Nassarius* sp. 1 was also present in lower numbers.

Site Three

The bivalve mollusc *Tellina deltoidalis* dominated Site 3 followed by the polychaete *Notomastus estuarius,* Nemertean sp. and *Owenia* sp. The gastropod *Nassarius* sp. 1 was also present in lower numbers.

Site Four

At Site 4 , *Owenia* sp. was highly abundant followed by Nemertean sp 1 and then *Notomastus estuarius.* Two bivalves were also present in lesser numbers *Tellina deltoidalis* and *Sollatelina donacioides*.

5.2.2 COMMUNITY COMPOSITION - 1997 AND 1999 BOAMBEE CREEK

5.2.2.1 DIFFERENCES BETWEEN SITES WITHIN BOAMBEE CREEK

Site One

1997 raw site data presented domination of the bivalve *Tellina deltoidalis* followed by the amphipod Urohaustorid sp. 1 with a range of polychaetes also present. In 1999 the species were dominated by the gastropod of the Family Potamididae, with nil Urohaustorid sp. 1 present, low numbers of the bivalve *Tellina deltoidalis* were also apparent.

Site 2

The dominant species at Site 2 was the amphipod Urohaustorid sp. 1, followed by the bivalve *Tellina deltoidalis.* Other species typifying this site were the polychaete *Australonereis ehlersi*, the gastropod *Nassarius* sp. 1 and the polychaete *Scoloplos simplex*.

Site 3

The bivalve *Tellina deltoidalis* dominated Site 3 followed in order of abundance by the polychaetes Sabellid sp. 1 Nepthyid sp. 1 and the bivalve *Sollatelina donacioides*.

Site 4

The dominant species at Site 4 were the Capitellid polychaetes *Capitella capitata* and *Notomastus estuarius.* The amphipod Hadziid sp. 1 was next in abundance followed by the bivalve *Tellina deltoidalis*. Two other polychaetes, Sabellid sp. 1 and *Scoloplos simplex*, were also characteristic of this site.

5.2.3 COMMUNITY COMPOSITION - 1997 AND 1999 COFFS CREEK

5.2.3.1 DIFFERENCES BETWEEN SITES WITHIN COFFS CREEK

Site 1

1997 data indicates dominance of the bivalve *Tellina deltoidalis* followed by the amphipod Urohaustorid sp. 1 with various polychaetes present, with the highest abundance of the polychaete *Scoloplos simplex*. 1999 data interpretation indicates a similar trend with dominance by *Tellina deltoidalis* followed by the amphipod Urohaustorid sp. 1 with relatively high numbers of the species *Scoloplos simplex*.

Site 2

Site 2 was dominated by the bivalves *Tellina deltoidalis* and *Sollatelina donacioides.* Polychaetes also were represented at this site, in descending order; Nepthyid sp. 1, *Scoloplos simplex* and *Australonereis ehlersi* consistently occurring.

Site 3

The amphipod Hadziid dominated at Site 3 followed by the polychaete *Scoloplos simplex*, two bivalves, *Tellina deltoidalis* and *Lasaea australis* and lower numbers of the polychaete Nereidid. sp.

Site 4

Site 4 supported a lower species diversity dominated by the Capitellid species *Notomastus estuarius.* In descending order, the amphipod Hadziid, the bivalves *Lasaea australis* and *Tellina deltoidalis*, and the polychaete, Sabellid sp. 1 were also present.

5.2.4 COMMUNITY COMPOSITION - 1997 AND 1999 MOONEE CREEK

5.2.4.1 DIFFERENCES BETWEEN SITES WITHIN MOONEE CREEK

Site One

Site 1 at Moonee was characterised by low abundances of fauna with a total of only 8 individuals across the five replicates for this site. *Tellina deltoidalis* dominated at this site with the polychaete *Scoloplos simplex* being the only other species present in 1997.

More animals were present in 1999 and samples were dominated by the amphipod Urohaustorid sp. 1 followed by the bivalve *Tellina deltoidalis*.

Site Two

Site 2 was dominated by the bivalve species *Tellina deltoidalis* followed by Urohaustorid sp. 1, Nemertean sp. 1 and *Scoloplos simplex*.

Site Three

The bivalve *Tellina deltoidalis* dominated Site 3followed by the polychaete Nepthyid sp. 1 and the gastropod *Nassarius* sp. 1. Lower numbers of the polychaete Sabellid sp. 1 and *Scoloplos simplex* were also present.

Site Four

Site 4 was again dominated by the bivalve mollusc *Tellina deltoidalis.* In descending order, the polychaete *Australonereis ehlersi*, the amphipod Hadziid sp. and both Nemertean sp. 1 and Nepthyid sp. 1 also occurred.

5.2.5 MACROBENTHIC DATA ANALYSIS - BETWEEN CREEKS

5.2.5.1 ABUNDANCE (N)

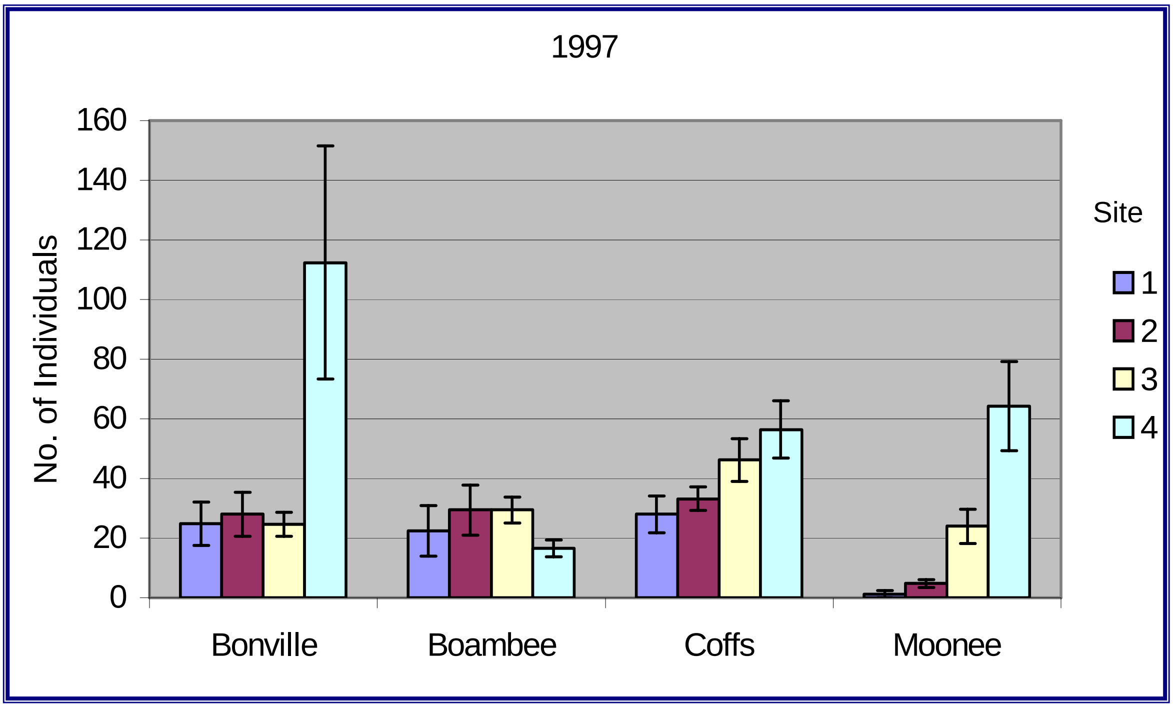


Figure 5-1 - Mean abundance (N) (± SE) in all creeks 1997

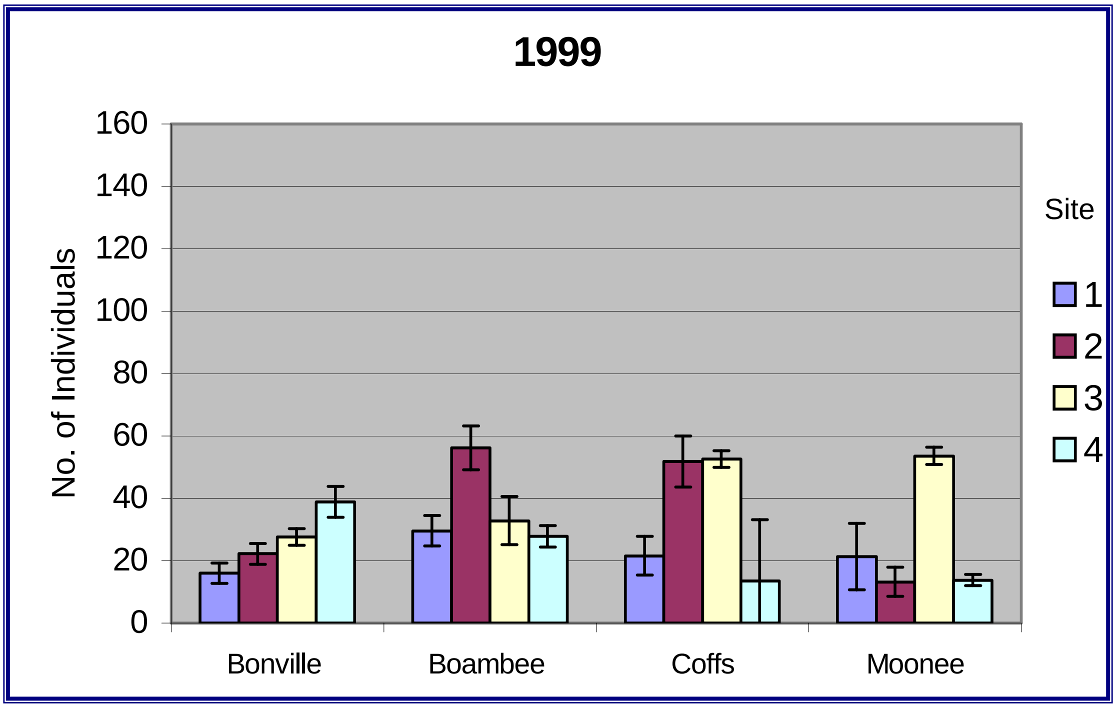


Figure 5-2 - Mean abundance (N) (± SE) in all creeks 1999

MEAN ABUNDANCE

The highest mean abundance (N) for a site in 1997 was Bonville Site 4 (112.4). The lowest was Moonee Site 1 (1.2). (Figure 5-1). In 1999 Boambee Site 2 (65.2) supported the highest number of individuals (N) with Moonee Site 2 (13.2) producing the lowest). (Figure Figure 5-2) The mean abundance totalled for all sites in 1997 indicated Bonville Creek (47.45) with the highest number of individuals and Moonee (23.55) evidencing the lowest. In 1999 Boambee (36.6) provided the highest total average number of individuals with Moonee (25.5) providing the lowest.

Interpretation of the 1997 data (Figure 5-1) indicate Bonville Site 4 supporting the largest contribution of individuals in comparison to all other sites. A trend of increasing abundance from Site 1 to Site 4 is evident in Coffs and Moonee Creeks. 1999 data (Figure 5-2) suggests Bonville supporting a trend of increased abundance from Site 1 to Site 4. All other creeks display consistently lower number of individuals at Site 4 than at Site 1, Sites 2 and 3 in Boambee and Coffs and Site 3 in Moonee supported the greatest species richness.

Levene's Test of equality variances indicated there were differences (p=0.008) and therefore data to transform the data (homogeneity is greater than 0.05). Different transformations were tried but these did not improve the homogeneity of variance.

Tests of between subject effects for creek, site and time, for the number of individuals (N) (Figure 5-2), indicated highly significant differences in interaction terms for time x creek; time x site; creek x site, but no significant differences for time x creek x site. That is, there is no consistence of trends across time, creek or site.

SPECIES ABUNDANCE - 1997 AND 1999 - DEPENDANT VARIABLE (N)

Table 5-2 -Tests of between-subjects effects - Dependent Variable: N for the interaction terms of time, creek and site

Source	**df**	**F**	**P**
Time	1	0.902	0.344
Creek	3	3.164	0.027
Site	3	7.459	0.000
Time * Creek (TxC)	3	4.098	0.008
Time * Site (TxS)	3	11.892	0.000
Creek * Site (CxS)	9	5.349	0.000
Time * Creek * Site (TxCxS)	9	1.755	0.081
Total Error	128		

Post hoc tests using Least Significant Difference (LSD) to detect where the differences lie were carried out for (N). There was a highly significant difference between Bonville and Moonee Creek and Coffs and Moonee Creek (Table 5-3).

Multiple comparisons for (LSD) between sites for (N) indicated highly significant difference between sites 1 and 3, 1 and 4, and 2 and 4 (Table 5-4). This is supported by visual interpretation of Figure 5-1 and Figure 5-2 between these sites. For example Site 1 and 4 in Bonville (1997 and 1999) and Sites 1, 2, 3 and 4 in Moonee (1997 and 1999).

Table 5-3 - Multiple comparisons using Least Significant Difference (LSD) for differences between creeks for N

CREEK	CREEK	P SIG
Bonville	Boambee	0.205
	Coffs	0.820
	Moonee	0.014
Boambee	Coffs	0.136
	Moonee	0.226
Coffs	Boambee	0.136
	Moonee	0.007

Table 5-4 - Multiple comparisons using Least Significant Difference (LSD) for differences between sites for N

CREEK	CREEK	SIG
Site 1	2	0.064
	3	0.002
	4	0.000
Site 2	3	0.190
	4	0.009
Site 3	4	0.183

5.2.5.2 SPECIES RICHNESS - (S) 1997 AND 1999

1997 figures indicate that the highest level of species richness was in Bonville Creek closely followed by Boambee with Moonee providing the least species richness (Figure 5-3). Similarly, 1999 data reveals Bonville with the highest species richness and Moonee with the least species richness. (Figure 5-4).

A clear trend in 1997 is that Site 3 supported the highest level of species richness across all creeks. Site 2 consistently supported the least (S) with the exception being Moonee which supported the least (S) at all sites compared to all other creeks (Figure 5-3).

1999 data suggests that Bonville supports the largest contribution to species richness. Boambee and Coffs supported higher (S) at Site 2 whilst Moonee at Sites, 1 2 and 3 presented the least (S) across all sites (Figure 5-4).

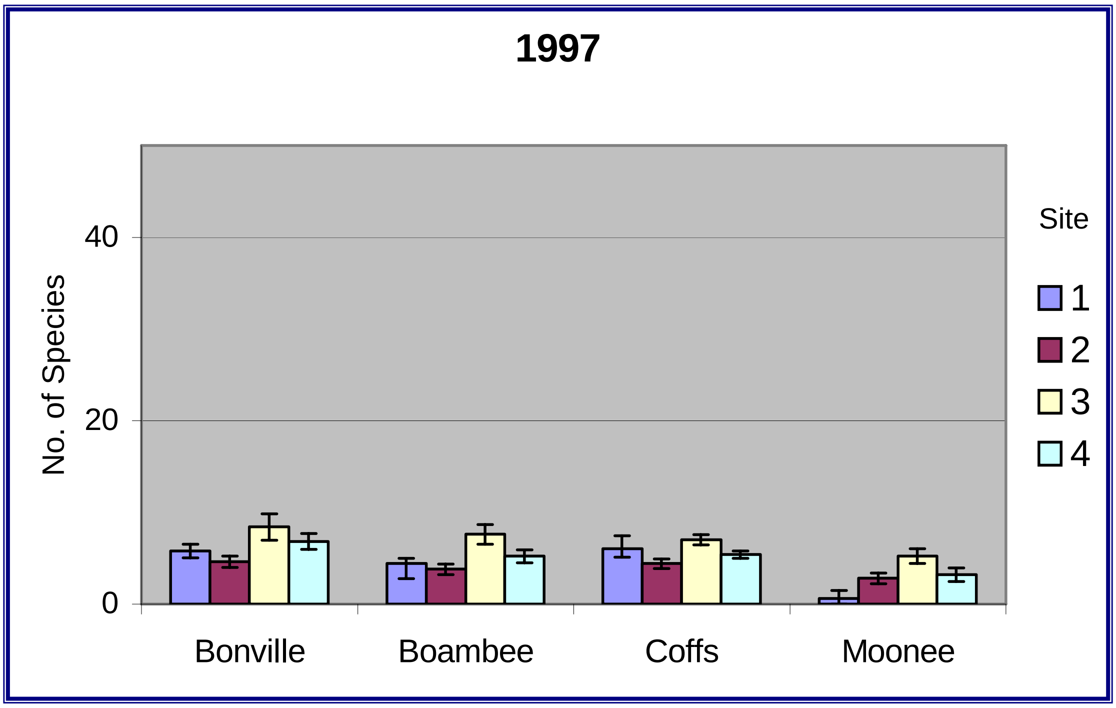


Figure 5-3 - Species richness (S) (± SE) in all creeks 1997

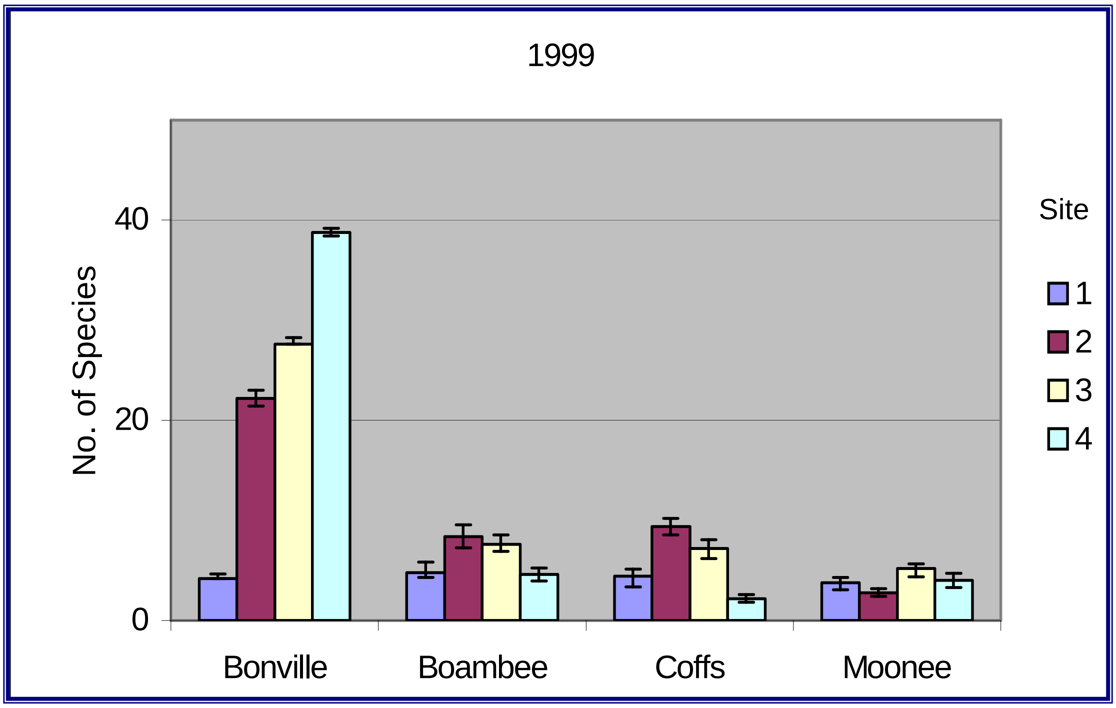


Figure 5-4 - Species richness (S) (± SE) in all creeks 1999

Tests of between subject effects for the fixed factors of creek, site and time, for Species Richness (S) indicated highly significant differences in interaction terms between time and site (TxS), creek and site (CxS). Time and Creek (TxC) was not significant. The added effect of the second order interaction of (TxCxS) was also highly significant. There is no consistence across time within sites and creeks.

Table 5-5 -Tests of between subject effects - dependant variable of S

Source	**F**	**F**	**P**
Time	1	1.656	0.201
Creek	3	18.448	0.000
Site	3	17.671	0.000
Time * Creek (TxC)	3	2.369	0.74
Time * Site (TxS)	3	6.653	0.000
Creek * Site (CxS)	9	2.665	0.007
Time * Creek * Site (TxCxS)	9	3.314	0.001
Total Error	128		

Tests using LSD for multiple comparisons between creeks for the variable of species richness (S) indicated highly significant differences between Bonville and Moonee Creeks, Boambee and Moonee creek and Coffs and Moonee creek. (Table 5-6). LSD were also carried out between sites and found highly significant differences between sites 1 and 3, sites 2 and 3 and sites 3 and 4 (

Table 5-7). Thus Site 3 was significantly different from all other sites (Figure 5-3 and Figure 5-4).

Table 5-6 - Multiple comparisons using least significant difference - between creeks for variable S

CREEK	**CREEK**	**SIG**
Bonville	Boambee	0.573
	Coffs	0.491
	Moonee	0.000
Boambee	Coffs	0.900
	Moonee	0.000
Coffs	Moonee	0.000

Table 5-7 - Multiple comparisons using least significant difference - between sites using dependant variable S

SITE	SITE	SIG.
Site 1	2	0.030
	3	0.000
	4	0.261
Site 2	3	0.000
	4	0.228
Site 3	4	0.000

5.2.5.3 MULTIVARIATE ANALYSIS

Non metric multidimensional scaling (nMDS) is a form of ordination, mapping in distances of similarity and dissimilarity between high dimensional data. The data are then displayed in a low dimensional format (e.g two or three dimensional plots) (Clarke 1993).

In this type of analysis, points which are in close proximity to other points (within the plots) can be interpreted as having similar faunal assemblages whereas those that are separated or apart have few species in common or have distinctly different abundance values.

Thus, ordination of the community data, (nMDS) allows visual interpretation of similarities between sample groups.

Kruskal's stress test was determined for each nMDS plot. Stress levels below 0.2 indicate the plots can be visually interpreted with reasonable confidence (Clarke and Warwick, 1994).

ESTUARINE BENTHOS

The (nMDS) has been broken into two analysis:

1. All sites for all creeks across the time periods of 1997 and 1999.
2. All time periods (1997 and 1999 combined) for each site between creeks.

This is done in order to identify which sites and creeks are different and which species are representative of the differences between these sites and creeks.

The interpretation of Figure 5-5 indicates considerable variation in creeks across time due to the absence of consistent groupings across 1997 and 1999. Some sites such as Bv1 and Bv1-97, C3 and C3-97 are closely grouped indicating some similarity across time. Bonville is grouped to the bottom left and top right with Boambee and Coffs showing little consistency around the centre of the Figure. Outlying sites (particularly Moonee) indicate the greatest variation.

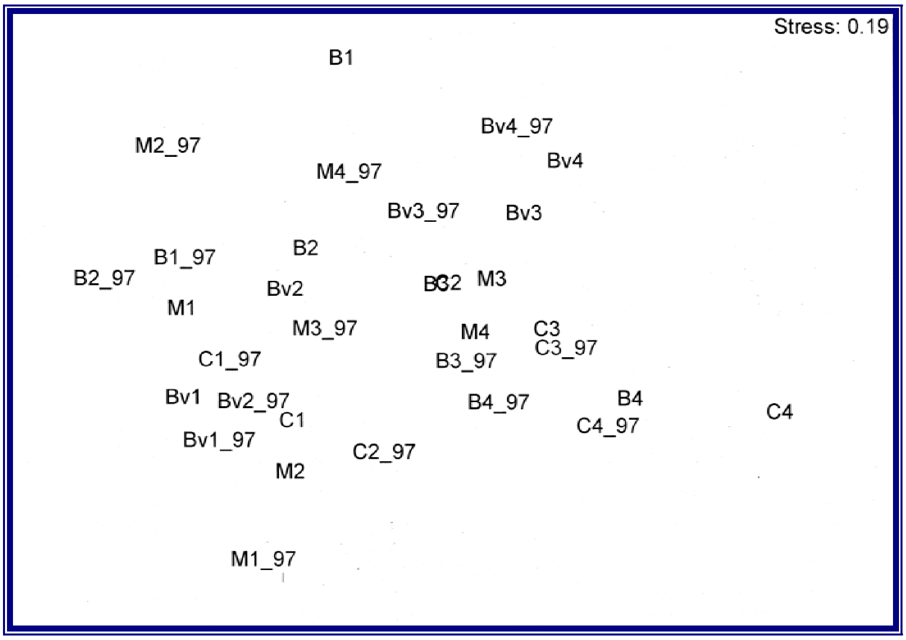


Figure 5-5 - Estuarine Benthos - All Sites Across Times 1997 - 1999
Bv1-Bv4_97= Bonville 1997, B1-B4_97 = Boambee 1997, C1-C4_97 = Coffs 1997 and M1-M4 1997 = Moonee 1997, Bv1-Bv4 = Bonville 1999, B1-B4 = Boambee 1999, C1-C4 = Coffs 1999, M1-M4 = Moonee 1999.
Each site represents an average of 5 replicates

Analysis of Similarities (ANOSIM) was used to test for differences between Creek groups (averaged across all site groups) and proved to be highly significant. A global R statistic ($R = 0.693$) indicated there was highly significant differences between Creek groups ($P < 0.01$).

Further pairwise comparisons revealed that each creek was significantly different to all other creeks ($P < 0.01$).

5.2.6 COMPARISONS BETWEEN SITES ACROSS ALL CREEKS

Comparisons between specific sites in all creeks was carried out to identify similarities or dissimilarities between sites within all creeks and to further identify those species responsible for any differences. Site 1 across all creeks presented the least fauna and hence the greatest number of zeros, and as such was excluded from the multi-variate analysis in order to avoid the confounding of the overall data.

5.2.7 MULTIVARIATE ANALYSIS - ALL TIME PERIODS (1997 AND 1999) FOR EACH SITE BETWEEN CREEKS.

5.2.7.1 SITE 2

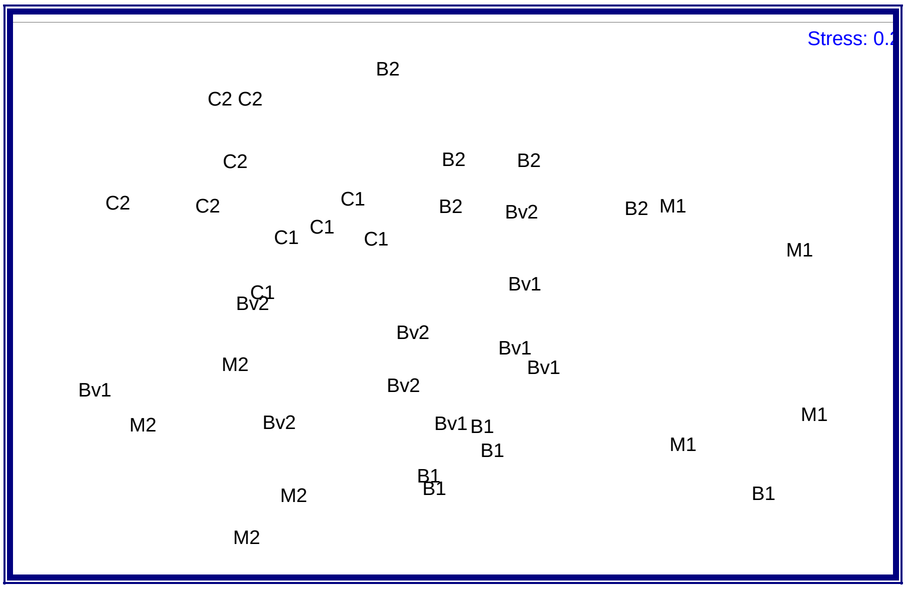


Figure 5-6 - nMDS Type for Analysis Site 2 Each Creek
Kruskal's Test = .0.2. Bv = Bonville. B = Boambee, C = Coffs and M = Moonee (1 = 1997, 2 = 1999)

Interpretation of Figure 5-6 indicates very little overlap between creeks or between times indicating considerable variation. Coffs is located by itself, with no overlap with other creeks though grouped in time to the top left. Bonville displays the closest grouping across time towards the centre of the Figure. Boambee presents clear separation across time indicating variation between the 1997 and 1999 sampling periods. Moonee provides the most outlying sites (the most different from others) and clear separation across time.

TWO WAY CROSSED ANOSIM

A two way crossed ANOSIM was used to test for differences within the data. Tests were carried out for differences between time groups (averaged across all creek groups) and differences between creek groups (averaged across all time groups). 5,000 permutations were used which provide powerful tests for differences. The R statistic (R=0.837) for differences between time groups indicated that there were highly significant differences ($P < 0.01$) across all creeks.

Tests for differences between creek groups (averaged across all time groups) indicated highly significant differences between the creek groups. ($R = 0.693$, $P \leq 0.01$). The results indicate highly significant difference across all creeks (Table 5-8).

To investigate where these differences lay pairwise test comparisons were carried out between all creek groups.

Table 5-8 - Tests for differences between creek groups (averaged across all time groups) - Site 2

Groups Used	R Stat Value	P Significance Level
Bonville, Boambee	0.498	P <0.01
Bonville, Coffs	0.818	P <0.01
Bonville, Moonee	0.486	P <0.01
Boambee, Coffs	0.849	P <0.01
Boambee, Moonee	0.713	P <0.01
Coffs, Moonee	0.903	P <0.01

** $p \leq .01$
* $p \leq .05$ *(Code: 1. Bonville; 2. Boambee; 3. Coffs; 4. Moonee)*

SIMILARITY PERCENTAGES (SIMPER) - SITE 2 - BETWEEN CREEKS

In order to identify the species principally responsible for determining groupings in the nMDS plots a SIMPER analysis was undertaken for all creek combinations, combining the 1997 and 1999 time groupings. These identified which species were responsible for dissimilarities between the creeks. Those comprising the first cumulative 50% have been listed (Appendix 4). Bonville consistently supported high numbers of *Tellina deltoidalis* and Urohaustorid than other creeks, Boambee supported substantially higher levels of Urohaustorid and *Australonereis ehlersi*, whereas Coffs consistently supported numbers of *Scoloplos simplex*, Nepthyid sp. and *Sollatelina donacioides*, contributing to community variation. Species typifying Moonee at this site were *Tellina deltoidalis* and *Scoloplos simplex*. (Table 5-9)

Table 5-9 - SIMPER - Site 2 (1997 - 1999)

	BOAMBEE		COFFS		MOONEE	
BONVILLE	*Tellina deltoidalis* Urohaustorid sp. 1 *Nassarius sp. 1* *Sollatelina donacioides*	*Australonereis ehlersi* *Scoloplos simplex* *Eumarcia fumigata*	Urohaustorid sp. 1	*Scoloplos simplex* Nepthyidae sp *Australonereis ehlersi* *Nassarius sp*. 1 *Sollatelina donacioides*	*Tellina deltoidalis* Urohaustorid sp. 1 *Nassarius sp*. 1 *Australonereis ehlersi*	*Scoloplos simplex* *Nemertean* sp. 1
BOAMBEE			Urohaustorid sp. 1 *Australonereis ehlersi*	*Scoloplos simplex* Nepthyidae sp. *Nassarius sp. 1* *Sollatelina donacioides*	Urohaustorid sp. 1 *Australonereis ehlersi*	*Tellina deltoidalis* Spionid sp. 1 *Scoloplos simplex* *Nassarius sp*. 1
COFFS					*Tellina deltoidalis* *Scoloplos simplex* Nepthyidae sp *Australonereis ehlersi* *Sollatelina donacioides*	Urohaustorid sp. 1

Table 5-9 Summary of SIMPER comparisons between Site 2 in all four creeks.
The benthic organisms which contributed to the first 50% of differences between groups are listed for each comparison. The highest rank (i.e., the most discriminatory) category is listed first in each cell and the components of the list are aligned to show in which creek they had greater abundance.

ANALYSIS OF SIMILARITIES (ANOSIM) SITE 2 BETWEEN ALL SITES ALL CREEKS

Table 5-10 - Tests for differences between site groups averaged across times, all creeks and all site groups

	Groups	R Statistic	Significance Level %
Bonville 1997, 1999	1, 5	0.656	0.008
Boambee 1997, 1999	2, 6	0.796	0.008
Coffs 1997, 1999	3, 7	0.972	0.008
Moonee, 1997, 1999	4, 8	0.99	0.029

An analysis of similarities (ANOSIM) using tests for differences between site groups across time, all creeks and all sites, indicated highly significant differences in community structure within all creeks and sites (Table 5-10).

It is clear from the above results and Table 5-10 and the comparisons in Table 5-9 that the benthic community structure between creek groups at Site 2 is significantly different.

SIMPER COMPARISONS FOR DIFFERENCES BETWEEN TIMES WITHIN EACH CREEK

In order to determine the species responsible for the variation across time SIMPER comparisons were undertaken (Appendix 4). The tables summarise those species responsible for the first 50% of species contributing to the most differences in community structure.

Bonville: Urohaustorid sp. 1 contributed 50.79% of total abundance in 1997 dropping to 7.69% in 1999 and was responsible for 15.14% of differences in community structure. *Nassarius* sp. 1 was not present in samples in 1997, contribution rising to 11.4% in 1999 with a total contribution of 10.57%. Sigalionid sp. 1 contributed 7.22% in 1997 and was not present in 1999 with a total contribution of 9.26%.

Boambee: *Tellina deltoidalis* represented 52.36% of total abundance in 1997 and 10.27% in 1999 with a total contribution of 9.76%. *Australonereis ehlersi* was not present in 1997 with a total abundance of 35.20% in 1999 contributing a total of 16% to community variation, followed by *Nassarius* sp. 1, not found in 1997 and 8.22% in 1999 contributing an overall total of 11.02% to differences in community structure.

Coffs: *Nassarius* sp. 1 was not present in samples in 1997 with 13.85% in 1999 supporting a combined total of 12.78%. *Australonereis ehlersi* supported 17.72% in 1997 and 0.33% in 1999 with a total contribution of 10.35%. Nepthyid sp. 1 contributed 2.11% contribution in 1997 and 19.05% in 1999 with a total contribution of 9.83%.

Moonee: *Tellina deltoidalis* was not present in 1997 and 71.99% in 1999 with a total contribution of 21.62%. Urohaustorid sp. 1 supported 47.78% in 1997, zero in 1999 with a total contribution of 19.42%. Spionid sp. 1 contributed 13.89% in 1997, was not present in 1999 and had a total contribution of 8.13% to differences in community structure.

BIOLOGICAL AND ENVIRONMENT MATCHING (BIOENV)

Correlations were carried out between faunal data and the environmental data with the best correlation occurring between pH and dissolved oxygen with a correlation coefficient of .473. This equates to an R squared value of 0.22 which means 22% of variations in community structure is explained by these two variables.

5.2.7.2 SITE 3

MULTIVARIATE ANALYSIS

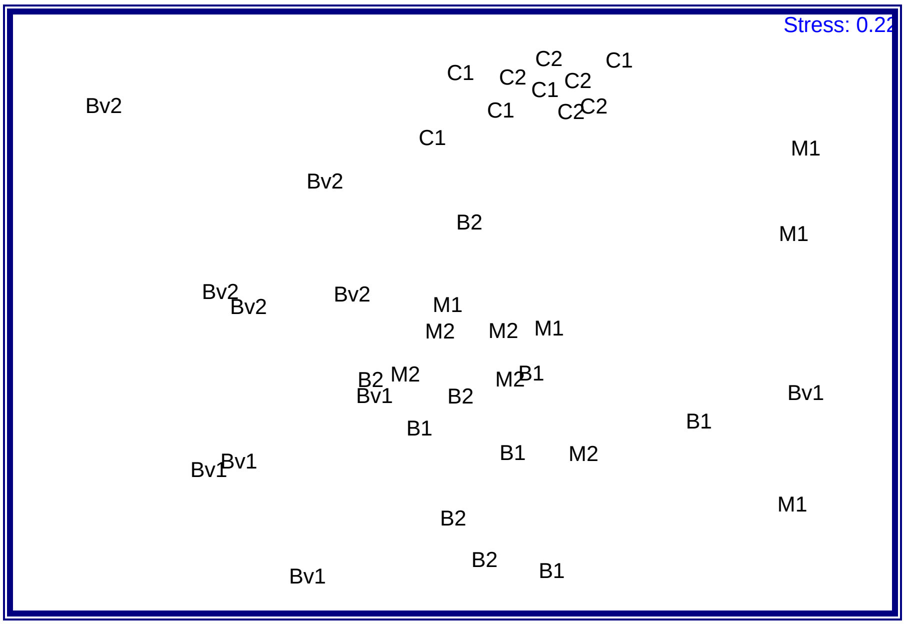


Figure 5-7- nMDS Type for Analysis Site 3 Each Creek
Kruskal's Test = .22. Bv = Bonville, B = Boambee, C = Coffs, M = Moonee
1 = 1997, 2 = 1999

The nMDS plot for Site 3 (Figure 5-7) has a high Kruskal stress of 0.22. 3D solutions were generated, the 2D plot presented as Figure 5-7 was found to closely represent the 3D presentation of samples.

Samples from Coffs creek form a tight grouping which indicates samples from each time are intermixed and different to all other creeks, providing the least variation across time. Moonee exhibits a very strong variation at time 1 and is grouped more closely at time 2 with some overlap between times. Bonville consistently groups to the left with samples for time 1 to the bottom and time 2 to the top both times considerably separate from other creeks. Boambee is represented at the central bottom of the plot and overlaps with Moonee and Bonville with very little overlap between times.

Coffs, for both times, is grouped separately and apart from all other creeks. This is consistent with the other sites displaying very little mixing or similarity with those of other creeks. Moonee and Bonville are separated by time indicating variation between the two time periods.

TWO WAY CROSSED ANOSIM

A Two Way Crossed ANOSIM was carried out for difference between time groups (averaged across all creek groups) and tests between creek groups (averaged across all time groups). 5,000 permutations were used which provide powerful tests for differences. The tests for difference between time groups indicated a highly significant difference ($R = .330$, $P \leq .01$).

Tests carried out for differences between creek groups also indicated a highly significant difference ($R=0.675$, $P < 0.01$).

To investigate where these differences lay, pairwise comparisons were made between all creeks. There were highly significant differences for all combinations ($P < 0.01$) (Table 5-11).

Table 5-11 - Tests for differences between creek groups (averaged across all site groups) Site 3

Groups Used	R Stat Value	Significant Statistic	P Significance Level
Bonville, Boambee	0.540	0	P <0.01
Bonville, Coffs	0.850	1	P <0.01
Bonville, Moonee	0.442	8	P <0.01
Boambee, Coffs	0.888	1	P <0.01
Boambee, Moonee	0.526	1	P <0.01
Coffs, Moonee	0.798	0	P <0.01

SIMILARITY PERCENTAGES - SITE 3 - BETWEEN CREEKS

Summary of similarity comparisons for the four creeks for Site 3 indicated that Bonville consistently supported high numbers of *Notomastus estuarius* and *Owenia* sp., Boambee consistently supported Sabellid sp. with a mixture of Nepthyidae sp. and *Sollatelina donacioides.* Coffs consistently supported the greatest number of Hadziid sp., *Scoloplos simplex* and *Lasaea australis* whilst Moonee supports higher densities of *Tellina deltoidalis* and Nepthyid sp. than other creeks. (Table 5-12).

Table 5-12 - SIMPER - Site 3 (1997 - 1999)

	BOAMBEE		COFFS		MOONEE	
BONVILLE	*Notomastus estuarius* *Owenia* sp. 1 *Nemertean sp.* 1 *Nassarius sp. 1* F. Potamididae	Sabellid 1 Nepthyidae sp. *Sollatelina donacioides* Hadziidae sp.	*Notomastus estuarius* *Owenia* sp. 1	Hadziidae sp. *Scoloplos simplex* *Lasaea australis*	*Notomastus estuarius* *Owenia* sp. 1 *Nemertean sp.* 1 F. Potamididae *Nassarius sp.* 1	*Tellina deltoidalis* Nepthyidae sp Sabellid sp. 1
		BOAMBEE	Sabellid sp. 1 Nepthyidae sp. *Sollatelina donacioides*	Hadziidae sp. *Scoloplos simplex* *Lasaea australis* Nereidid sp. 3	Sabellid sp. 1 *Sollatelina donacioides* Hadziidae sp. *Notomastus estuarius*	*Tellina deltoidalis* Nepthyidae sp. *Scoloplos simplex* *Nassarius sp. 1* *Nemertean sp.* 1
				COFFS	Hadziidae sp. *Scoloplos simplex* *Lasaea australis* Sabellid sp. 1	*Tellina deltoidalis* Nepthyidae sp.

Table 5-12 Summary of SIMPER comparisons between the four creek routes at Site 3. The benthic organisms which contributed to the first 50% of differences between groups are listed for each comparison. The highest rank (i.e., the most discriminatory) category is listed first in each cell and the components of the list are aligned to show in which creek they had greater abundance.

ANALYSIS OF SIMILARITIES (ANOSIM) - SITE 3 BETWEEN ALL SITES, ALL CREEKS

Table 5-13 - Tests for differences between site groups averaged across time, all creeks and all site groups

	Groups	R Statistic	Significance Level %
Bonville 1997, 1999	1, 5	0.348	0.024
Boambee 1997, 1999	2, 6	0.276	0.024
Coffs 1997, 1999	3, 7	0.384	0.04
Moonee, 1997, 1999	4, 8	0.312	0.04

An analysis of similarities (ANOSIM) using tests for differences across time, within each creek for Site 3 indicated significant differences in community structure (Table 5-13).

SIMPER COMPARISONS FOR DIFFERENCES BETWEEN TIMES WITH EACH CREEK - SITE 3

The species contributing to the greatest differences in community structure across the combined periods of 1997 - 1999 were:

Bonville: F. Potamididae contributed 0.53% of total abundance in 1997 increasing to 14.65 in 1999, 7.9% of differences in community structure. *Owenia* sp. represented 20.7% of total abundance in 1997 and dropped to 3.6% in 1999 with a total contribution of 6.88%. Nepthyid sp. 1 contributed to 8.25% in 1997 and 2.11% in 1999 accounting for 21.56% of the total contribution to differences in community structure.

Boambee: *Sollatelina donacioides* represented 0.65% in 1997 and 10.46% in 1999 with total contribution of 9.15%. *Nassarius* sp. 1 was not present in samples in 1997 though had a total abundance of 4.87% in 1999 with a total contribution of 6.69%. Hadziid sp. 1 contributed 5.57% in 1997 with 3.07% in 1999, contributing to a total of 6.56%. to the differences in community structure.

Coffs: Nereidid sp. 3 contributed 1.05% of total abundance in 1997, with 6.32% in 1999 and a total contribution of 13.03%. Sabellid sp. 1 presented 7.86% in 1997 and 5.79% in 1999 with a total contribution of 11.44%. *Notomastus estuarius* supported 4.02% in 1997 and 0.91% in 1999 with a total contribution of 10.63% to differences in community structure.

Moonee: *Scoloplos simplex* contributed 9.87% to total abundance in 1997 and was not present in 1999, with a total contribution of 12.65%. Nepthyid sp. 1 supported 4.51% in 1997, 7.85% in 1999 with a total contribution of 11.12%. Sabellid sp. 1 supported 4.51% in 1997, 6.00% in 1999 and a total contribution to differences in community structure of 9.87%.

BIOLOGICAL AND ENVIRONMENT MATCHING (BIOENV)

The best correlation was for turbidity alone (r = 0.367). Thus, with an r² value of 0.13, only 13% of the pattern of community structure could be explained for Site 3 using physico-chemical measures taken in this study.

5.2.7.3 SITE 4

MULTIVARIATE ANALYSIS

Bonville and Moonee are grouped separately from all the other creeks and separate from each other in both 1997 and 1999 sample periods, whereas some overlap has occurred between Boambee and Coffs, direct overlap between some sites indicates possible similarities. All creeks display a degree of grouping not evident at other sites.

There is distinct grouping relative to both site and time. Bonville has direct overlap between samples taken in 1997 and 1999, as does Coffs and Boambee.

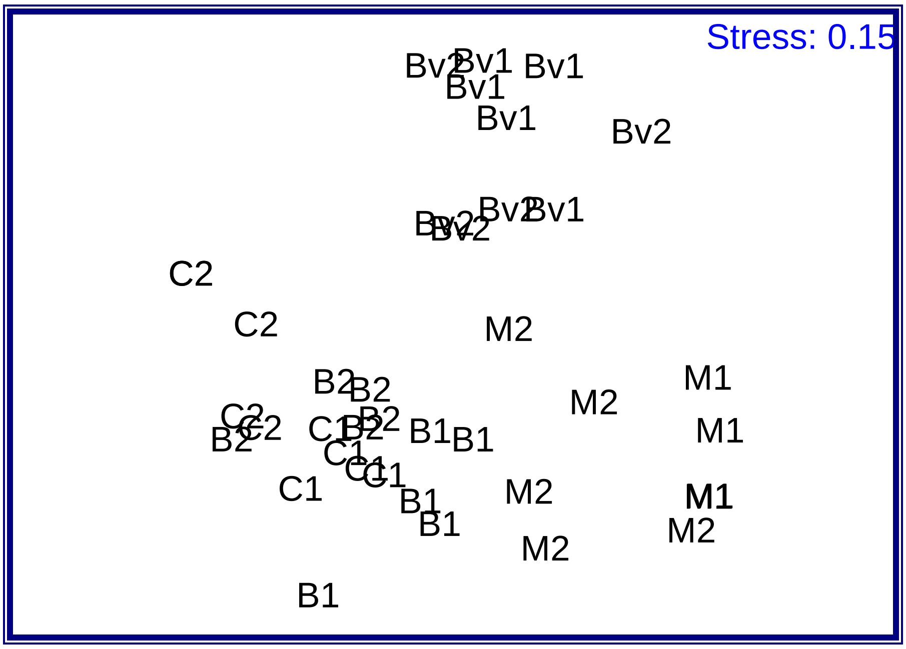


Figure 5-8 - nMDS Type for Analysis Site 4 Each Creek with a Kruskal's Stress of 0.15
Kruskal's Test = 0.15 Bv = Bonville. B = Boambee, C = Coffs and M = Moonee
1 = 1997, 2 = 1999

TWO WAY CROSSED ANOSIM

Tests were carried out for differences between time groups (averaged across all creeks) and for differences between creek groups (averaged across time groups). 5,000 permutations were used which provide powerful tests for differences. The R statistic (R= 0.375) indicated that there were highly significant differences between time group combinations ($P < 0.01$). A further test was carried out for differences between creek groups ($R = 0.831$) indicating a highly significant difference between creek groups ($P \leq .01$).

To investigate further where these differences lay, pairwise comparisons were made between all creeks. There were highly significant differences between all creeks ($P< 0.01$) (Table 5-14).

Table 5-14 - Tests For Differences Between Creek Groups (Averaged Across All Site Groups) (Site 4)

Groups Used	Stat Value	Significant Statistic	Significance Level
Bonville, Boambee	0.936	0	P < 0.01
Bonville, Coffs	0.964	0	P < 0.01
Bonville, Moonee	0.874	0	P < 0.01
Boambee, Coffs	0.580	0	P < 0.01
Boambee, Moonee	0.818	0	P < 0.01
Coffs, Moonee	0.940	0	P < 0.01

SIMILARITY PERCENTAGES (SIMPER)

SIMPER results for the four creeks for Site 4 indicated Owenia sp. dominated in Bonville with Nemertean sp. 1 and *Notomastus estuarius* also contributing. Boambee consistently supported levels of Hadziid sp. and *Notomastus estuarius*. Coffs consistently features *Lasaea australis*, *Notomastus estuarius* and Hadziid sp. Moonee supported *Tellina deltoidalis* as the major contribution to community structure.

Table 5-15 - SIMPER - Site 4 (1997 - 1999)

	BOAMBEE		COFFS		MOONEE	
BONVILLE	Owenia sp. 1	*Notomastus estuarius* Hadziidae sp.	*Owenia* sp. 1 *Nemertean sp. 1*	*Notomastus estuarius* Hadziidae sp. *Lasaea australis*	*Owenia* sp. 1 *Notomastus estuarius* *Nemertean sp. 1* *Sollatelina donacioides*	*Tellina deltoidalis*
	BOAMBEE		Hadziidae sp. Sabellid sp. 1 *Scoloplos simplex* *Tellina deltoidalis*	*Lasaea australis*	*Notomastus estuarius* Hadziidae sp. Sabellid sp. 1 *Scoloplos simplex*	*Tellina deltoidalis*
			COFFS		*Notomastus estuarius* Hadziidae sp. *Lasaea australis*	*Tellina deltoidalis* *Australonereis ehlersi*

Table 5-15 Summary of SIMPER comparisons between the four creek routes at Site 4. The benthic organisms which contributed to the first 50% of differences between groups are listed for each comparison. The highest rank (i.e., the most discriminatory) category is listed first in each cell and the components of the list are aligned to show in which creek they had greater abundance.

ANALYSIS OF SIMILARITIES - SITE 4

Table 5-16 - Tests for differences between site groups averaged all time, all creek and all site groups

	Groups	R Statistic	P
Bonville 1997, 1999	1, 5	0.216	0.111
Boambee 1997, 1999	2, 4	0,916	0.008
Coffs 1997, 1999	3, 6	0.38	0.016
Moonee, 1997, 1999	4, 8	0.332	0.024

An analysis of similarities (ANOSIM) for differences across time, within each creek for Site 4, indicated significant differences in community structure for Boambee, Coffs and Moonee Creeks (Table 5-16).

SIMPER COMPARISONS FOR DIFFERENCES BETWEEN TIMES WITHIN EACH CREEK - SITE 4

The species contributing to the greatest differences in community structure across the combined time periods of 1997 and 1999 were:

Bonville: *Tellina deltoidalis* contributed 4.65% of total abundance in 1997 with 6.35% in 1999 and an overall contribution of 11.47%. *Notomastus estuarius* presented 2.88% in 1997 and 21.85% in 1999 with a total contribution of 10.8%. Sabellid sp. 1 supported 2.52% in 1997, was not present in 1999 with a total contribution to differences in community structure of 10.13%.

Boambee: Sabellid sp. 1 (16.23%) contributed 26.8% of total abundance in 1997 with 1.13% in 1999 and an overall contribution of 16.23%. Hadziid sp. 1 supported 13.67% in 1997, 36.68% in 1999 and an overall contribution of 16.16%. *Scoloplos simplex* presented 18.92% in 1997 and 1.08% in 1999 with an overall contribution to the most differences in community structure of 14.92%.

Coffs: *Lasaea australis* contributed 27.23% in 1997 with 13.53% in 1999 with a total contribution of 21.34%. Hadziid sp. 1 accounted for 35.24% in 1997, 11.85% in 1999 with a total contribution of 19.28%. *Tellina deltoidalis* supported 2.32% in 1997 and was not present in 1999 with an overall contribution to differences in community structure of 14.38%.

Moonee: *Australonereis ehlersi* contributed 2.86% in 1997 and was not present in 1999, total contribution was 15.33%. Hadziid sp. 1 was not present in 1997, 8.10% in 1999 and a total contribution of 14.25%. Nepthyid sp. 1 supported 0.19% in 1997, 3% in 1999 and an overall contribution of 9.93% to the differences in community structure.

BIOLOGICAL AND ENVIRONMENT MATCHING (BIOENV) - SITE 4

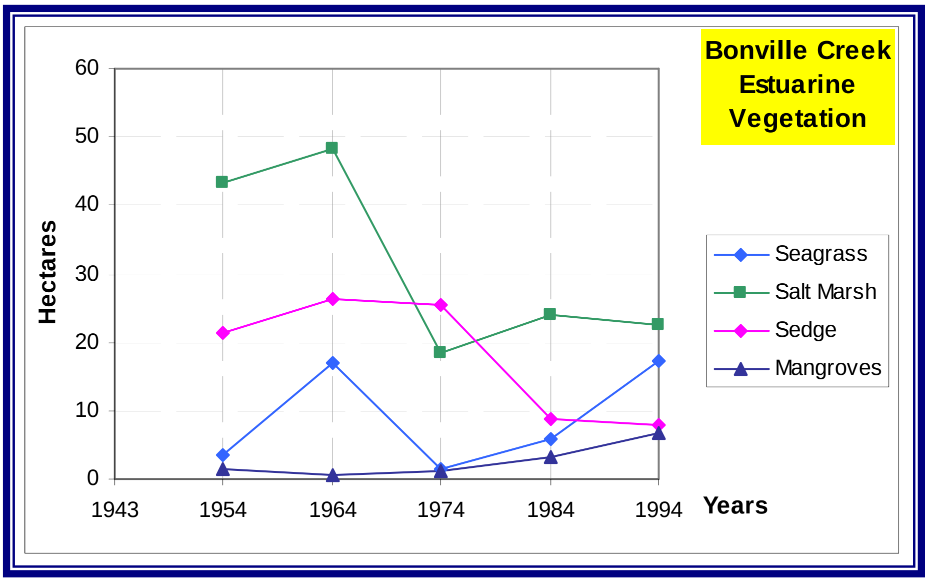
The best correlation was for DO, salinity, depth and granulometry ($r = 0.555$). Thus, with an r^2 value of 0.25, 25% of the pattern of community structure could be explained for Site 4 using physico-chemical measures taken in this study.

5.3 AN ANALYSIS OF CHANGES WITHIN BONVILLE CREEK SYSTEM

5.3.1 ESTUARINE VEGETATION - BONVILLE CREEK - 1954 - 1994

Changes in the area of the 4 major vegetation types over the period 1954 to 1999 in Bonville Creek are summarised in Figure 5-9. In addition using the 1954 figures as a baseline (that is, equalling 100% cover) the percentage change in the cover of each vegetation type is summarised in Table 5-17 (raw data is presented in Appendix 6). Maps of the Bonville Creek at each sampling time showing the actual distribution of each vegetation type are shown in Figure 5-10 to Figure 5-14).

Figure 5-9 Changes in estuarine vegetation in Bonville Creek - 1954 - 1994



Seagrass underwent a four-fold increase since 1954 (3.4 hectares (ha)) increasing to 17.4 ha in 1994 (Table 5-17), an increase of 410% on 1954 data. Seagrass levels fluctuated considerably within the same period from a 1954 total of 3.4 ha seagrass increasing to 16.9 ha in 1964, markedly dropping off in 1974 to 1.41 ha. Seagrass cover rose to 5.9 ha in 1984 and further expanded to 17.38 ha in 1994. Saltmarsh has had a decline across the 40 years from 1954, when 43.45 ha of saltmarsh was present, this marginally increased in 1964 to 48.2 ha, then dropped off to 18.3 ha in 1974. Saltmarsh once more increased in 1984 to 24.1 ha and then declined in 1994 to 22.43 ha, a net loss of 48.3% since 1954. Mangroves have experienced a marked increase since 1954 with a total increase of 405% over the 40 year time period to 1994 (Table 5-17). 1.33 ha of mangrove were present in 1954, dropping to 0.59 ha in 1964, rising to 1.1 ha in 1974, with a further increase to 3.2 ha in 1984 and then doubling in 1994 to 6.7 ha.

Sedge/coastal heath also experienced a decline from 1954 (21.4 ha) to 1994 (8.0 ha) with considerable fluctuation within this time period, representing an overall loss of 62.4% based on the 1954 figures (Table 5-17). A small landlocked area of sedge/coastal health appeared to the south of the confluence of Bonville and Pine Creeks in 1964 and disappeared by 1984.

Table 5-17 Percentage change in estuarine vegetation in Bonville Creek from 1954 - 1994

BONVILLE CREEK – ESTUARINE VEGETATION (% Change)				
Year	Mangrove	Salt Marsh	Sea Grass	Sedge
1954	100.00	100.00	100.00	100.00
1964	-56.28	10.97	396.78	22.93
1974	-16.49	-57.88	-58.64	19.38
1984	141.91	-44.60	73.38	-58.34
1994	405.70	-48.35	410.81	-62.44

Aerial photography indicates that the majority of vegetation is evident in the Bonville Creek arm of the Bonville/Pine Creek system with the major changes to the estuarine vegetation having occurred at the confluence of the Bonville and Pine Creek system adjacent to the residential areas of the Bonville Waters estate (Figure 5-10 to 5.14). Seagrass has proliferated adjacent to this residential area, and has increased both downstream and upstream, this is in a similar area to the increase in mangroves. The location, size and type of estuarine vegetation for each of the time periods relative to the creek and catchment has exhibited considerable variation across time (Figs. 5-10 - 5.14).

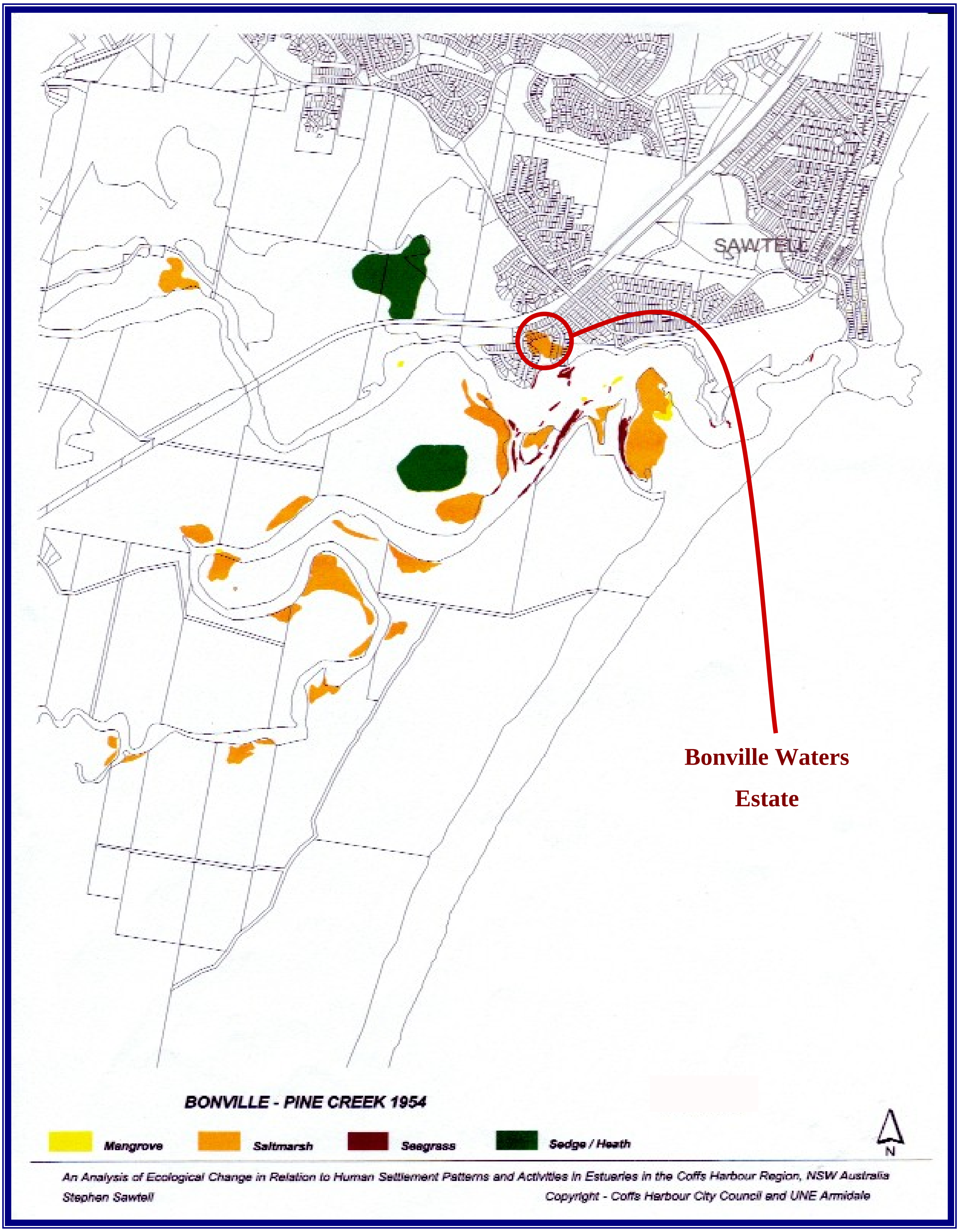


Figure 5-10 - Bonville - Pine Creek
Distribution of the 4 vegetation types in Bonville - Pine Creek in 1954

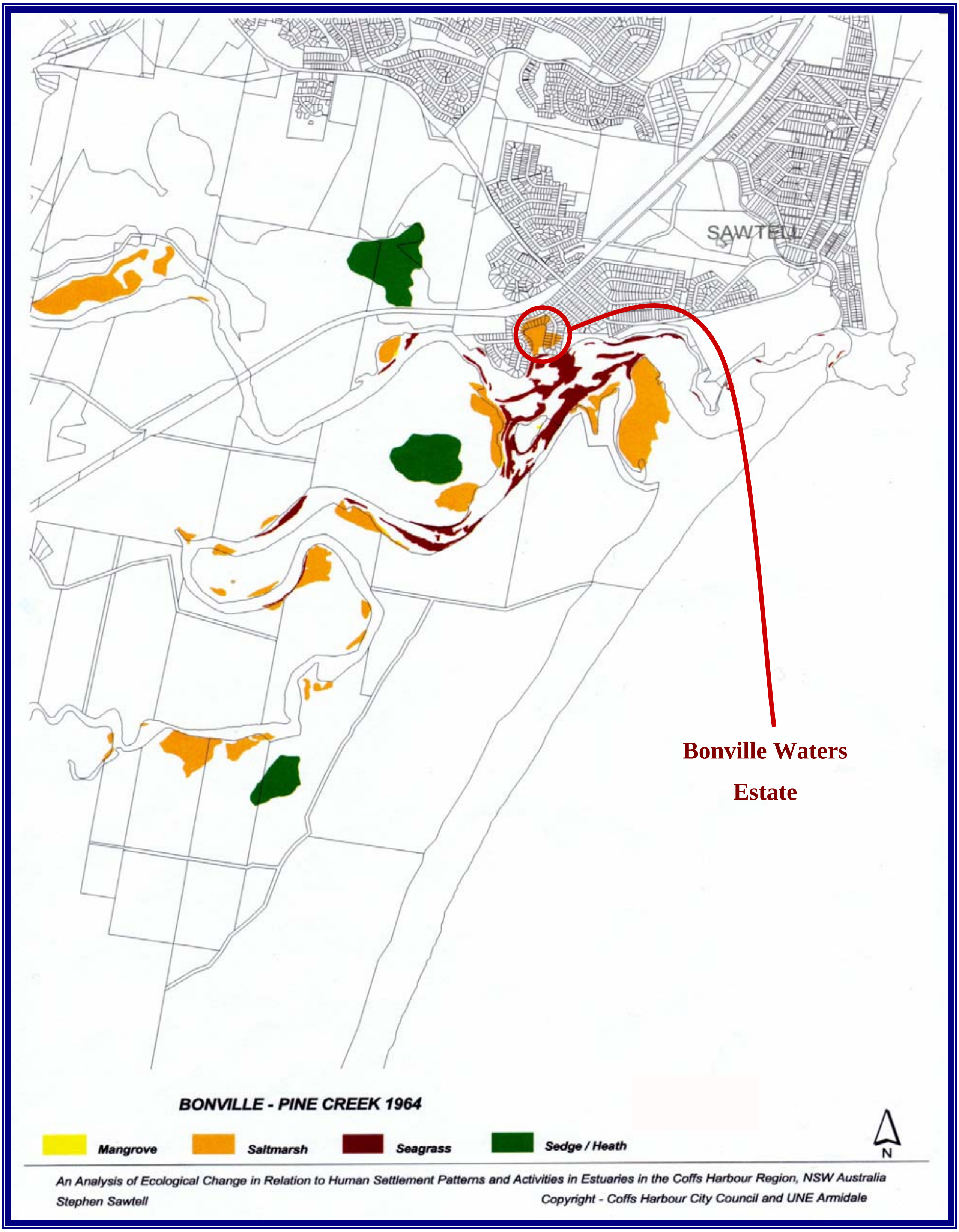


Figure 5-11 - Bonville - Pine Creek

Distribution of the 4 vegetation types in Bonville - Pine Creek in 1964

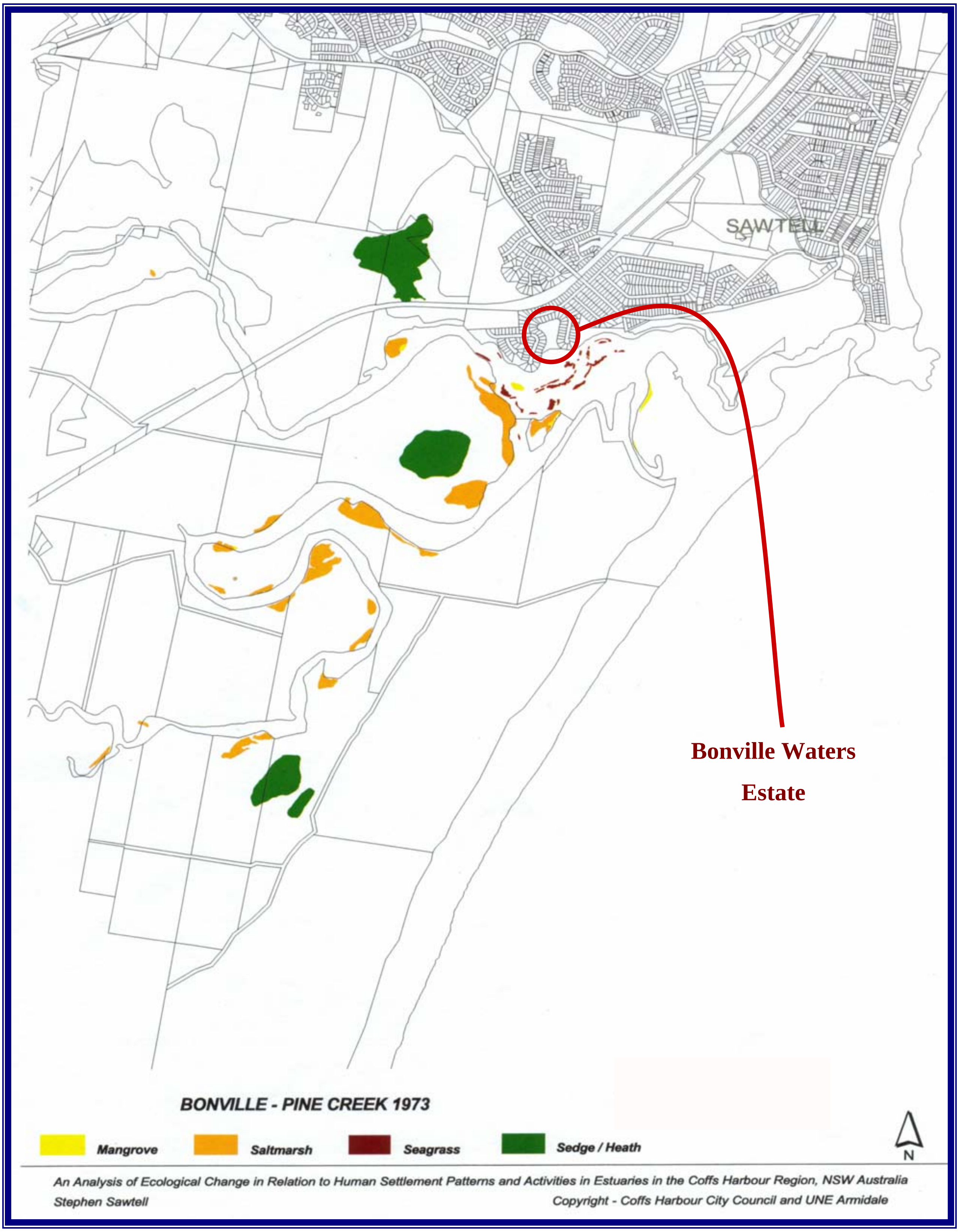


Figure 5-12 - Bonville - Pine Creek
Distribution of the 4 vegetation types in Bonville - Pine Creek in 1973

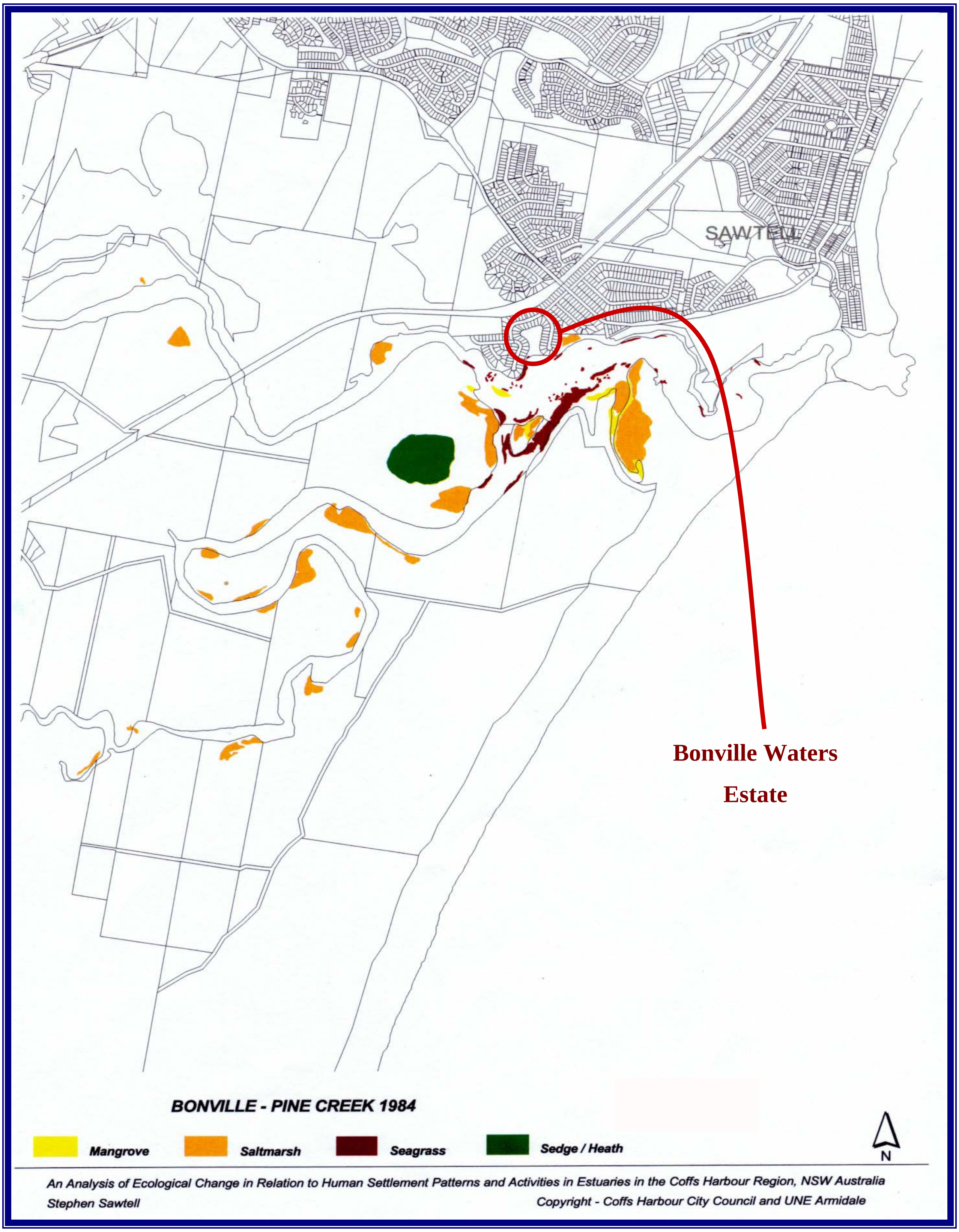


Figure 5-13 - Bonville - Pine Creek
Distribution of the 4 vegetation types in Bonville - Pine Creek in 1984

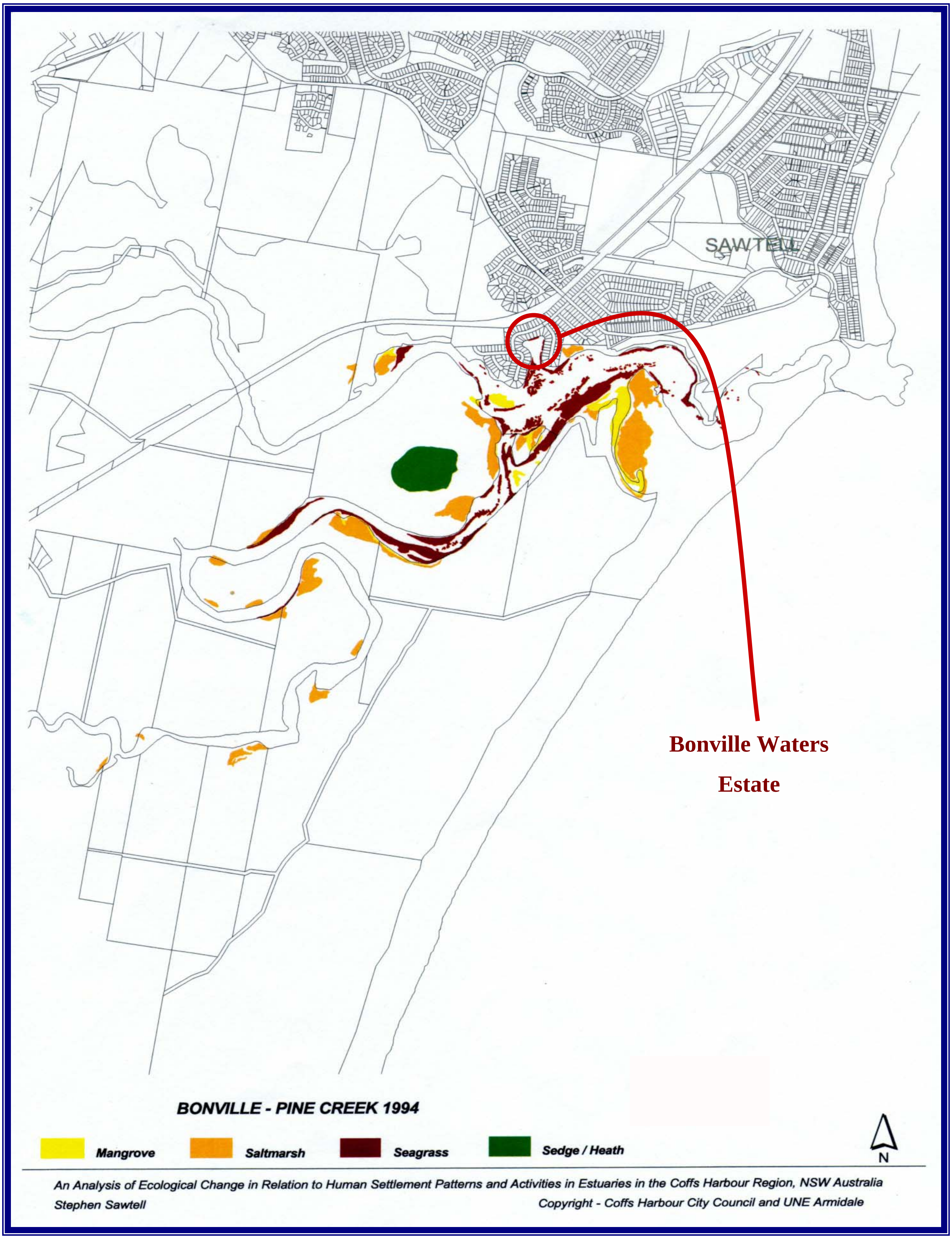


Figure 5-14 - Bonville - Pine Creek
Distribution of the 4 vegetation types in Bonville - Pine Creek in 1994

5.3.2 HUMAN SETTLEMENT PATTERNS - BONVILLE

The human settlement patterns identified in this study include houses, paved areas, sealed roads, unsealed roads, tracks and banana cultivation. A formula of 150 square metres has been applied to each house or unit area to arrive at a total area taken up by housing, with percentage change calculated across the 40 year period. All raw data appear in Appendix 6.

Housing increased 400% from 1954 to 1994. In 1954, 755 houses were present, by 1974 this figure had risen to 1151 then to 3,769 in 1994. A total of 56.53 ha is attributed to housing in 1994 compared to a total of 11.32 ha in 1954. The temporal distribution of human settlement patterns (HSP) is shown in Figs 5-15 - Figure 5-18.

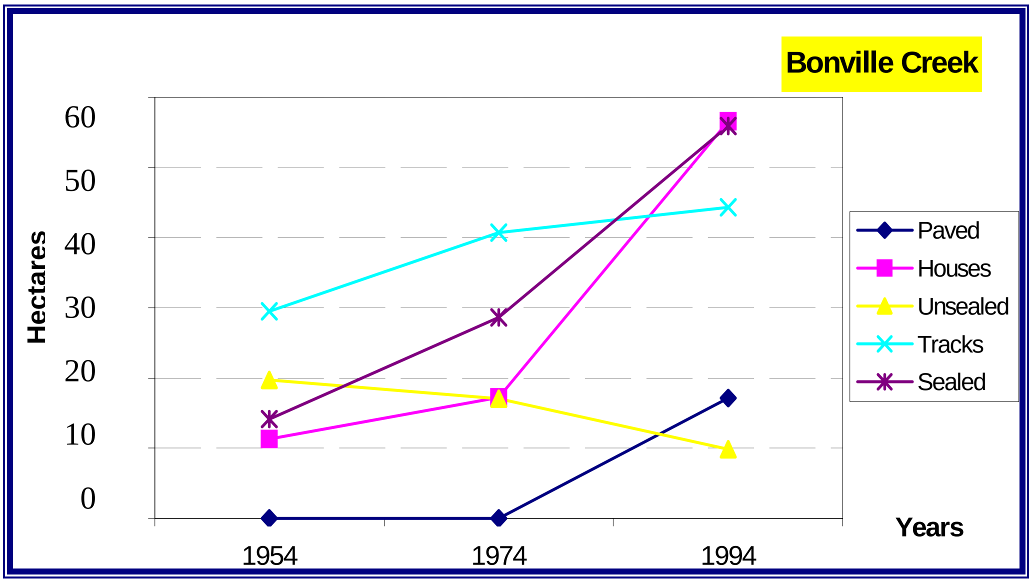


Figure 5-15 - Human settlement patterns Bonville Creek 1954 - 1994 Lineal interpretation

Table 5-18 - Human settlement patterns Bonville Creek 1954 1994. Totals represented in hectares

BONVILLE CREEK – HUMAN SETTLEMENT PATTERNS (ha)					
	Paved	**Houses**	**Unsealed**	**Tracks**	**Sealed**
1954	0	11.32	19.69	29.50	14.18
1974	0	17.26	17.07	40.71	28.60
1994	17.10	56.53	9.84	44.33	55.90

Between 1954 and 1974 there were no paved industrial areas in the Bonville catchment; 1994 indicated an area of 17.10 ha (Table 5-18, Figure 5-15). A marked increase (294%) occurred in the area of sealed roads in the Bonville catchment rising from 14.18 ha in 1954, to 28.6 ha in 1974, and to a total of 55.9 ha in 1994.

There has been a 50% decline in unsealed roads between 1954 and 1994. The 1954 figures indicated a total of 19.69 ha, this dropped to 17.07 ha in 1974 with a further decrease to 9.84 ha in 1994, representing an overall decrease of 50% (Table 5-18).

A 50% increase has occurred in tracks in the Bonville catchment between 1954 and 1994, 29.5 ha were evident in 1954 with a total of 44.3 ha present in 1994 (Table 5-18).

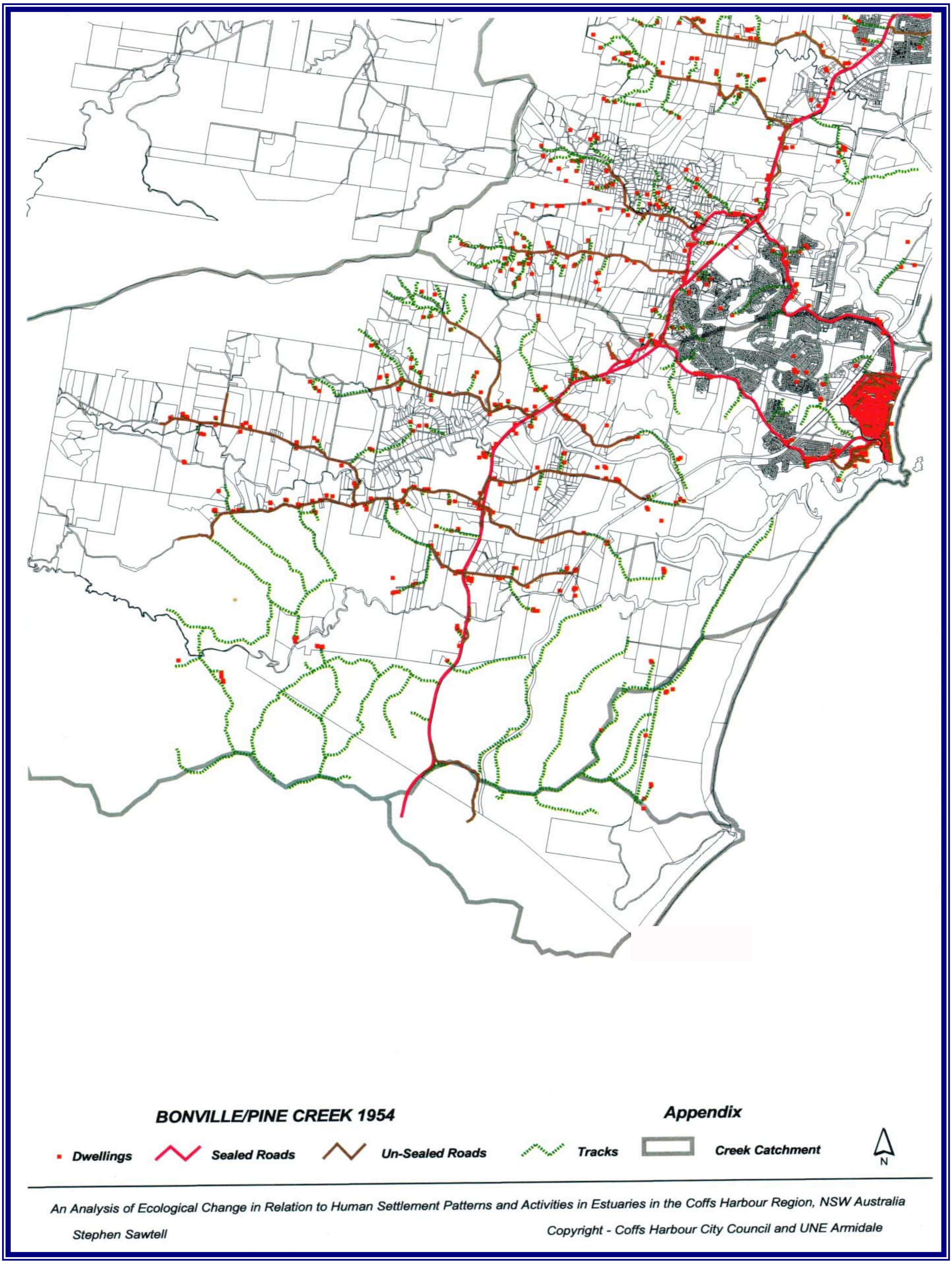


Figure 5-16 - Human settlement patterns Bonville/Pine Creek - 1954

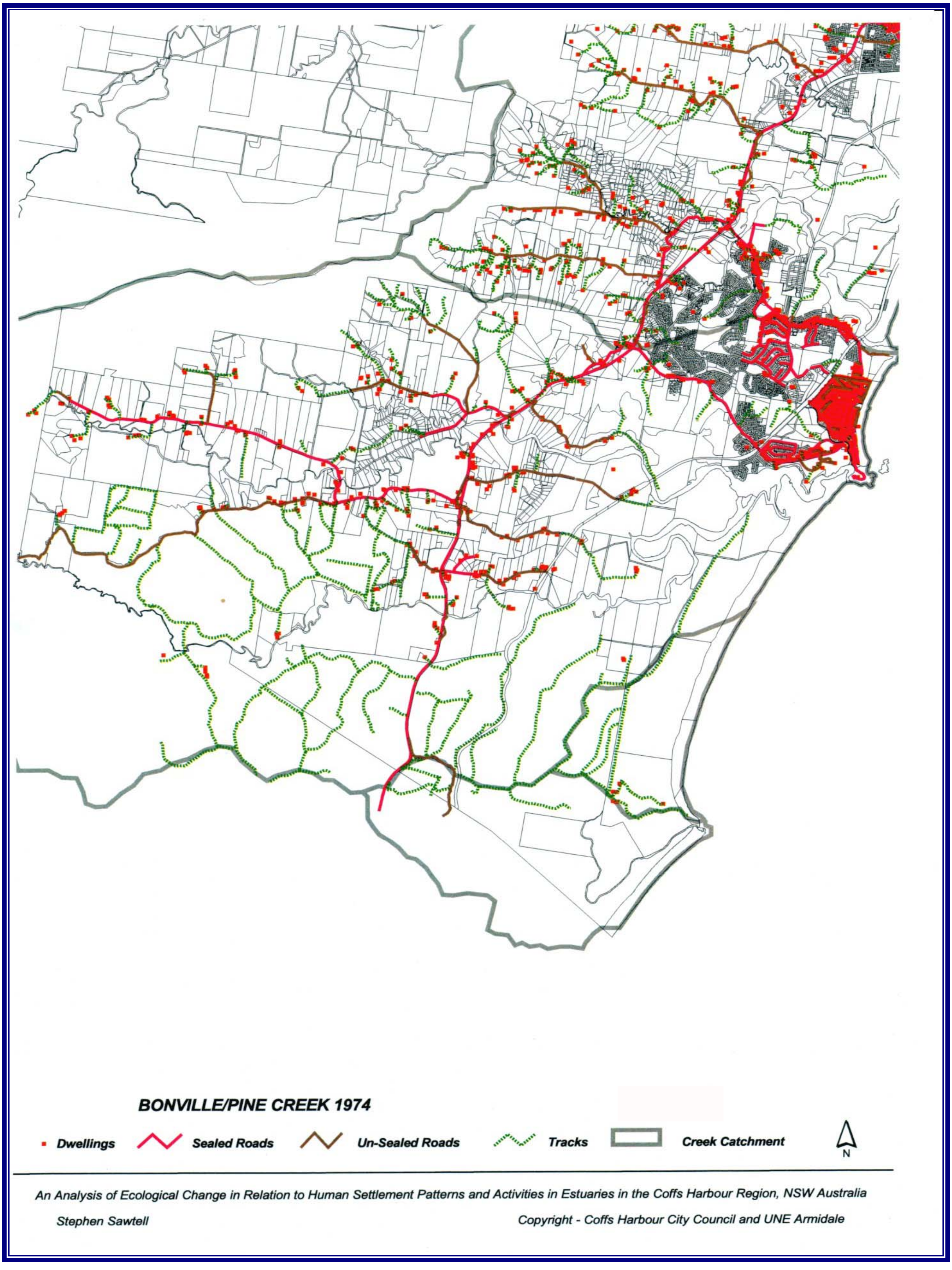


Figure 5-17 - Human settlement patterns Bonville/Pine Creek - 1974

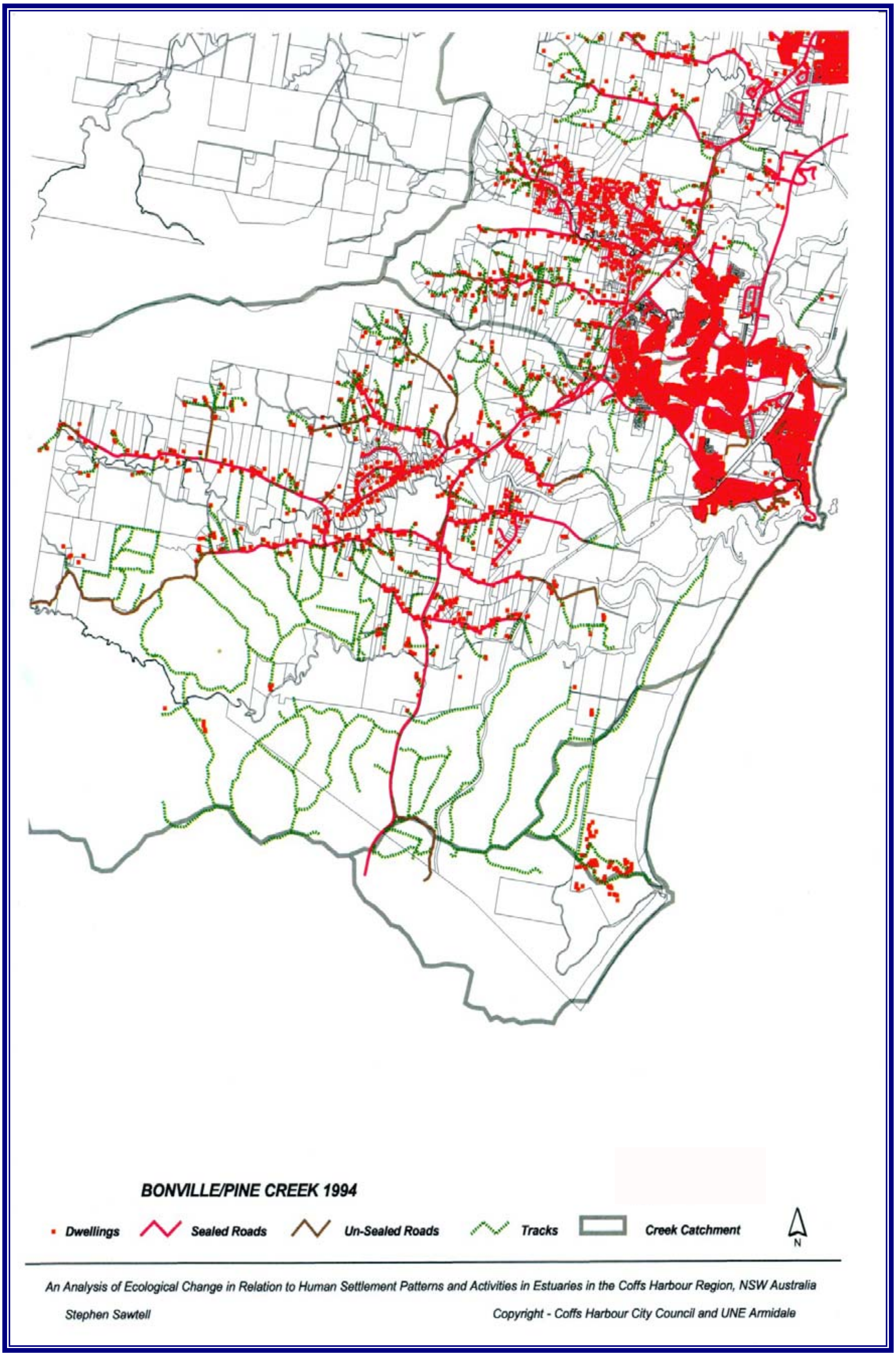


Figure 5-18 - Human settlement patterns Bonville/Pine Creek - 1994

5.3.2.1 BANANA CULTIVATION - BONVILLE CREEK (1954 - 1994)

Banana cultivation experienced a net increase from a 1954 total of 11.95 ha, to 88.48 ha in 1974 with a decrease to 74.43 ha in 1994 (Figure 5-19 to Figure 5-21). Raw data appears in Appendix 5.2

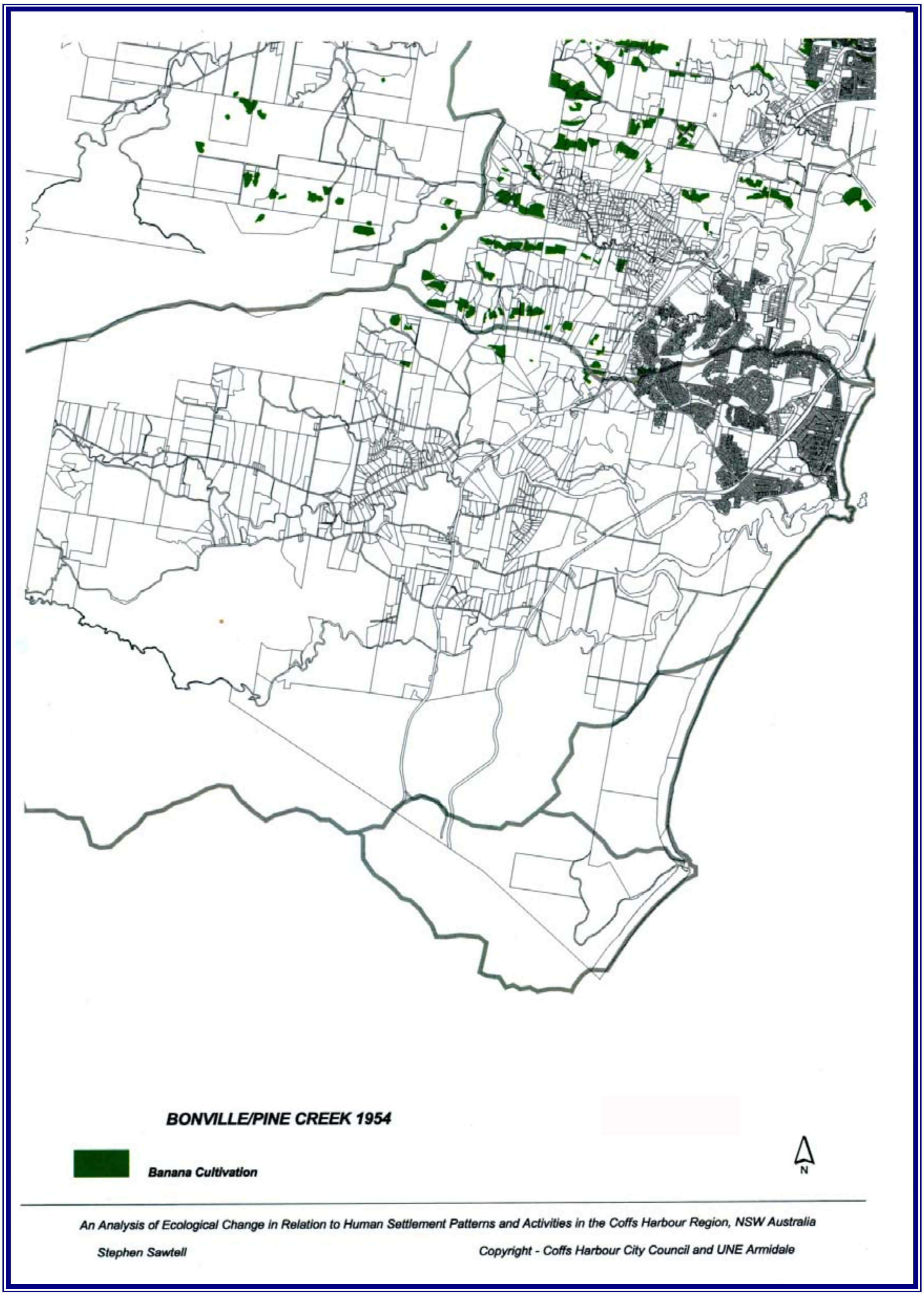


Figure 5-19 - Banana cultivation Bonville/Pine Creek 1954

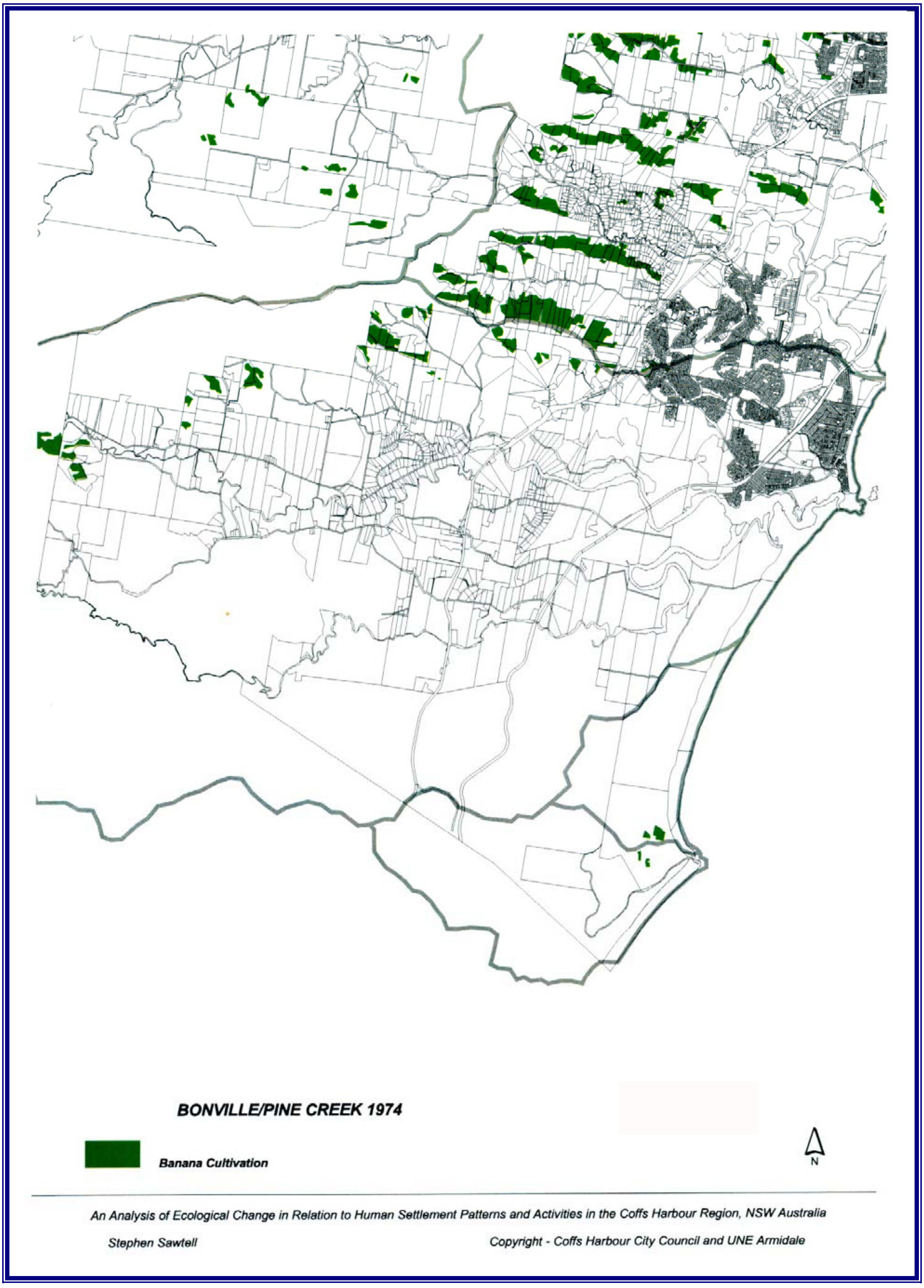


Figure 5-20 - Banana cultivation Bonville /Pine Creek 1974

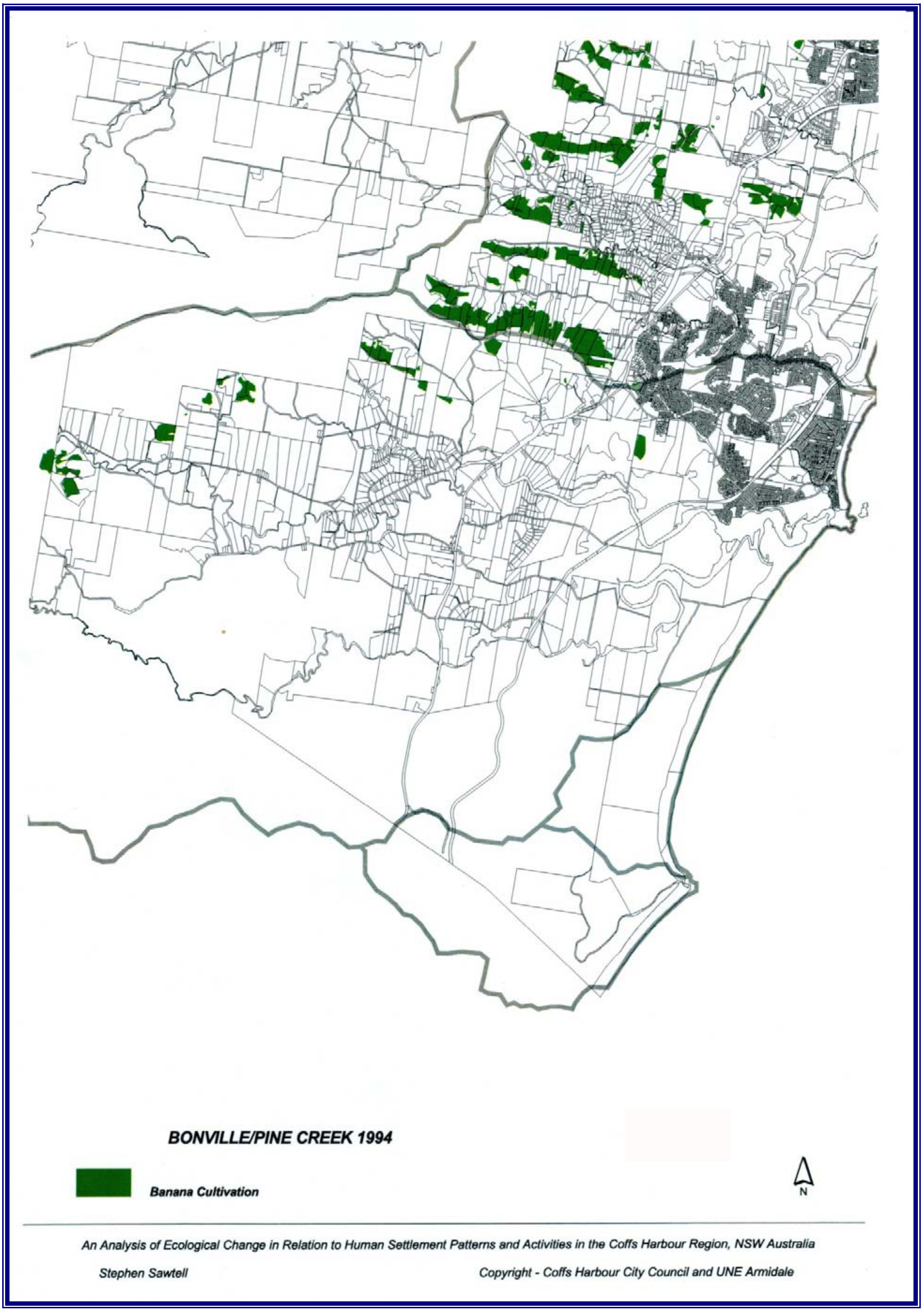


Figure 5-21 - Banana cultivation Bonville/Pine Creek 1994

5.3.3 PHYSICO/CHEMICAL VARIABLES, WATER QUALITY AND GRANULOMETRY - BONVILLE CREEK

5.3.3.1 WATER QUALITY

All water quality data are displayed graphically in Appendix. 1. pH in 1999 varied from 8.6 at Site 1 down to a pH of 7.9 at Site 4. Surface and depth readings were similar for pH although surface pH varied more than bottom pH in 1999. Site 1 had a depth of 2 metres, down to 2.5 metres at Site 4, which is towards the upper reaches of the creek system.

Conductivity at the surface and on the bottom were similar in 1997, though conductivity at the surface was lower in the 1999 sampling period dropping from 50 ms/cm down to 21 ms/cm at Site 4. Turbidity fluctuated in bottom readings between sites in 1997 and remained constant at the surface, 1999 turbidity readings were constant at surface and depth. Dissolved oxygen showed a marginal decrease from Site 1 to Site 4 in 1997; 1999 results displayed a marked decrease in dissolved oxygen ranging from Site 1 to Site 4 with surface reading being marginally higher than the bottom reading.

A decline occurred in salinity from Site 1 at 35‰ to Site 4 at 31‰ in 1997 for both surface and bottom. In 1999 there was a change in salinity at the surface from Site 1 at 35‰ to Site 4 at 12‰, which represents an overall decrease in salinity in moving from Site 1 to Site 4. Temperature remained reasonably constant in 1997 between 18ºC and 19ºC, this was markedly lower than the sampling period for 1999, where the surface sample at Site 4 increased to 25ºC. Bottom temperature remained constant at 24ºC. Raw data appear in Appendix 8.

5.3.3.2 FAECAL COLIFORM:

Geometric means (n=24 per annum) were taken across each year for both faecal and total coliforms. Bonville 1997 had a geometric mean of 49.2 faecal coliforms and 80.4 total coliforms, whilst in 1999 there was a mean of 75.04 faecal coliforms and 255.16 total coliforms, representing an increase in faecal and total coliform counts in the sampled water. (Appendix 9).

5.3.3.3 GRANULOMETRY

Sediment samples were taken at each site in the 1999 sampling period. Interpretation through the Wentworth grade classification indicates fine sand for each of the four sampling sites. Grain sizes ranged from 144.42 Um at Site 1; 149.2 Um at Site 2; 127.9 Um at Site 3 and 130.8 Um at Site 4 (Appendix 10). Grain size date were utilised in the calculation of Biological - Environmental (BIOENV) variables.

5.4 AN ANALYSIS OF CHANGES WITHIN THE BOAMBEE CREEK SYSTEM

5.4.1 ESTUARINE VEGETATION - BOAMBEE CREEK (1954 - 1994)

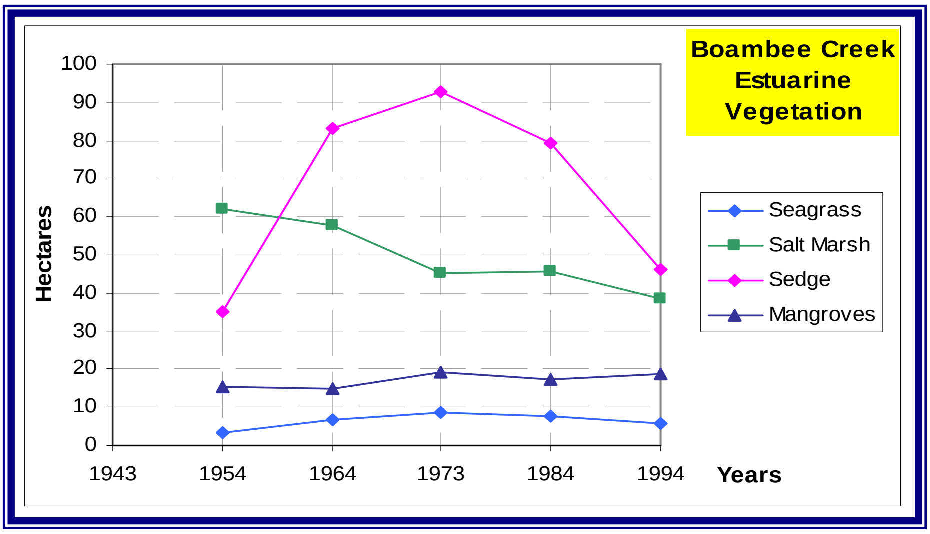


Figure 5-22- Estuarine vegetation 1954 - 1994 Boambee

Seagrass experienced a net increase rising from 3.6 ha in 1954 to 6.58 ha in 1964. This trend continued with 8.46 ha in 1974, 1984 dropped to 7.5 ha then increased again to 5.68 ha in 1994, which equates to a 57% increase on the 1954 figure (Table 5-19). Saltmarsh experienced a decline in area between 1954 and 1994 of 37%, the 1954 figure of 62.05 ha, is in contrast to 38.65 ha in 1994. Mangroves have experienced a net increase in area of 20.3%, 1954 recorded 15.45 ha in contrast to the 1994 figure of 18.58 ha, mangroves peaked in 1974 with 19.3 ha. Sedge/coastal heath presents a net increase in area of 31% on the 1954 figure, with considerable fluctuation in that period. The 1954 figure of 35 ha rose to a peak of 92.9 ha in 1974 which then dropped off to 46.39 ha in 1994, this fluctuation relates to the clearing, regrowth and clearing again of vegetation in the airport precinct.

Table 5-19 Percentage change in estuarine vegetation in Boambee Creek from 1954 - 1994

Percentage change for estuarine vegetation for Boambee Creek for the period 1954 - 1994

BOAMBEE CREEK – ESTUARINE VEGETATION (% Change)				
Year	Mangrove	Salt Marsh	Sea Grass	Sedge
1954	100.00	100.00	100.00	100.00
1964	-3.09	-7.03	82.95	135.88
1974	24.99	-27.04	135.06	164.05
1984	13.20	-26.48	108.12	125.33
1994	20.31	-37.72	57.94	31.86

Boambee Creek has evidenced less fluctuations in vegetation area than Bonville Creek. This has resulted in a net increase in mangroves, seagrass and sedge with a decline occurring in saltmarsh. Interpretation of aerial photography indicates a disappearance of sedge/heath in the Hi-Tech Drive industrial area with considerable diminishment of sedge in the airport precinct. Saltmarsh has gone through a discernable decrease to the north of the confluence of Boambee and Newports Creek. Changes to seagrass and mangroves are particularly concentrated above and below the confluence of Boambee and Newports Creek area.

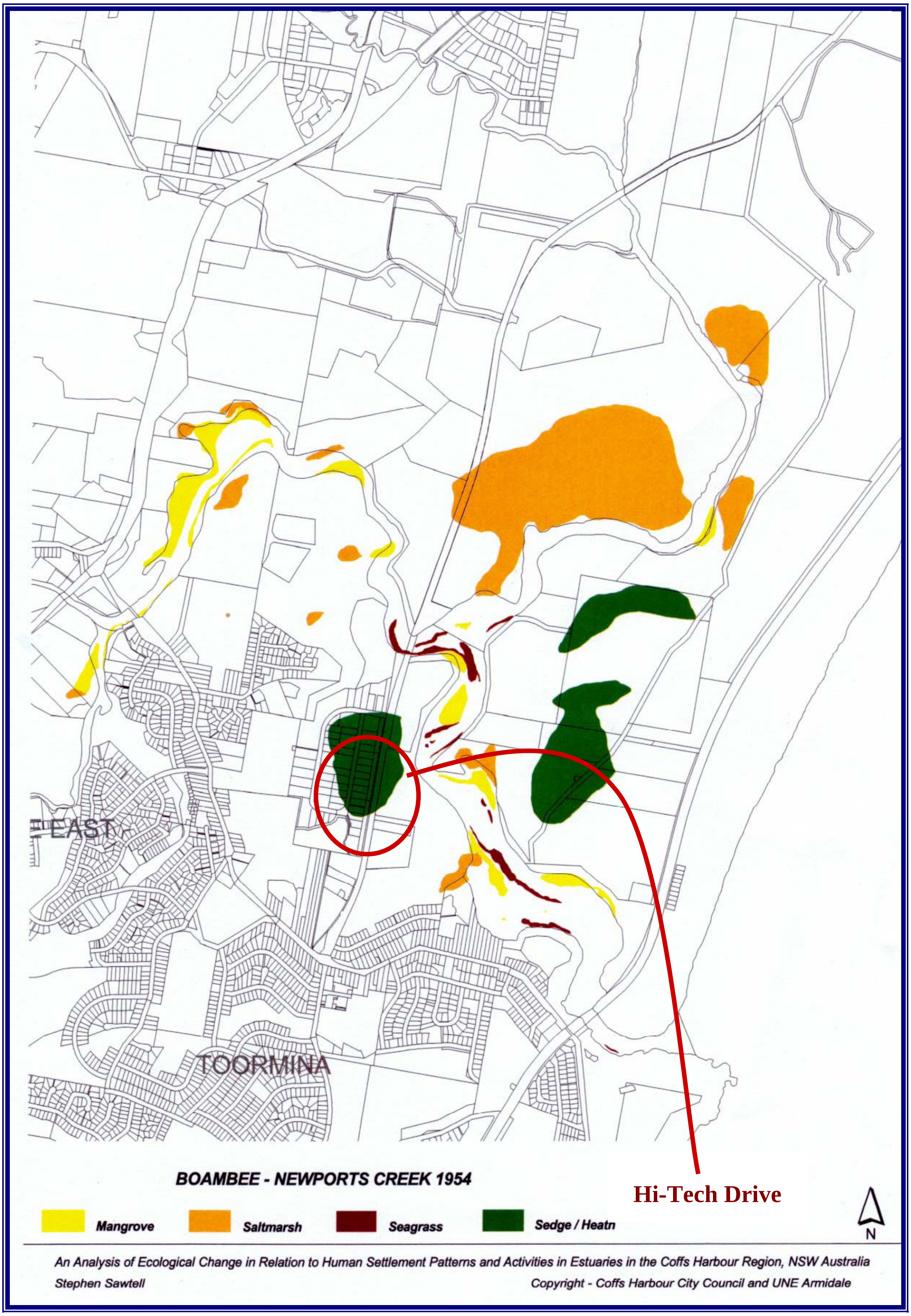


Figure 5-23 - Estuarine vegetation - Boambee - Newports Creek 1954

Distribution of the 4 vegetation types in Boambee - Newports/Creek in 1954

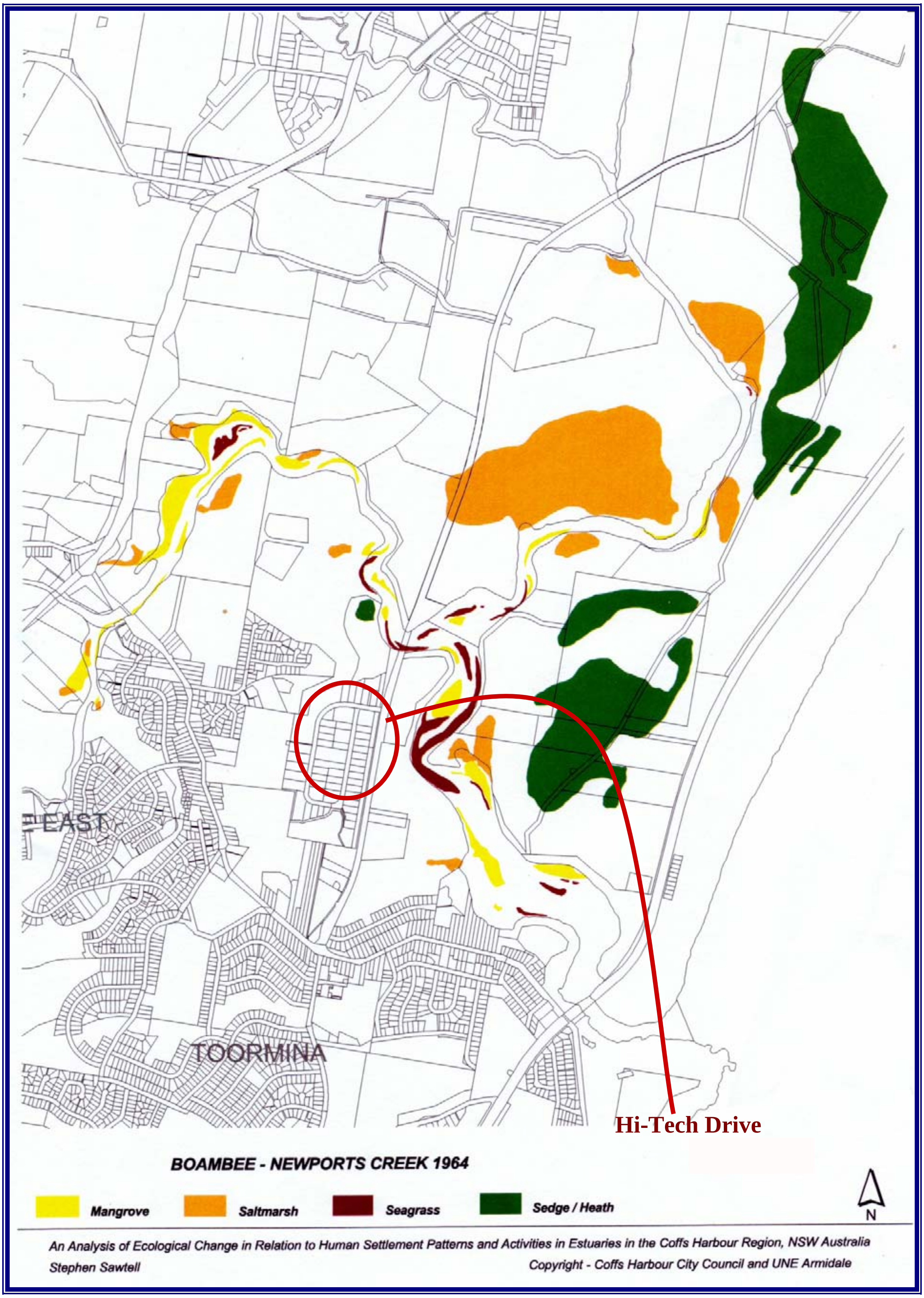


Figure 5-24 - Estuarine vegetation - Boambee - Newports Creek 1964
Distribution of the 4 vegetation types in Boambee - Newports/Creek in 1964

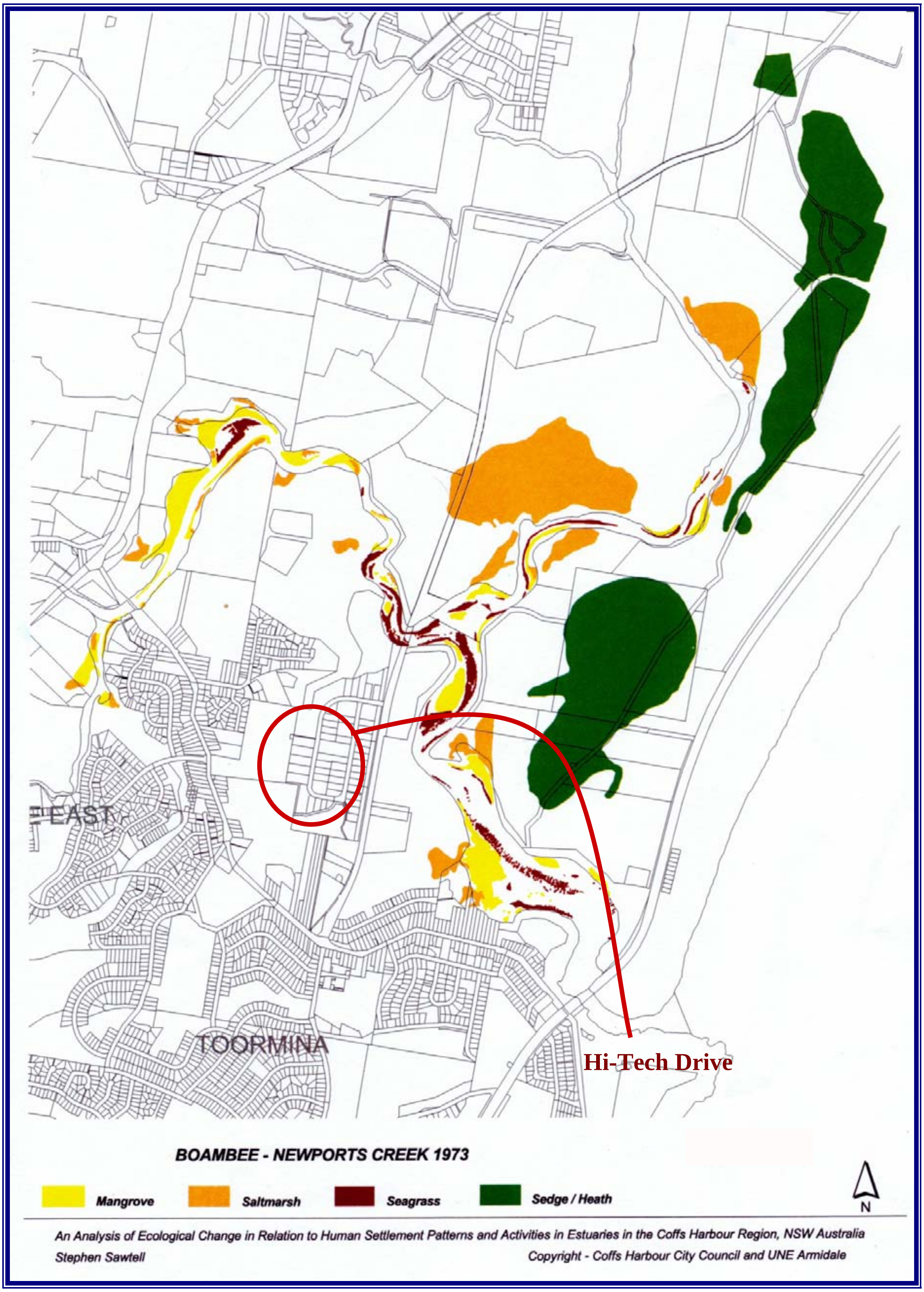


Figure 5-25 - Estuarine vegetation - Boambee - Newports Creek 1973
Distribution of the 4 vegetation types in Boambee - Newports/Creek in 1973

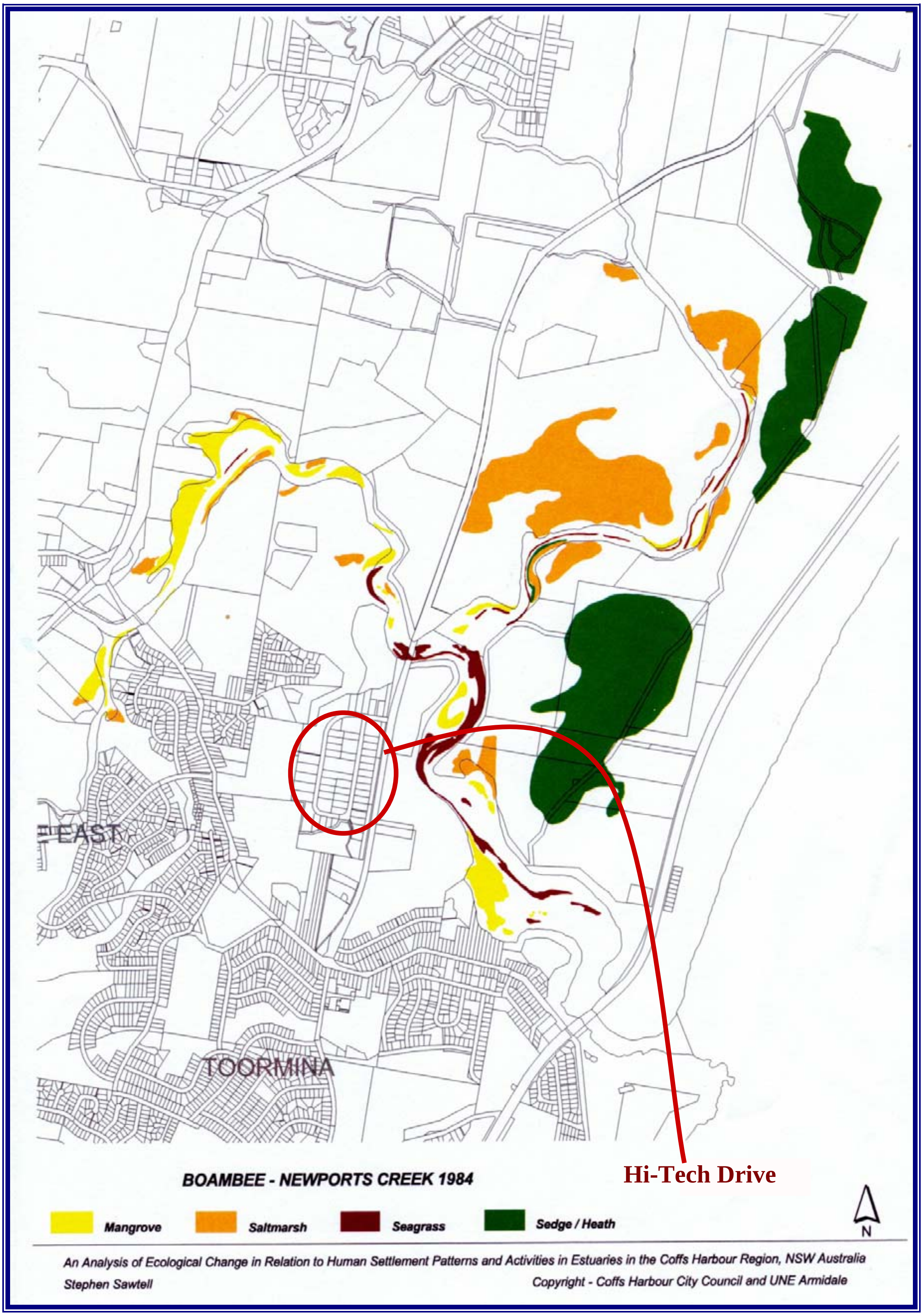


Figure 5-26 - Estuarine vegetation - Boambee - Newports Creek 1984
Distribution of the 4 vegetation types in Boambee - Newports/Creek in 1984

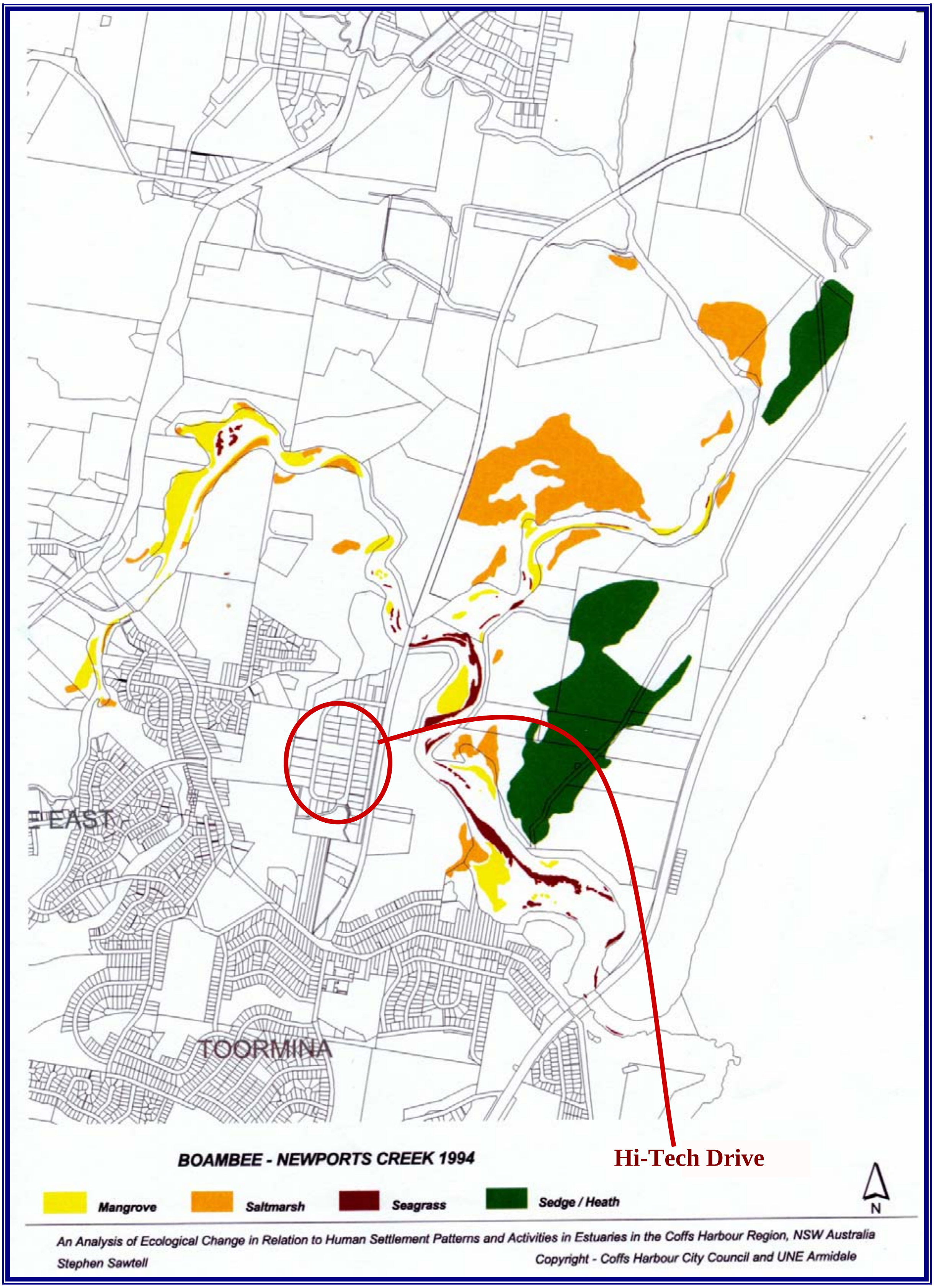


Figure 5-27 - Estuarine vegetation - Boambee - Newports Creek 1994
Distribution of the 4 vegetation types in Boambee - Newports/Creek in 1994

5.4.2 HUMAN SETTLEMENT PATTERNS - BOAMBEE

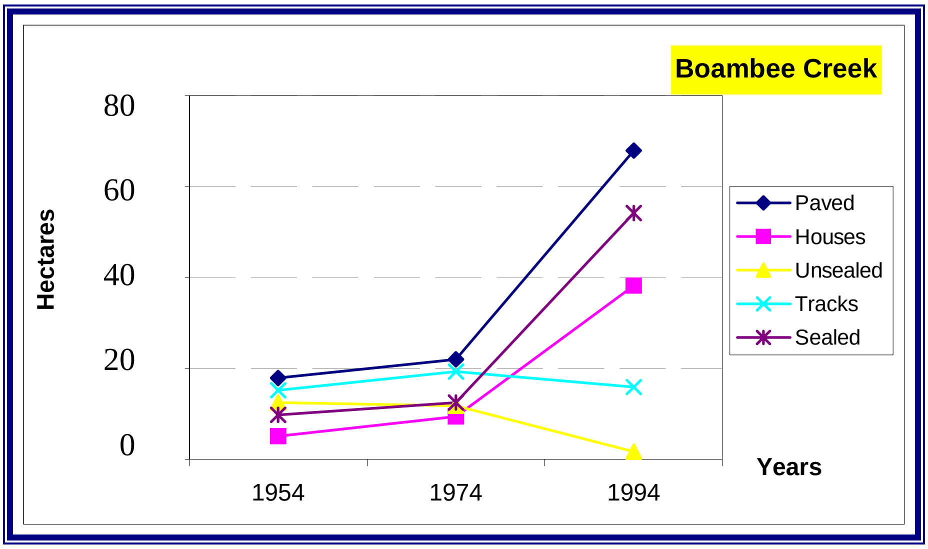


Figure 5-28 - Human settlement patterns Boambee Creek 1954 - 1994

Table 5-20 - Human settlement patterns Boambee Creek 1954 - 1994

BOAMBEE CREEK – HUMAN SETTLEMENT PATTERNS (Ha)					
	Paved	**Houses**	**Unsealed**	**Tracks**	**Sealed**
1954	17.81	5.05	12.49	15.11	9.75
1974	21.99	9.42	11.70	19.29	12.46
1994	67.92	38.20	1.68	15.88	54.21

Boambee catchment showed a 655% increase in housing area between 1954 and 1994. In 1954 there was a total of 337 houses with an area of 5.055 ha, which expanded to a total of 2,547 houses occupying an area of 38.2050 ha in 1994 (Table 5-20). A net increase of 281% in paved areas has occurred (representing industrial areas) since 1954, the 1954 figure of 17.81 ha increased up to 1994 to 67.9238 ha. Sealed roads have increased 455% between 1954 and 1994. In 1954 a total of 9.76 ha of sealed roads were evident, with an increase to 54.21 ha in 1994. The area of unsealed roads decreased by 86% from 12.49 ha in 1954 to 1.68 ha in 1994. For the same period tracks increased by 5.09% rising from 15.16 ha in 1954 to 15.87 ha in 1994.

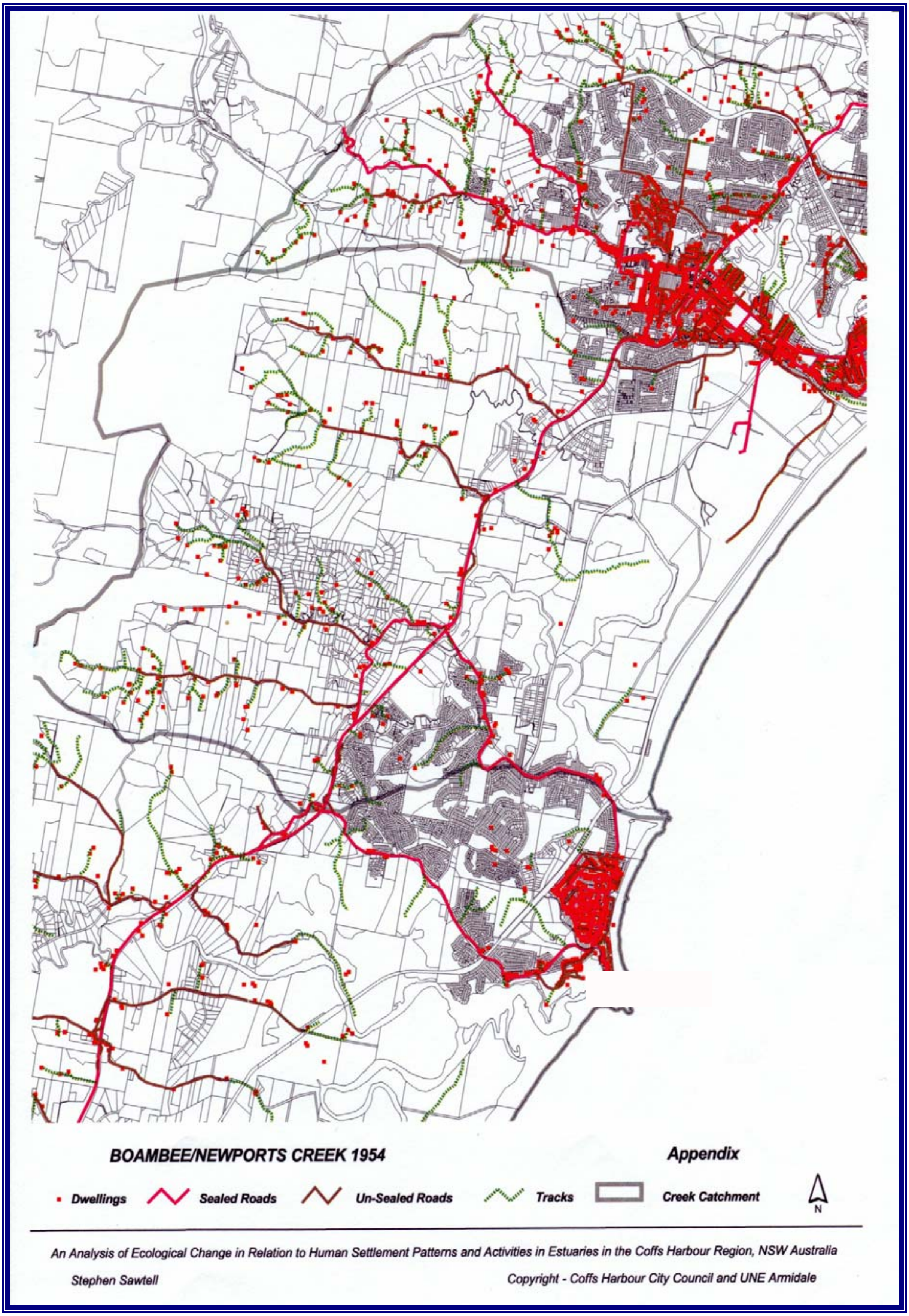


Figure 5-29 - Human settlement patterns - Boambee - Newports Creek 1954

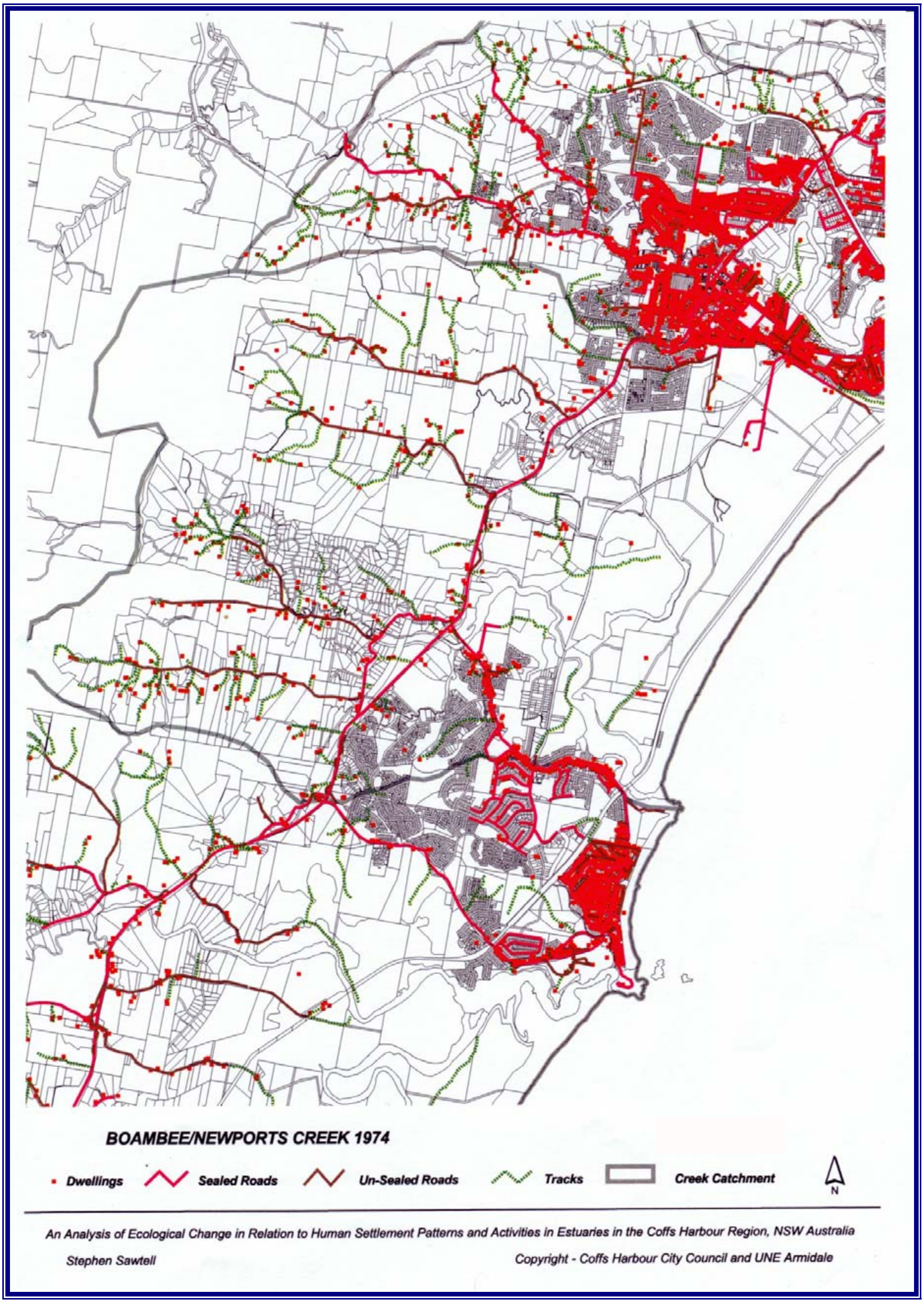


Figure 5-30 - Human settlement patterns - Boambee - Newports Creek 1974

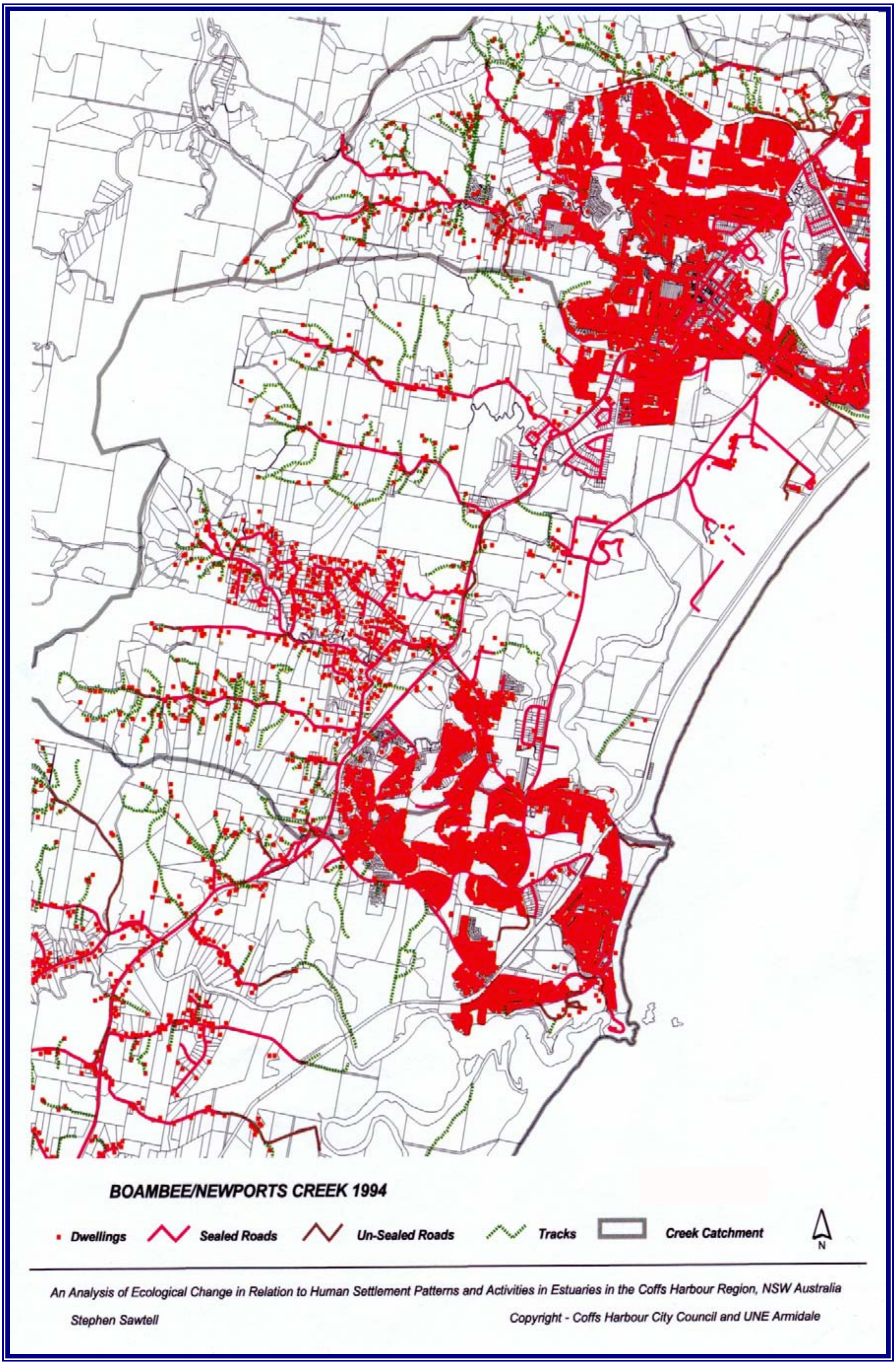


Figure 5-31 - Human settlement patterns - Boambee - Newports Creek 1994

5.4.2.1 BANANA CULTIVATION

Banana cultivation evidenced 261.98 ha in 1954 which then rose to 476.75 ha in 1974 and then dropped off to 413.73 ha in 1994. Raw data appears in Appendix 5.2.

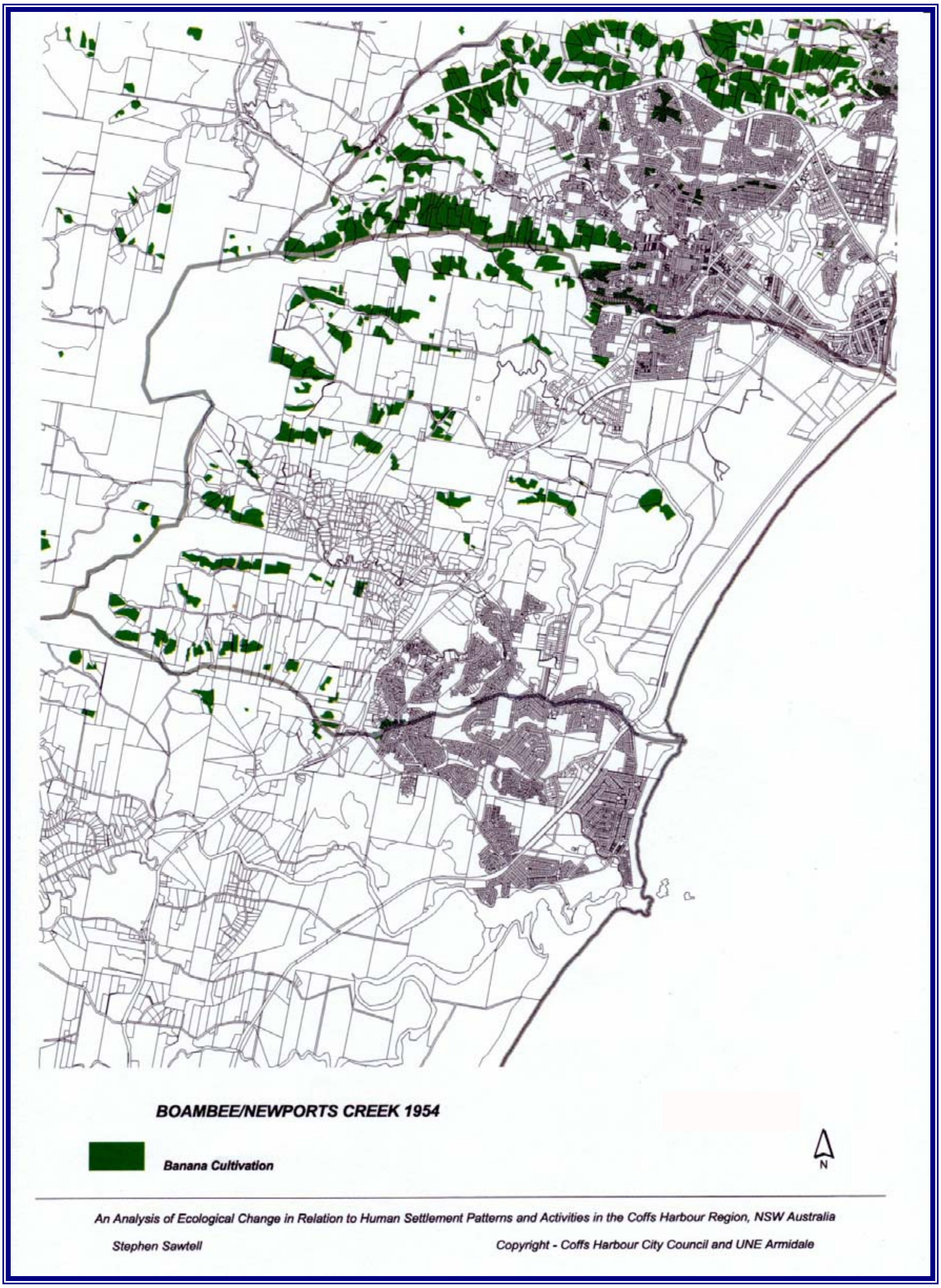


Figure 5-32 - Banana cultivation - Boambee - Newports Creek 1954

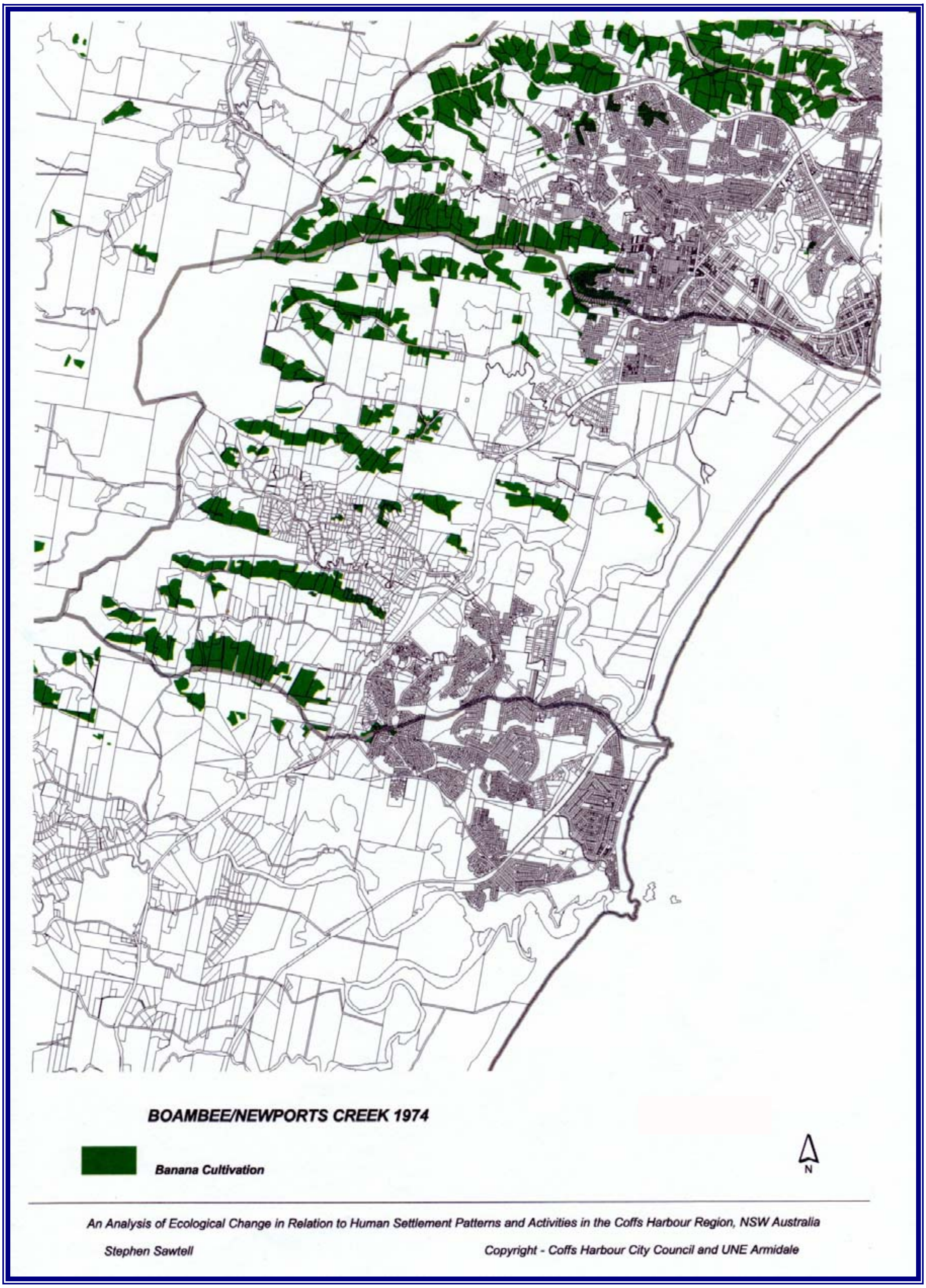


Figure 5-33 - Banana cultivation - Boambee - Newports Creek 1974

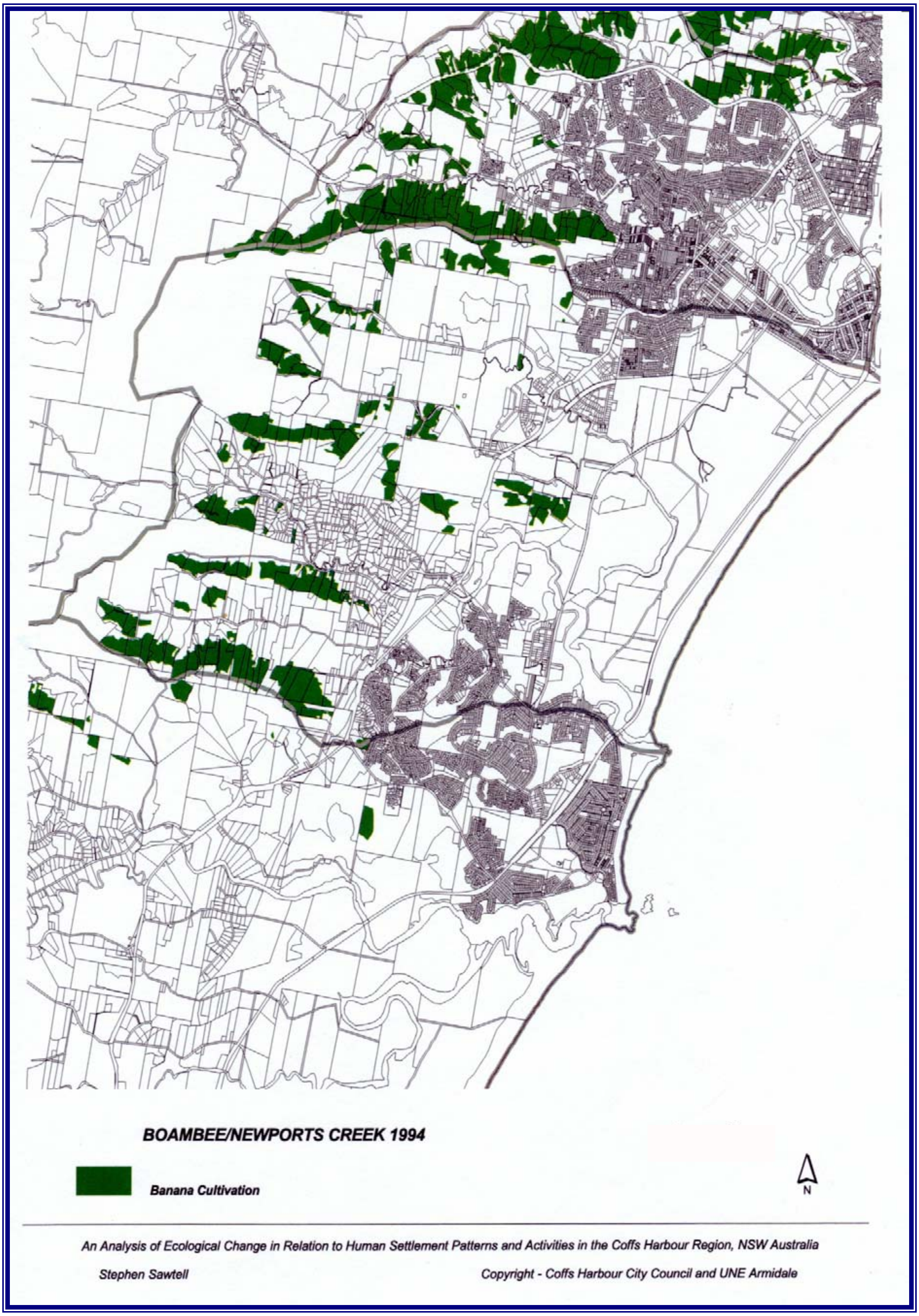


Figure 5-34 - Banana cultivation - Boambee - Newports Creek 1994

5.4.3 PHYSICO/CHEMICAL VARIABLES, WATER QUALITY AND GRANULOMETRY - BOAMBEE CREEK

5.4.3.1 WATER QUALITY

pH remained constant at 8 for the 1997 sample period, both at surface and at depth. A variation occurred in 1999 between surface and bottom readings, site 1 and 2 were similar, site 3 differentiated from a pH of 8.2 at surface to 8.5 at depth, with site 4 reading 8.1 at the surface and 8.4 at depth. Depth ranged from 1.3 metres at the mouth (site 1) to 1.7 metres at site 4 in the upper reaches, sample depth for 1999 was 1 metre at site 1 and 1.8 metres at site 4. Conductivity remained similar at both the surface and at depth for the 1997 sample period with a marked difference occurring in 1999 between sites 1 and 4, particularly between surface and depth. Surface conductivity dropped to 35 ms/cm at depth compared to 50 ms/cm at surface for site 1 (1999) and site 4 was 15 ms/cm at surface compared to 50 ms/cm at depth. Turbidity fluctuated in the 1997 period ranging from 15 to 30 NTU, in 1999 there was very little turbidity occurring at sites 1, 2 and 3 with a marked difference at site 4 with increased turbidity at depth to 60 NTU.

1997 sampling showed a drop in DO from site 1 progressively to site 4 commencing at 7 mg/L dropping to less than 5 mg/L, a degree of mixing was apparent at surface and depth with results remaining the same. 1999 sampling sites 1, 2 and 3 were the same fluctuating around a DO of 5mg/L with variation occurring between depth of 3.8 compared to surface at 5.5 for site 4. Salinity dropped marginally at sites 3 and 4 in 1997 from 35‰ to 3‰. There was a marked difference in the 1999 sample period results. Salinity decreased from sites 1 to 4 at surface with bottom salinity remaining reasonably constant at around 35‰, only slightly decreasing from site 1. Temperature in 1997 dropped markedly from site 1 at 21ºC to site 4 with 18ºC, both depth and surface were similar. In 1999 depth and surface were the same at a constant temperature of 23ºC.

5.4.3.2 FAECAL COLIFORM:

The geometric mean (n=24 per annum) was taken for faecal coliform and total coliform readings for the periods 1997 and 1999. Boambee 1997 had a geometric mean of 36.74 faecal coliform and 50.20 total coliform whilst 1999 presented 139.11 faecal coliform and 335.55 total coliform, representing an overall increase.

5.4.3.3 GRANULOMETRY

Refer to Appendix for Materials Grading Data. All samples were converted to weighted means.

Interpretation through the Wentworth grading classification indicates site 1 and 2 were classified as fine sands, site 3 was classified as very fine sand and site 4 was classified as silty clay. Grain sizes ranged from 129.57 Um at site 1, 144.79 Um at site 2, 95.77 Um at site 3 and 83.74 Um at site 4.

5.5 AN ANALYSIS OF CHANGES WITHIN THE COFFS CREEK SYSTEM

5.5.1 ESTUARINE VEGETATION: - COFFS CREEK (1954 - 1994)

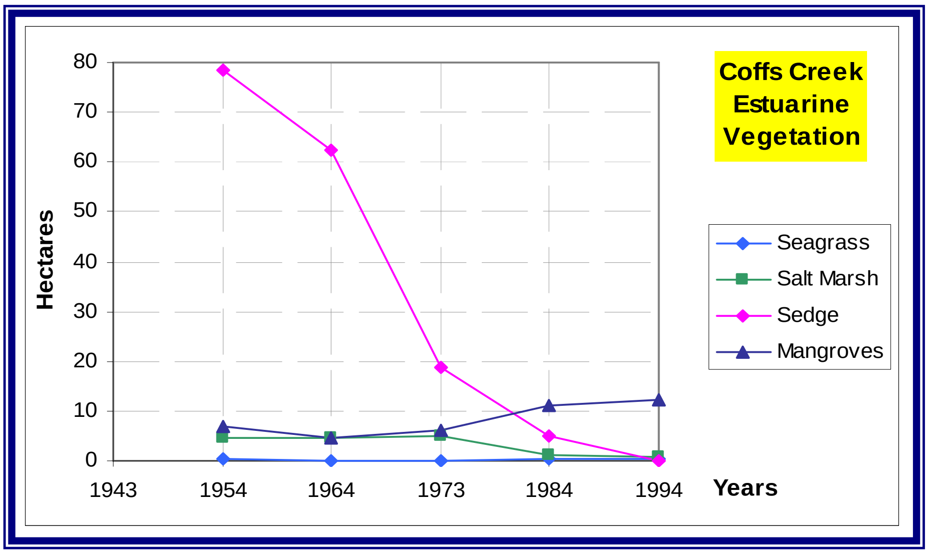


Figure 5-35- Estuarine vegetation 1954 - 1994 Coffs Creek

Table 5-21 - Percentage change in estuarine vegetation in Coffs Creek from 1954 - 1994

COFFS CREEK – ESTUARINE VEGETATION (% Change)				
Year	Mangrove	Salt Marsh	Sea Grass	Sedge
1954	100.00	100.00	100.00	100.00
1964	-35.44	3.46	-32.48	-20.43
1974	-11.16	7.48	-39.00	-75.90
1984	62.46	-77.39	-31.47	-93.58
1994	78.18	-79.20	36.55	-100.00

An increase in seagrass has occurred in the period between 1954 and 1994, the 1954 figure of .28 ha dropped in the period 1964 to 1984, then increased to 0.384 ha in 1994. This represents a 36.5% net increase, though measured in very low square metre area. Saltmarsh indicated a net loss of 79.2% dropping from a 1954 figure of 4.6 ha to 0.96 ha in 1994. Mangroves experienced a net increase of 78% based on the 1954 figure of 6.9 ha increasing to a 1994 figure of 12.3 ha. Sedge/coastal heath suffered a 100% loss dropping from 78.37 ha in 1954 to zero in 1994, a remnant of 5.02 ha was still evident in 1984. In summary, Coffs Creek experienced considerable loss of sedge and saltmarsh with a marginal increase in seagrass and a dramatic increase in mangroves.

Interpretation of aerial photography from 1954 indicates a complete loss of sedge from the Lawson Crescent Industrial area through into the Park Beach residential areas. A loss of saltmarsh is coincidental with an increase of mangroves. This is evident in at least eight positions along the creek. (Figs. 5-36 to 5 - 39.)

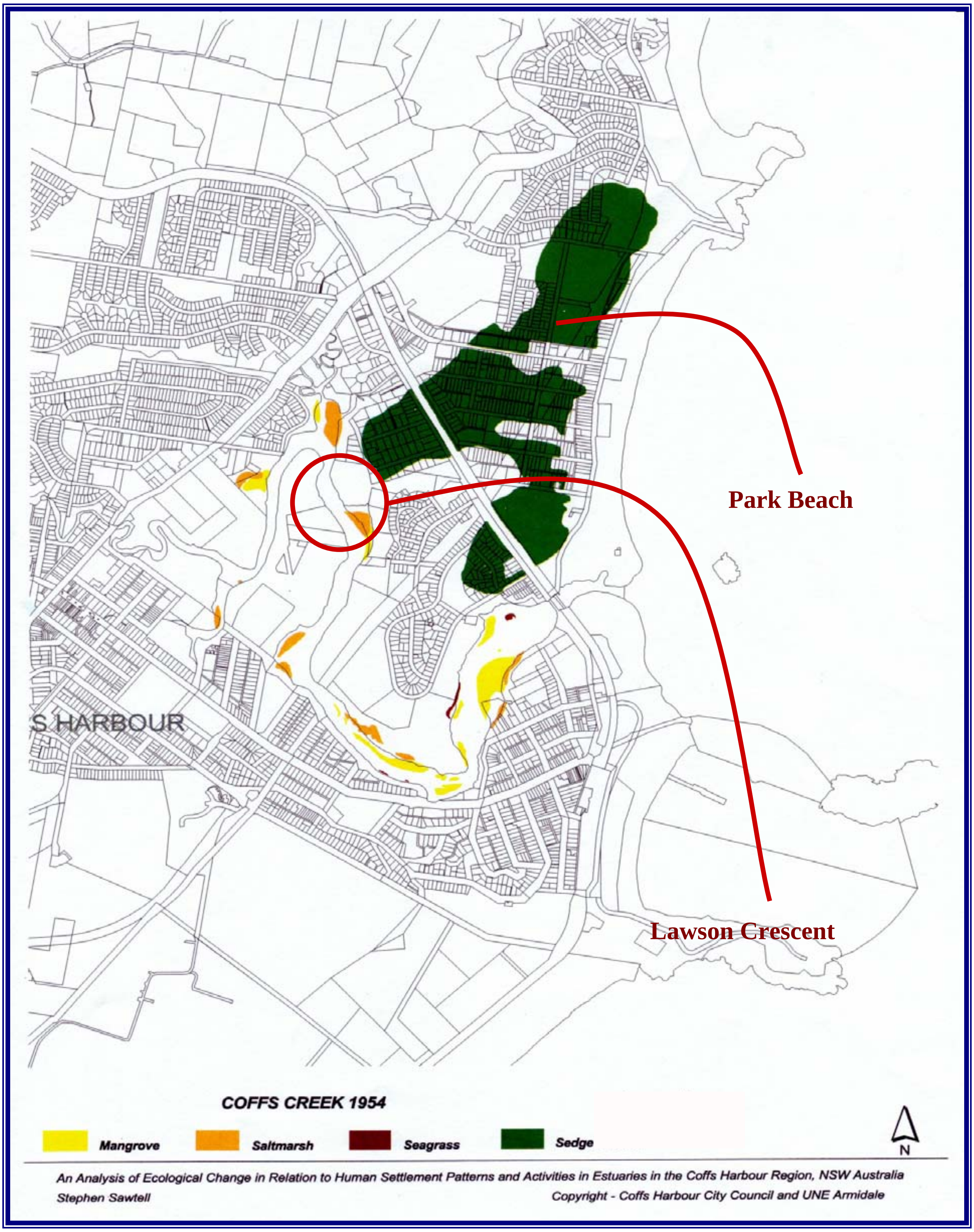


Figure 5-36 - Estuarine vegetation - Coffs Creek 1954

Distribution of the 4 vegetation types in Coffs Creek in 1954

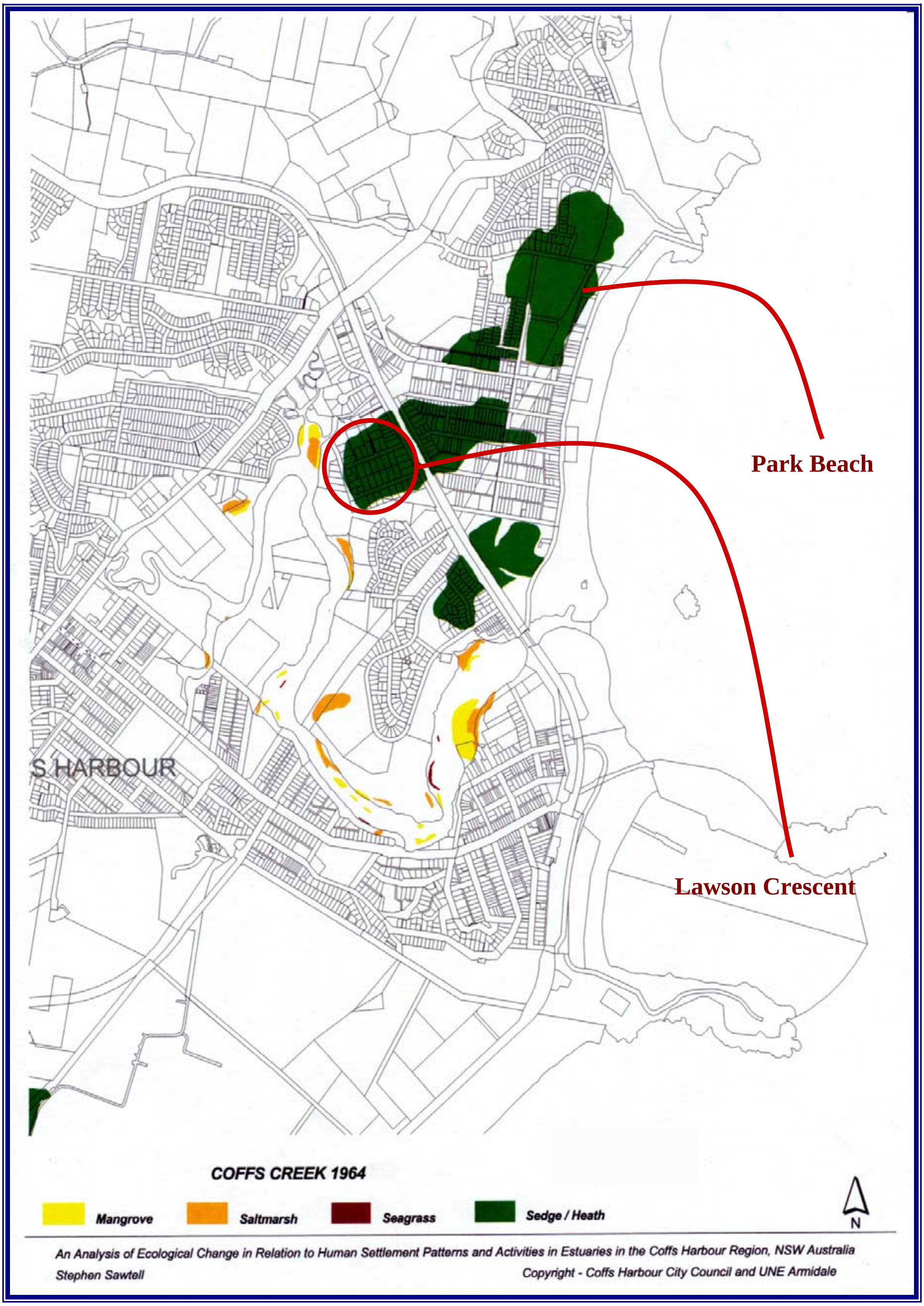


Figure 5-37 - Estuarine vegetation - Coffs Creek 1964
Distribution of the 4 vegetation types in Coffs Creek in 1964

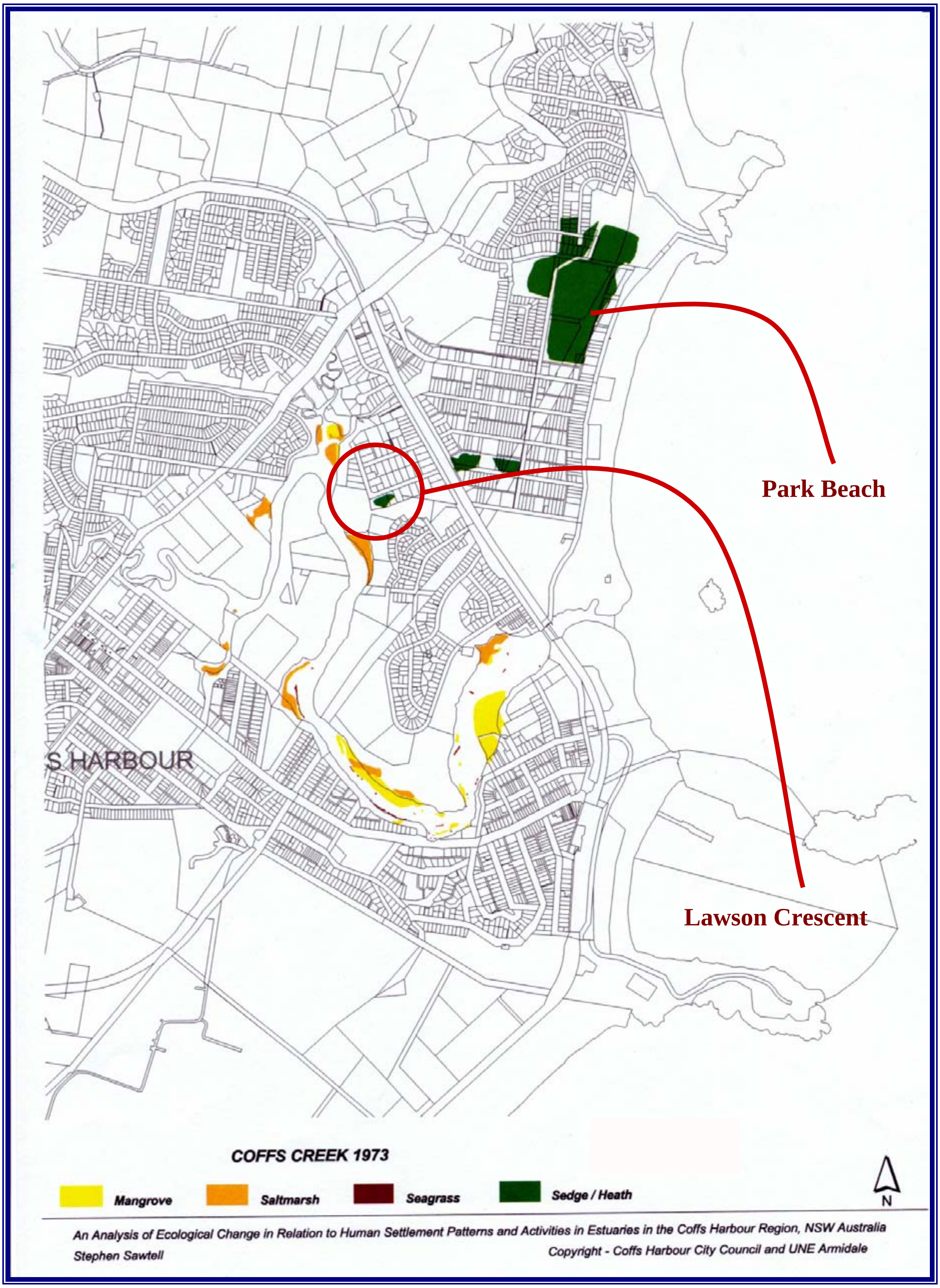


Figure 5-38 - Estuarine vegetation - Coffs Creek 1973
Distribution of the 4 vegetation types in Coffs Creek in 1973

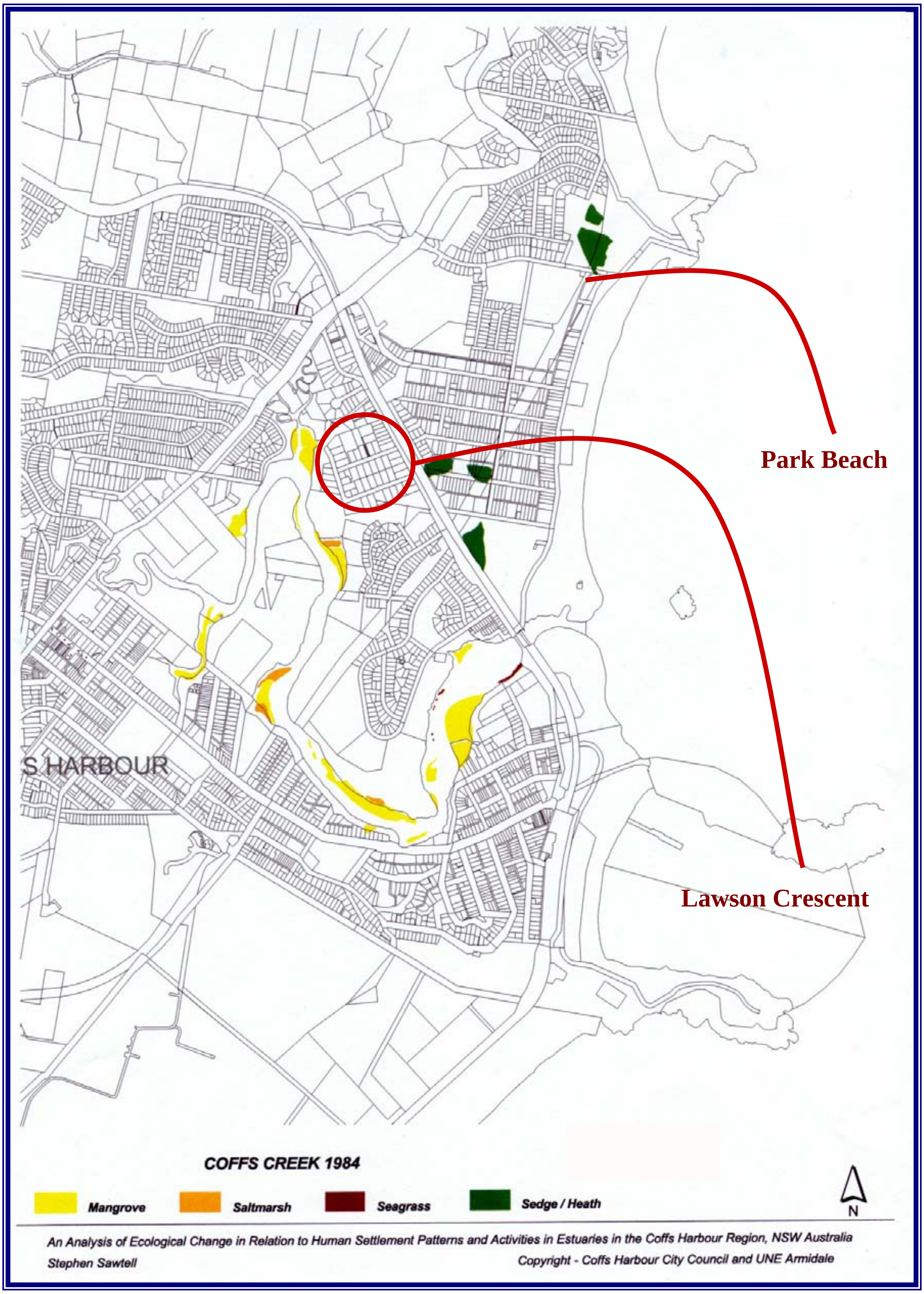


Figure 5-39 - Estuarine vegetation - Coffs Creek 1984
Distribution of the 4 vegetation types in Coffs Creek in 1984

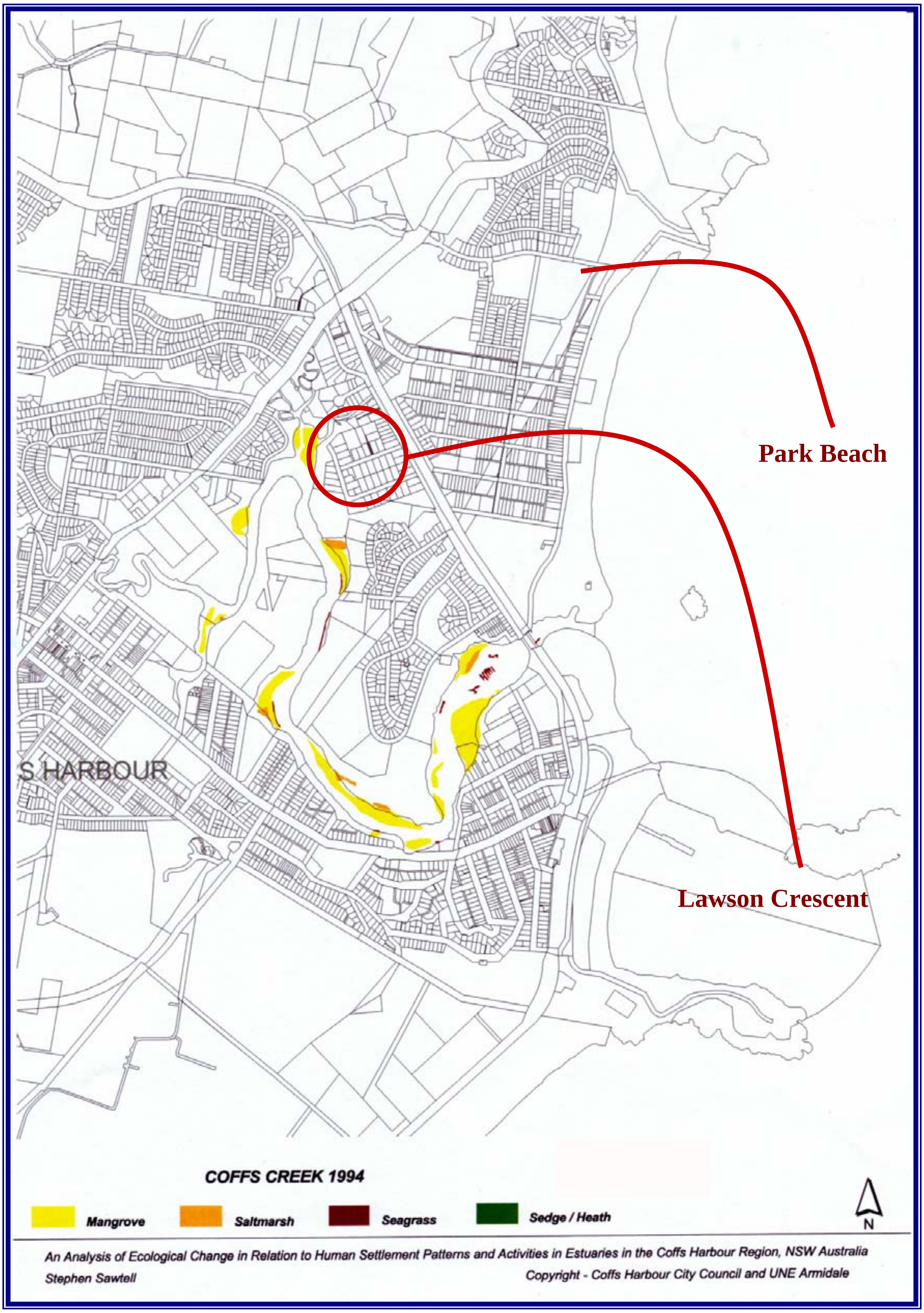


Figure 5-40 - Estuarine vegetation - Boambee - Newports Creek 1994
Distribution of the 4 vegetation types in Coffs Creek in 1994

5.5.2 HUMAN SETTLEMENT PATTERNS - COFFS CREEK

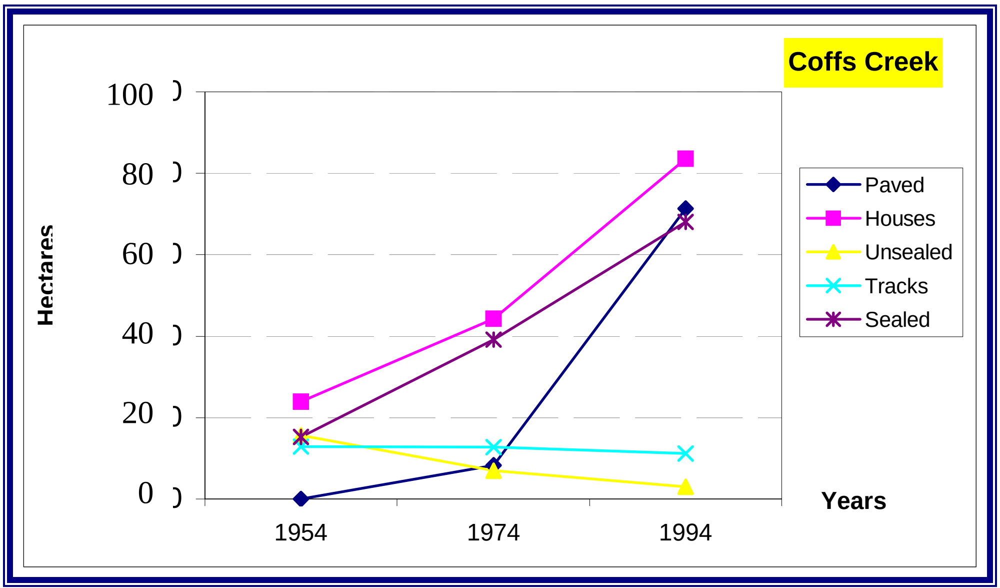


Figure 5-41 - Human settlement patterns Coffs Creek 1954 - 1994

Table 5-22 - Human settlement patterns Coffs Creek 1954 - 1994

COFFS CREEK – HUMAN SETTLEMENT PATTERNS (Ha)					
	Paved	**Houses**	**Unsealed**	**Tracks**	**Sealed**
1954	0	23.92	15.68	12.85	15.26
1974	82.60	44.31	6.92	12.71	39.19
1994	71.32	83.56	3.03	11.19	68.07

Housing has increased by 249% in the Coffs catchment, from a 1954 figure of 1,595 houses (23.92 ha) to 5,571 houses (83.56 ha) in 1994. Paved areas were not evident in 1954, the 1974 figure of 8.2 ha rose to 71.32 ha in 1994. Sealed roads have increased by 345% between 1954 (15.27 ha) and 1994 (68.08 ha). Unsealed roads decreased by 80% dropping from a 1954 figure of 15.69 ha to 3.04 ha in 1994. Tracks decreased by 12% from 1954 area of 12.856 ha to an area of 11.19 ha in 1994.

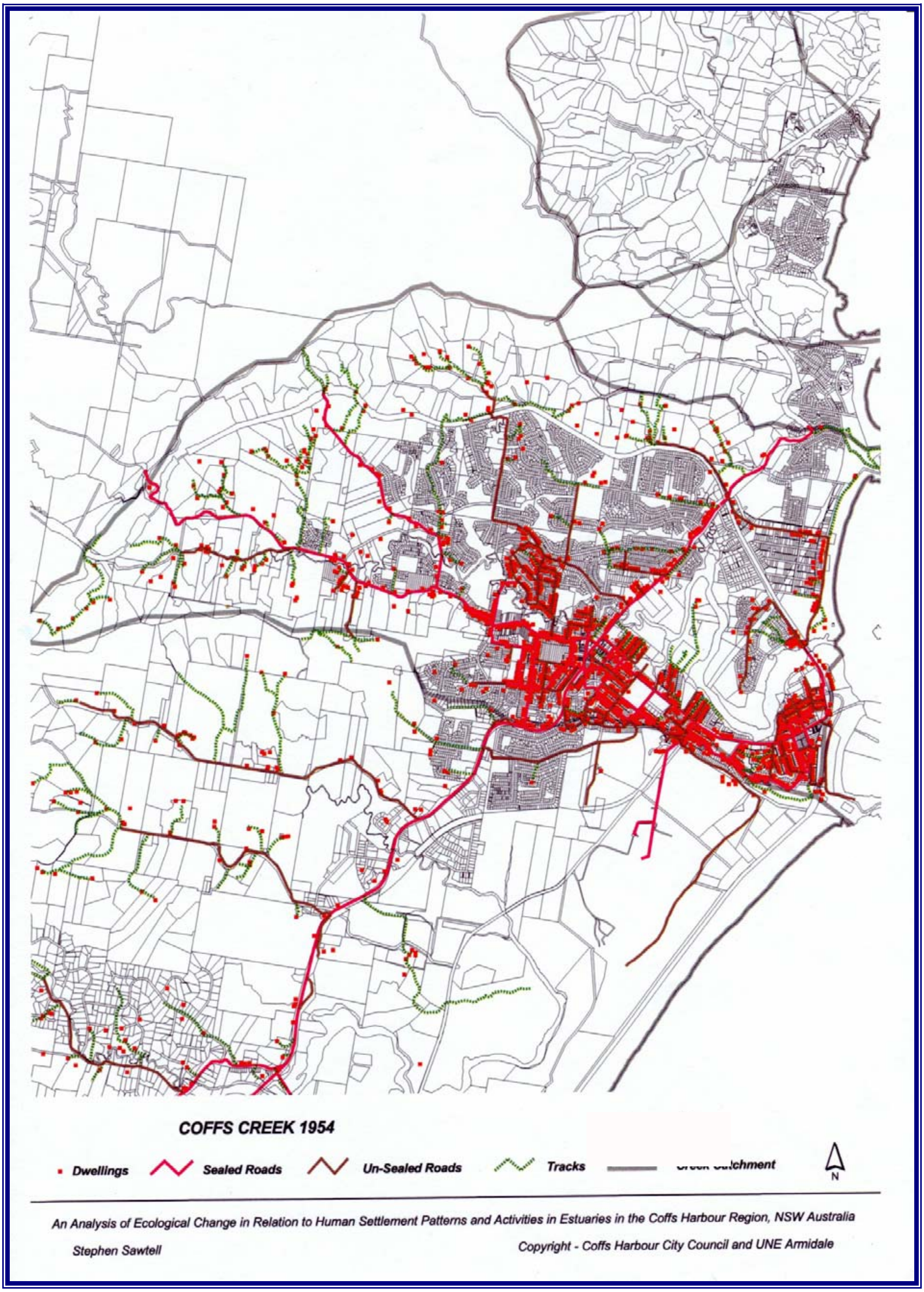


Figure 5-42 - Human settlement patterns Coffs Creek 1954

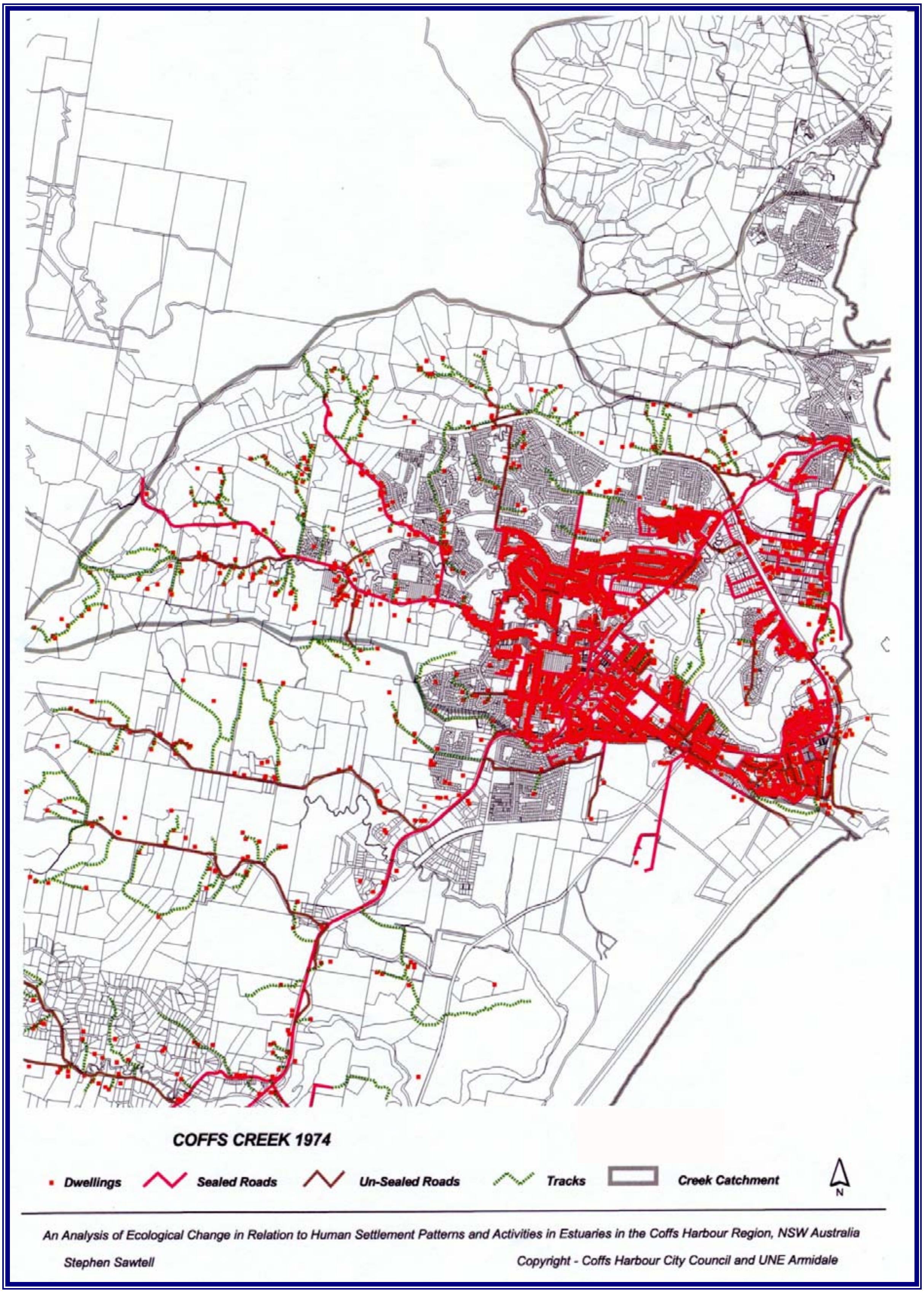


Figure 5-43 - Human settlement patterns Coffs Creek 1974

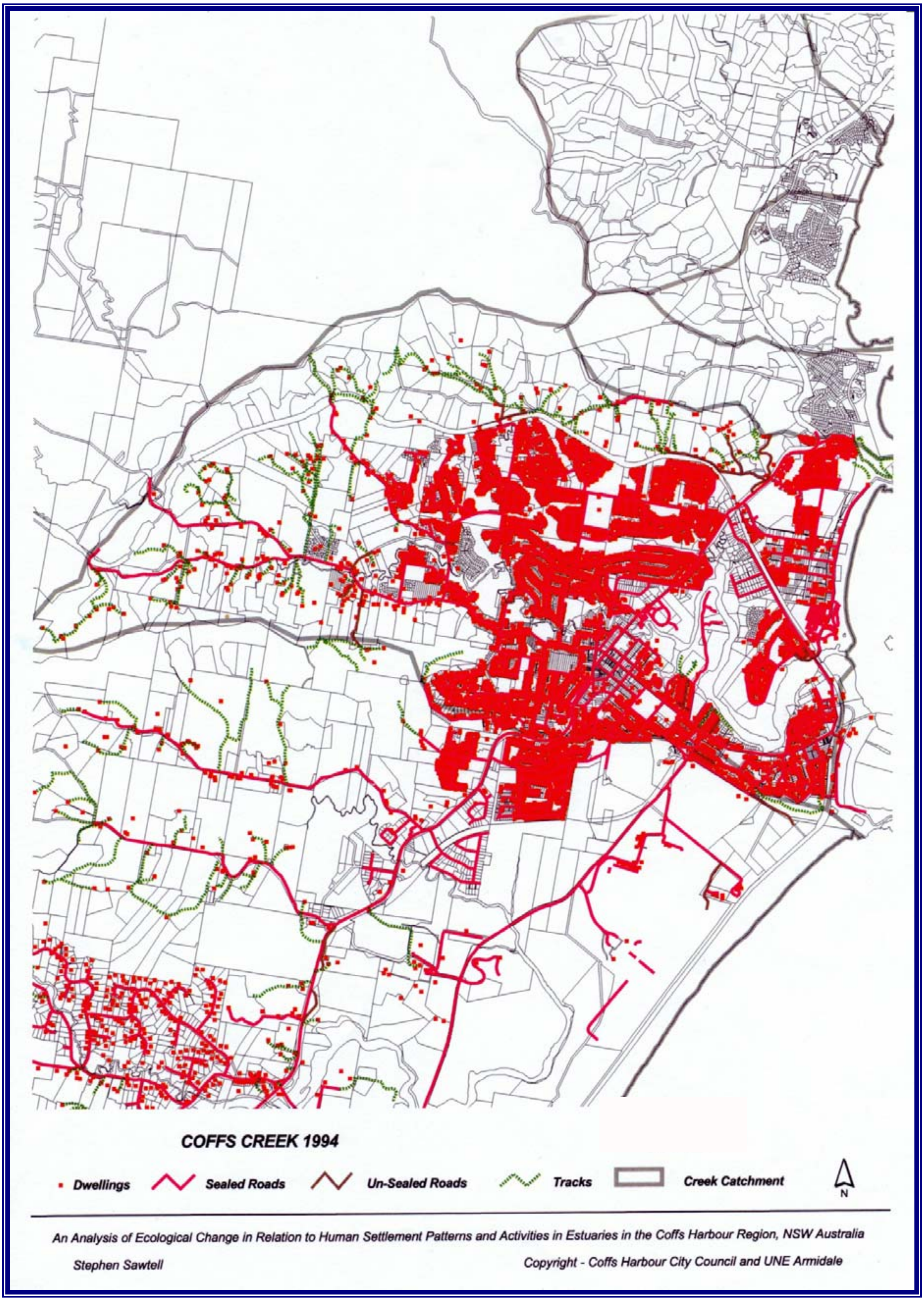


Figure 5-44 - Human settlement patterns Coffs Creek 1994

5.5.2.1 BANANA CULTIVATION - COFFS CREEK

Banana cultivation increased from the 394.59 ha in 1954 to a peak in 1974 of 490.25 ha, this dropped to an area of 409.50 ha in 1994. Interpretation of aerial photography from 19954 to 1994 clearly indicates an increase in housing densities of both residential and rural residential classifications encroaching into past banana growing areas.

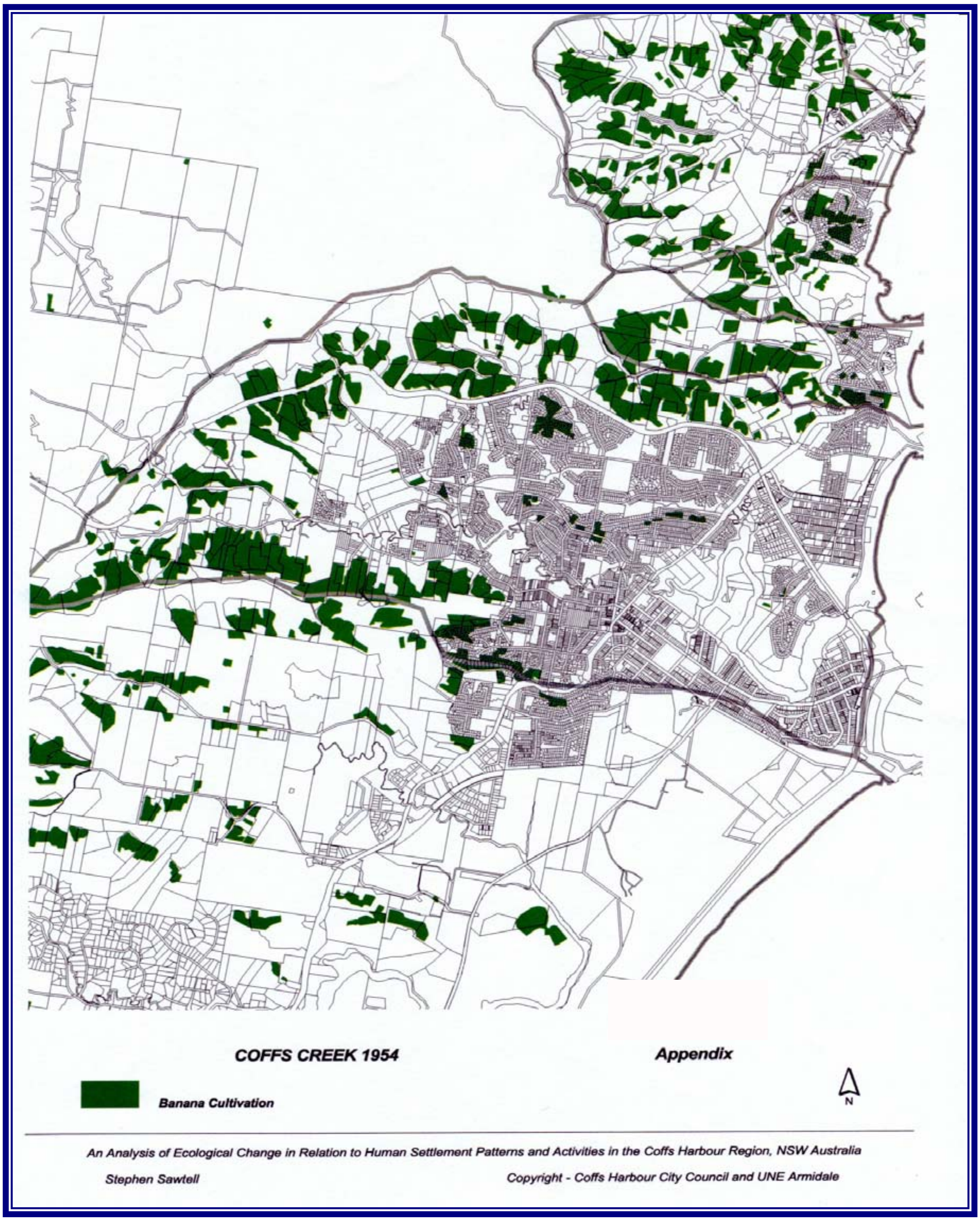


Figure 5-45 - Banana cultivation - Coffs Creek 1954

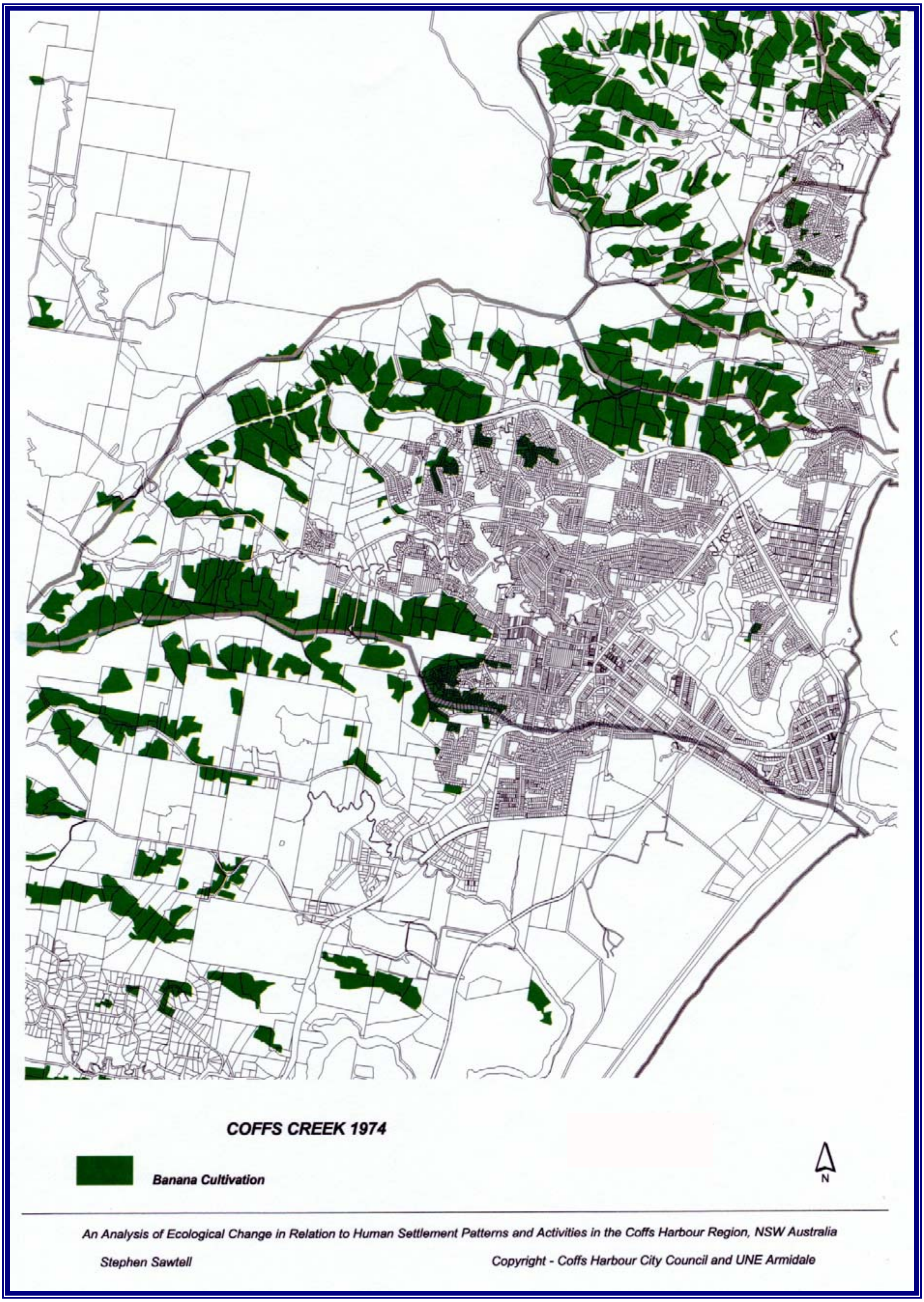


Figure 5-46 - Banana cultivation - Coffs Creek 1974

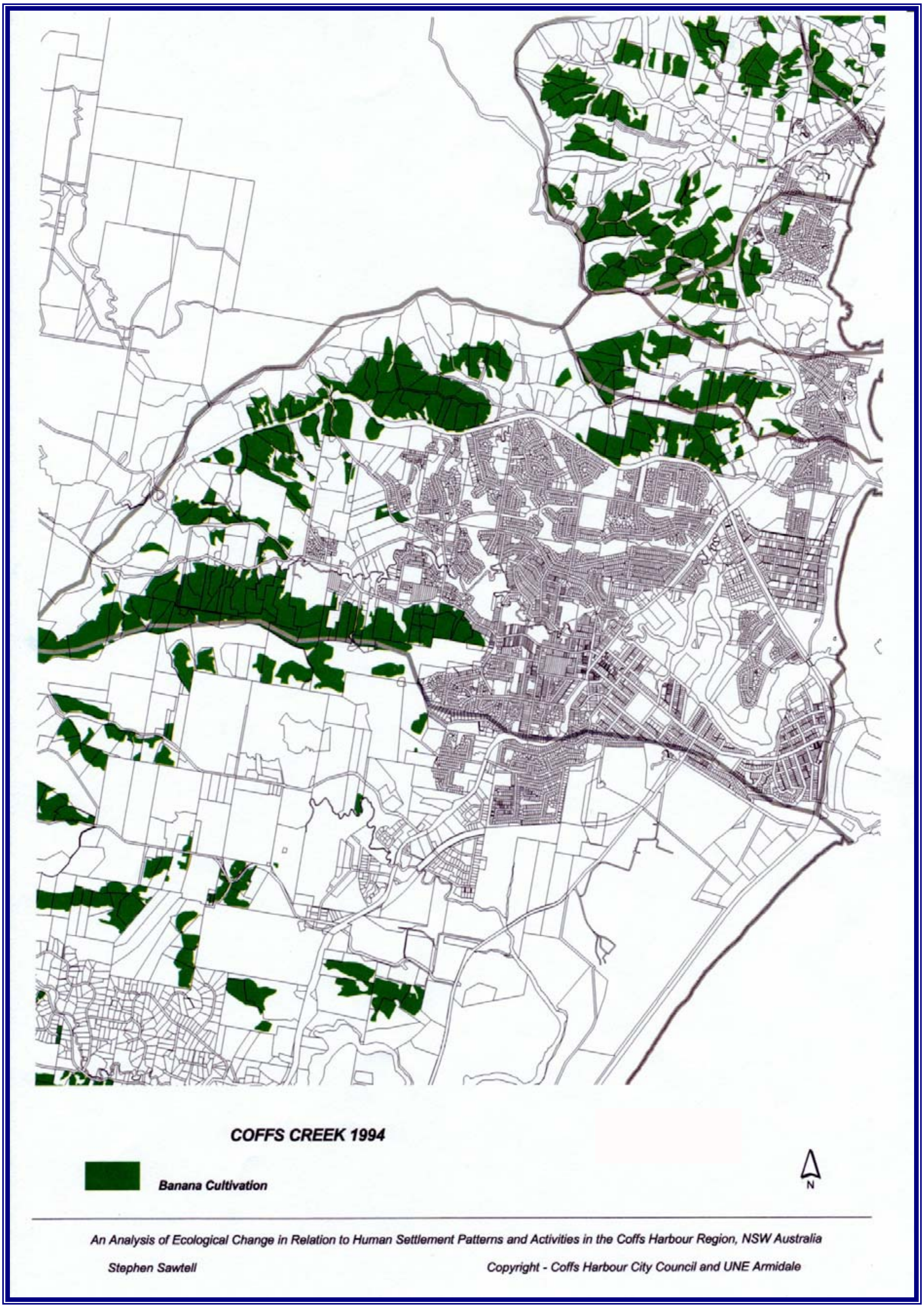


Figure 5-47 - Banana cultivation - Coffs Creek 1994

5.5.3 PHYSICO/CHEMICAL VARIABLES, WATER QUALITY AND GRANULOMETRY

5.5.3.1 WATER QUALITY - COFFS CREEK

pH dropped in the 1997 sample period from 8 at site 1 to 7.4 at site 4, this was a trend of both the surface and bottom samples, this was duplicated in the 1999 sample period where pH increased from 7.7 on the surface to 8.4 at depth, experiencing considerable fluctuation across all sites. Depth in 1997 was 1.5 metres at site 1 and 1.5 metres at site 4, depth in 1999 was 1 metre at site 1 and 1 metre at site 4. Conductivity for 1997 sample fluctuated with an overall decrease from site 1 to site 4 at depth with a minor decrease from site 1 to site 4 at surface. Turbidity for 1997 sampling period fluctuated considerably within the bottom samples, site 1 had a turbidity of 15 NTU, this increased markedly to 120 NTU for site 2 dropping off at site 3 to 30 NTU, then rising slightly to 40 NTU for site 4 at depth. 1999 sample period evidenced very little turbidity, surface ranged from 0 to 10 and depth ranged from 5 to 33 at site 2 and 3, dropping to 18 at site 4.

Dissolved oxygen displayed a marked drop-off from the entrance to the upper creek for the 1997 period with site 1 having a DO in excess of 6 mg/L dropping down at both surface and bottom to 3.5 mg/L at site 4. The 1999 sample period evidenced fluctuating DO between site 1 and 4 with a decrease from 5 mg/L at site 1 to 2.5 at site 4, this is in direct contrast to surface readings which evidenced an increase from 5mg/L at site 1 to 6.8 mg/L at site 4. Salinity in the 1997 sample period evidenced a drop from 35‰ at site 1 to 3‰ at site 4, the 1999 sample period evidenced divergent readings with a drop off at surface from 25‰ at site 1 to 4‰ at site 4 whilst the bottom readings fluctuated from 25‰ (site 1) up to 35% at site 2, then dropping down to 2‰ at site 4. This indicates considerable fresh water influence, not uniformly mixed in a gradient from the mouth to the upper reaches. Temperature for the 1997 sample period had a net decrease from 20ºC to 18ºC at site 4, the 1999 sample period provided divergent readings between surface and bottom. Surface readings averaging 18ºC and bottom readings rising from 19º for site 1 to 21º for sites 2, 3 and 4 were recorded.

5.5.3.2 FAECAL COLIFORMS

An increase in faecal and total coliform contamination has occurred in the estuary from 1997 to 1999 (n=25 per annum). Faecal coliform increased from 113.85/100ml in 1997 to 186.59/100 ml in 1999, total coliform increased from 161.1/100 ml in 1997 to 931.21 in 1999.

5.5.3.3 GRANULOMETRY

Interpretation using the Wentworth grading classification indicates that granulometry fluctuated from fine sand at site 1 (164.4 Um) to very fine sand at site 2 (113.4Um), fine sand at site 3 (126.5 Um) and very find sand again at site 4 (100.95 Um).

During field work to establish sites 3 and 4, grab sampling revealed a large stretch of gravel substrate downstream of Carrolls Creek which consisted of a crushed coarse gravel (0-4 mm) of basalt origin. This was adjacent to the stormwater drains and appears to be the gravel wash, or runoff, from the shoulders of the nearby roadways.

5.6 AN ANALYSIS OF CHANGES WITHIN THE MOONEE CREEK SYSTEM

5.6.1 ESTUARINE VEGETATION - MOONEE CREEK (1954 - 1994)

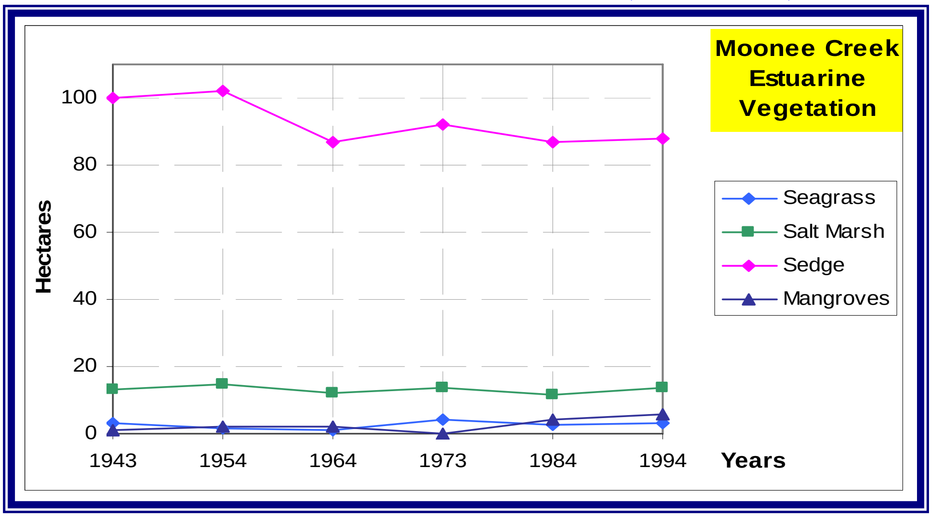


Figure 5-48 - Estuarine vegetation 1954 - 1994

Table 5-23 - Estuarine vegetation 1954 - 1994

MOONEE CREEK – ESTUARINE VEGETATION (% Change)				
Year	Mangrove	Salt Marsh	Sea Grass	Sedge
1954	100.00	100.00	100.00	100.00
1964	12.87	-14.92	-32.10	-14.93
1974	38.83	-4.48	144.05	-9.72
1984	129.45	-19.38	44.62	-14.72
1994	204.51	-5.09	76.81	-14.00

Seagrass experienced a net increase of 76.81% based on the 1954 area of 1.65 ha which increased to 2.92 ha. in 1994. Saltmarsh evidenced a 5% decline from the 1954 figure of 14.53 ha to 13.79 ha in 1994, during this time, the saltmarsh fluctuated dropping to 11.71 ha in 1984 and then increasing to 13.79 in 1994. Mangroves had a net increase of 204% based on the 1954 figure of 1.857 ha expanding to 5.66 ha in 1994.

A loss of 14% sedge occurred between 1954 and 1994, based on the 1954 area of 102.7 ha which dropped to 87.8 ha in 1994. The sedge fluctuated, ranging from 86.8 ha in 1964, increasing to 92.1 ha in 1974, slowly decreasing to 1984 (87.05 ha) with a minor rise in 1994 to 87.78 ha.

Interpretation of aerial photography indicates a variation of sedge to the west of Moonee Creek and to the north of the confluence with Skinners Creek (Fig 5.49 to Fig. 5.53).

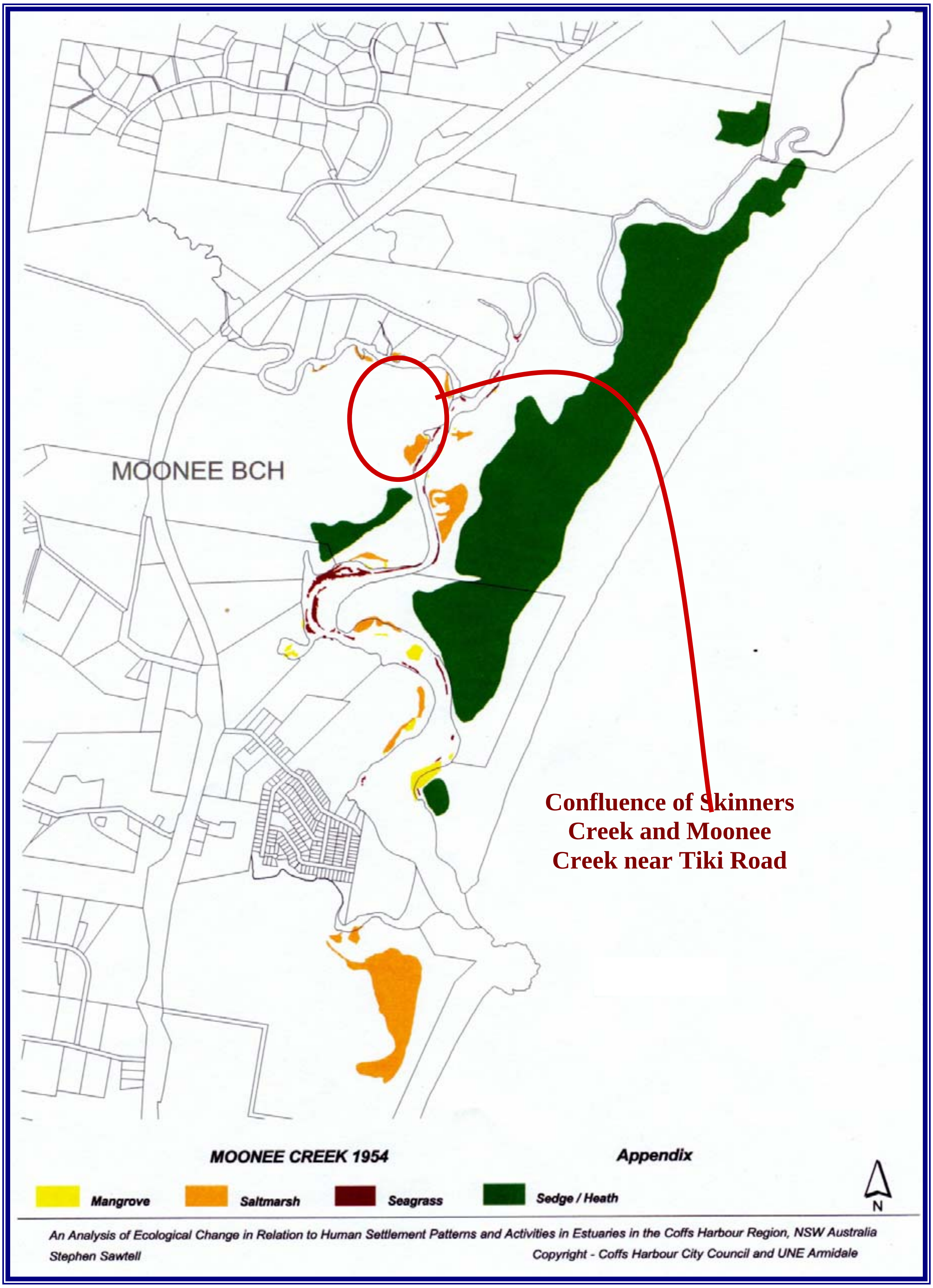


Figure 5-49 - Estuarine vegetation - Moonee Creek 1954
Distribution of the 4 vegetation types in Moonee Creek in 1954

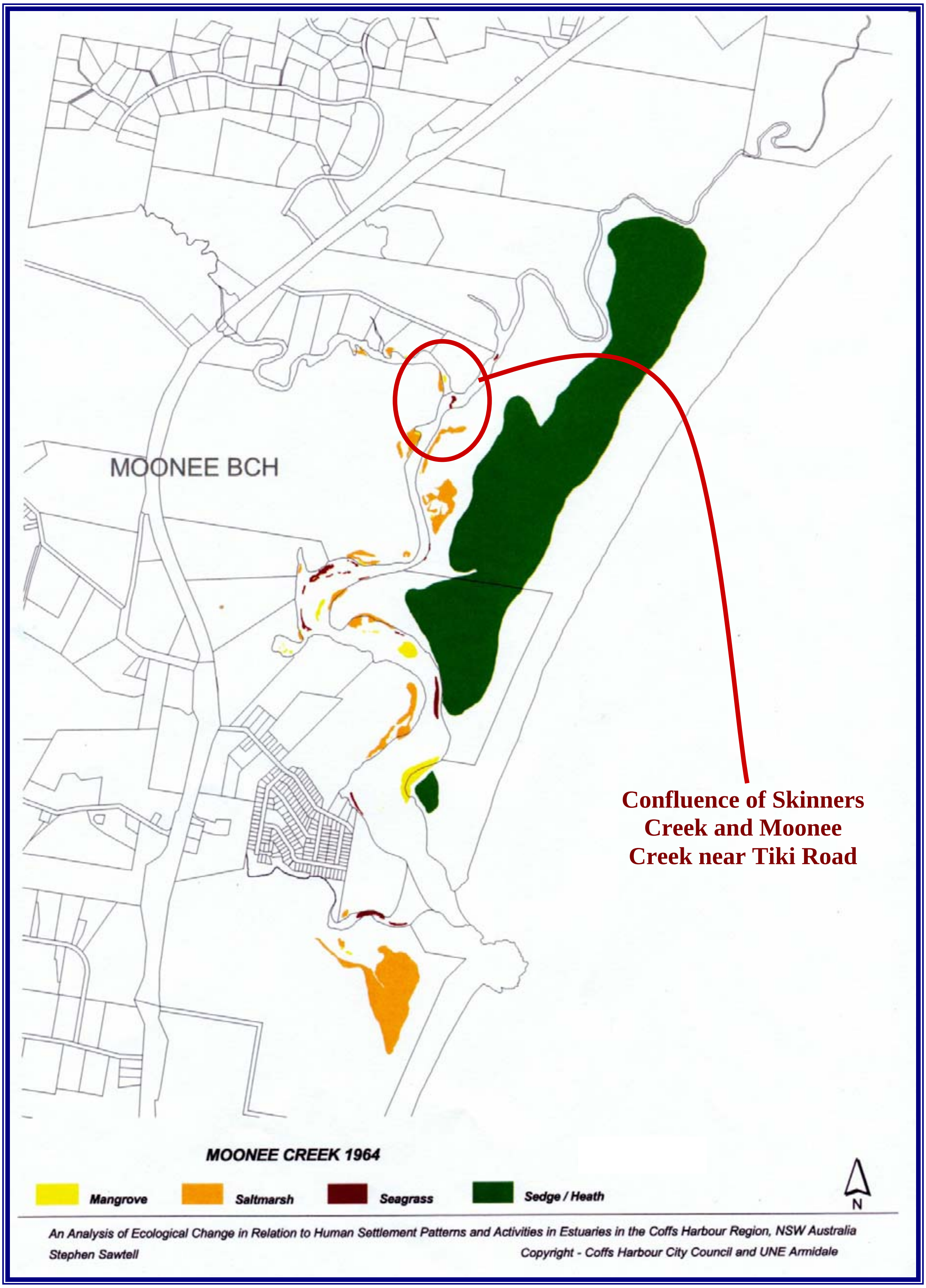


Figure 5-50 - Estuarine vegetation - Moonee Creek 1964
Distribution of the 4 vegetation types in Moonee Creek in 1964

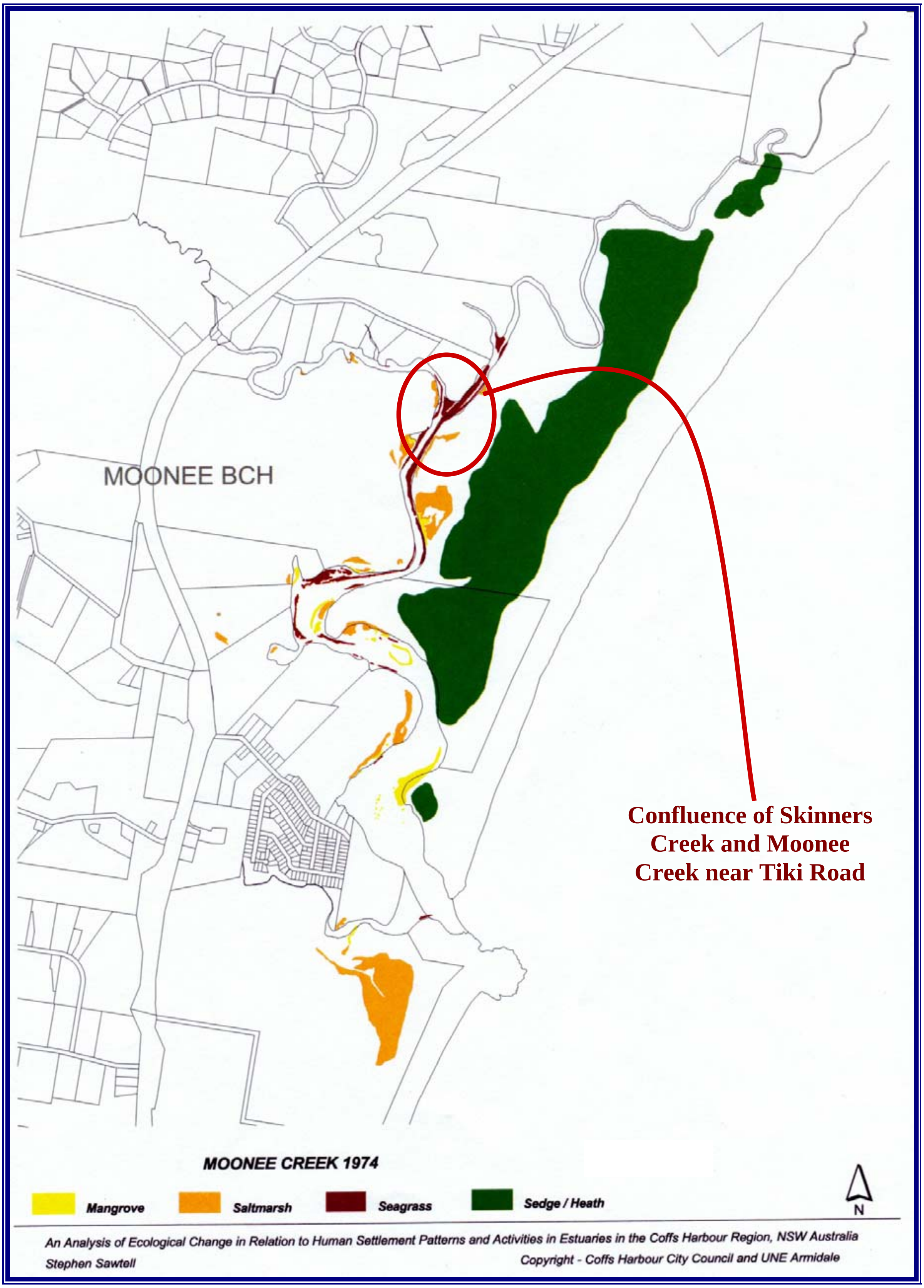


Figure 5-51 - Estuarine vegetation - Moonee Creek 1974
Distribution of the 4 vegetation types in Moonee Creek in 1974

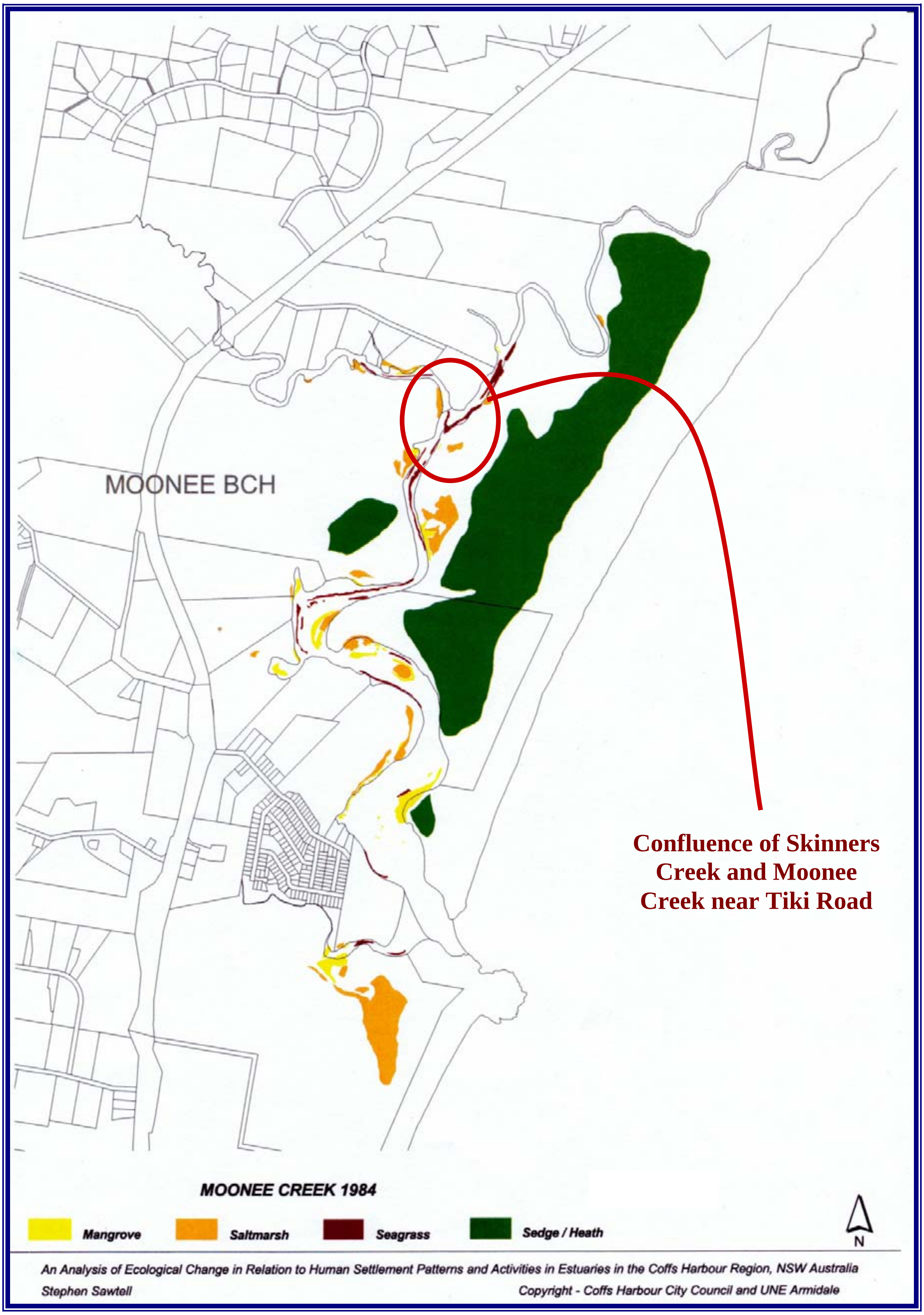


Figure 5-52 - Estuarine vegetation - Moonee Creek 1984
Distribution of the 4 vegetation types in Moonee Creek in 1984

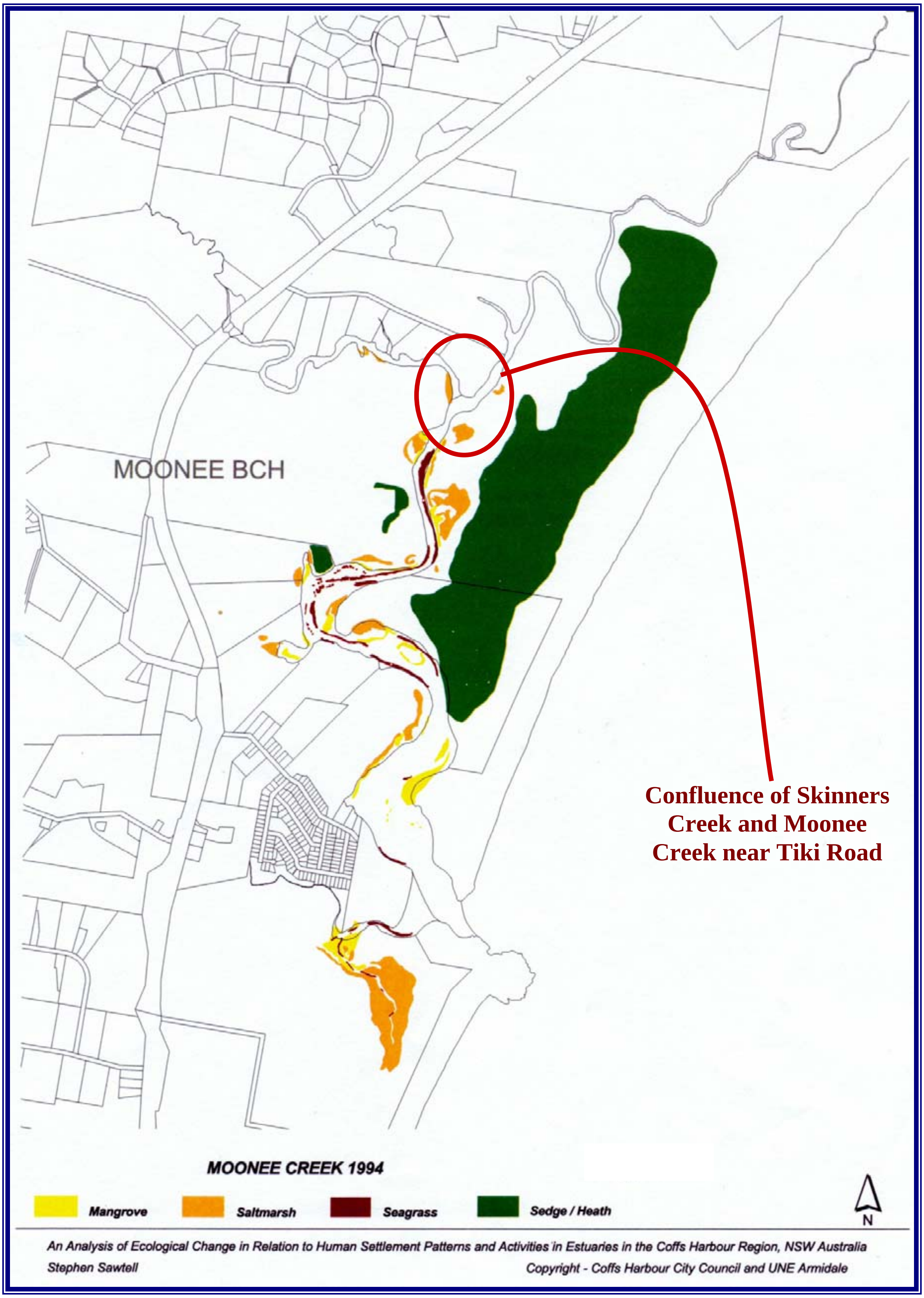


Figure 5-53 - Estuarine vegetation - Moonee Creek 1994
Distribution of the 4 vegetation types in Moonee Creek in 1994

5.6.2 HUMAN SETTLEMENT PATTERNS: 1954 - 1994 - MOONEE CREEK

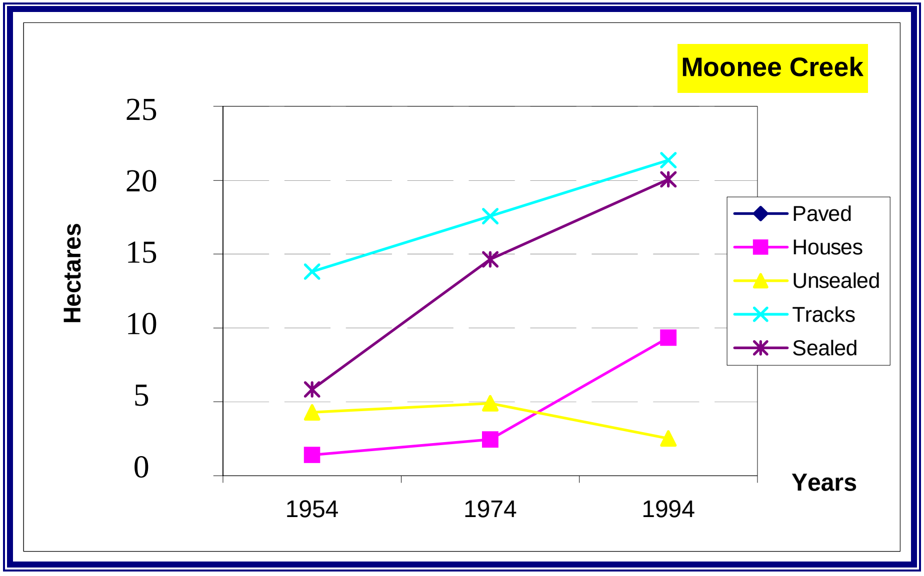


Figure 5-54 - Human settlement patterns Moonee Creek 1954 - 1994

Table 5-24 - Human settlement patterns Moonee Creek 1954 - 1994

MOONEE CREEK – HUMAN SETTLEMENT PATTERNS (% Change)					
	Paved	**Houses**	**Unsealed**	**Tracks**	**Sealed**
1954	0.00	1.41	4.28	13.81	5.83
1974	0.00	2.46	4.89	17.55	14.65
1994	0.00	9.34	2.50	21.34	20.07

Housing increased by 562.7% between 1954 and 1994. This is based on the initial figure of 94 houses with an area of 1.41 ha in 1954 increasing to a 1994 figure of 623 house with a total area of 9.35 ha. There is zero paved area (that is industrial area) in the Moonee catchment for the period 1954 to 1994. Sealed roads increased by 244% from a 1954 area of 5.83 ha to a 1994 area of 20.07 ha. Unsealed roads have diminished by 41.5% from 4.28 ha in 1954 to 2.51 ha in 1994. Tracks increased by 54.5% based on the 1954 figure of 13.8 ha rising to a 1994 figure of 21.34 ha.

The interpretation of aerial photography for human settlement patterns indicates a predominance of housing appearing in the Moonee village area with an intensity of development in the rural residential component west of the highway, together with an intensification of the residential area of Moonee Village (Figs. 5-55 to 5.57).

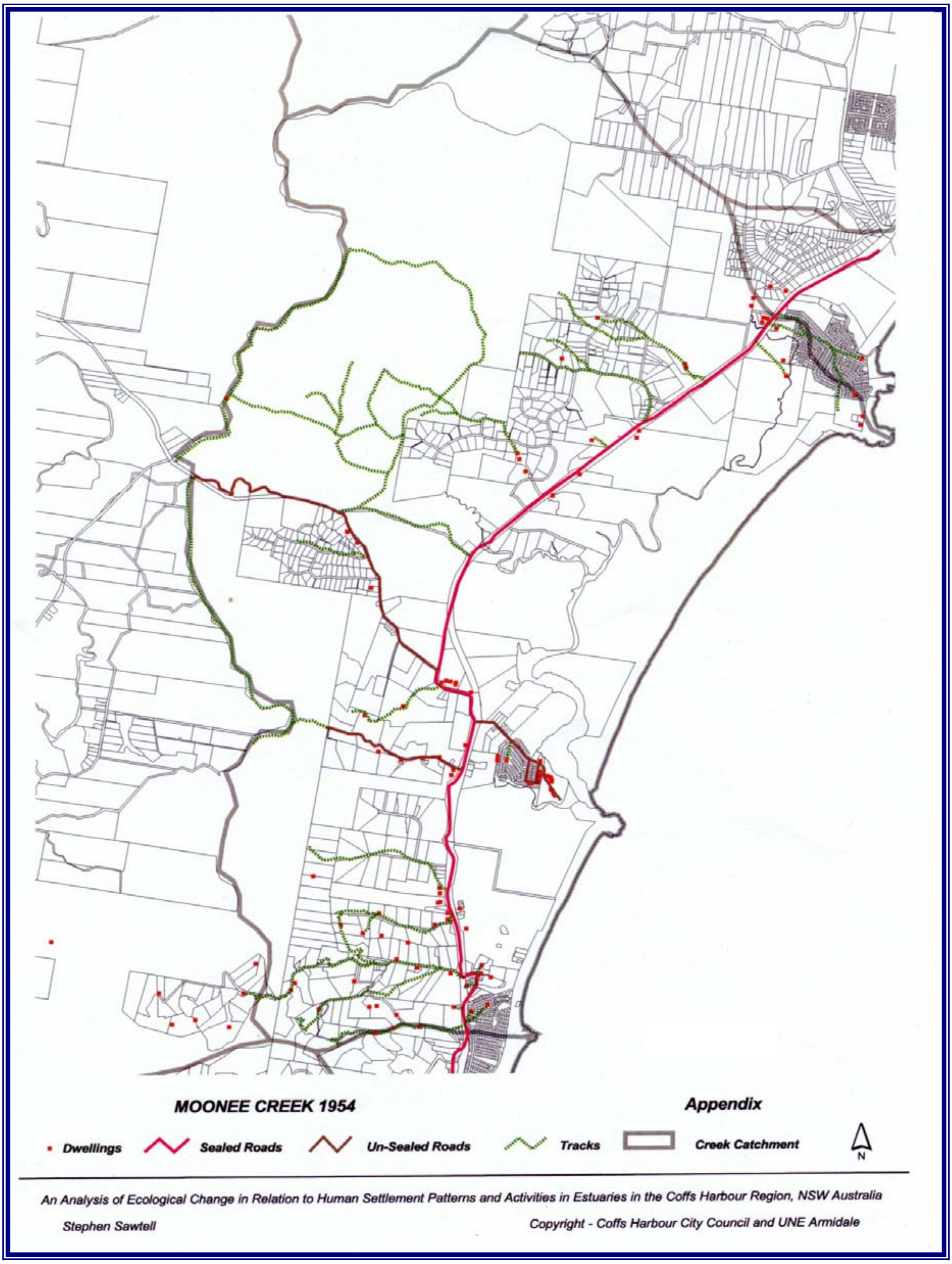


Figure 5-55 - Human settlement patterns - Moonee Creek 1954

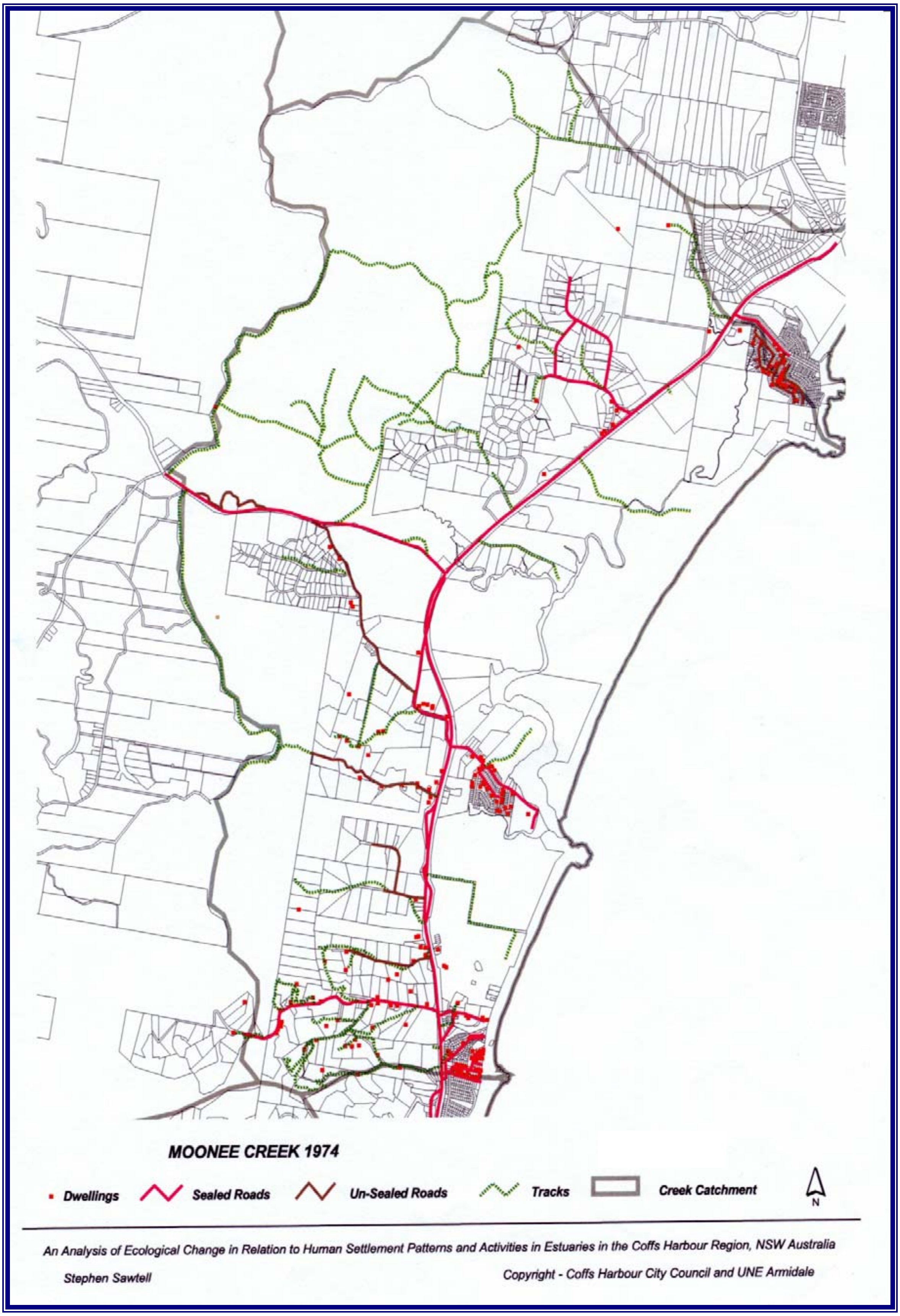


Figure 5-56 - Human settlement patterns - Moonee Creek 1974

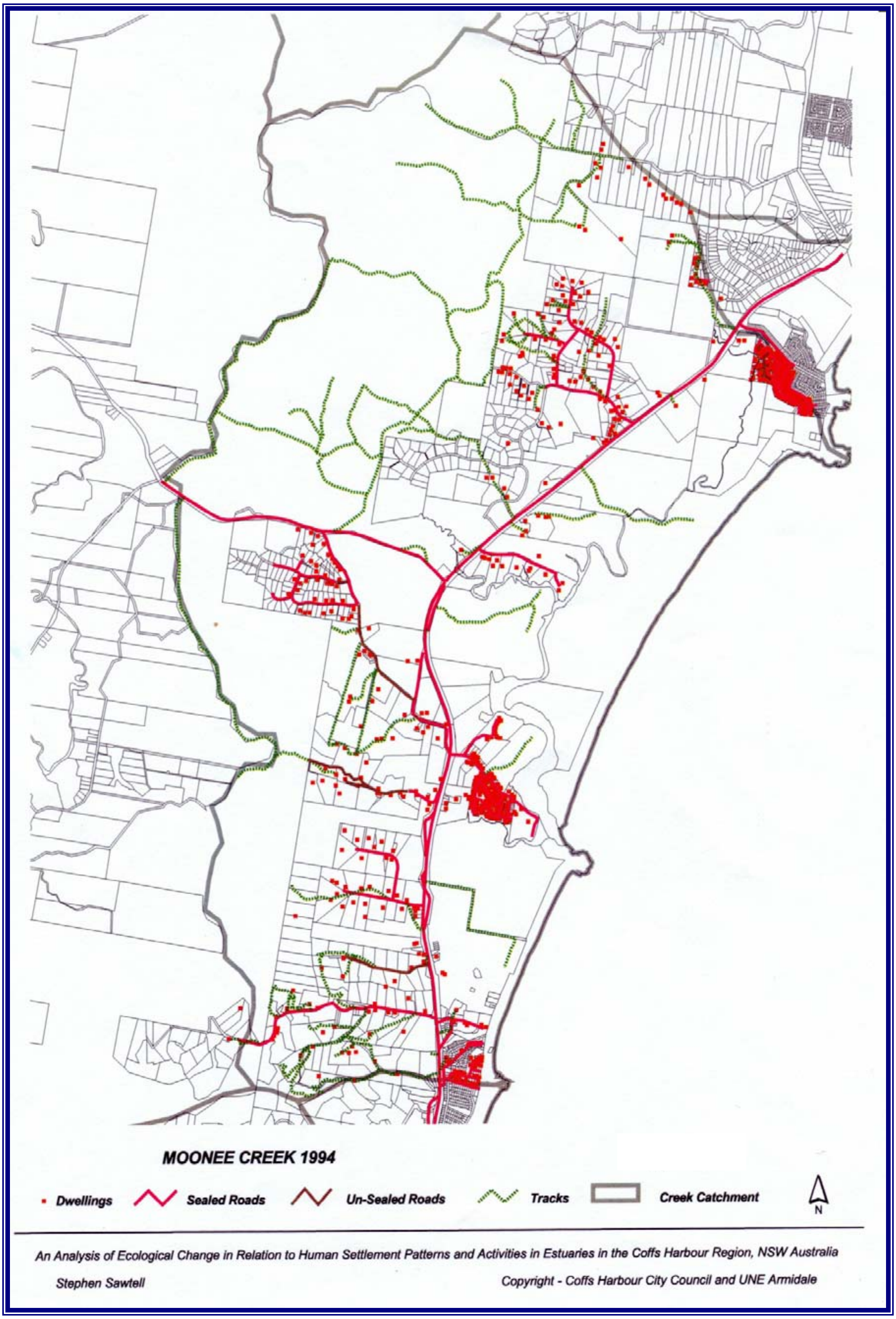


Figure 5-57 - Human settlement patterns - Moonee Creek 1994

5.6.2.1 BANANA CULTIVATION - MOONEE CREEK

Bananas have fluctuated across the time period of the study rising from the 1954 figure of 92.67 ha to a 1974 figure of 160.62 ha and then decreasing to 109.1 ha in 1994. At the time of expansion, banana cultivation plots increased in area to the south of the catchment entering the sub-catchment of Stingray Creek and to the north of the catchment in the Emerald Heights area (Figs. 5-58 - 5-60).

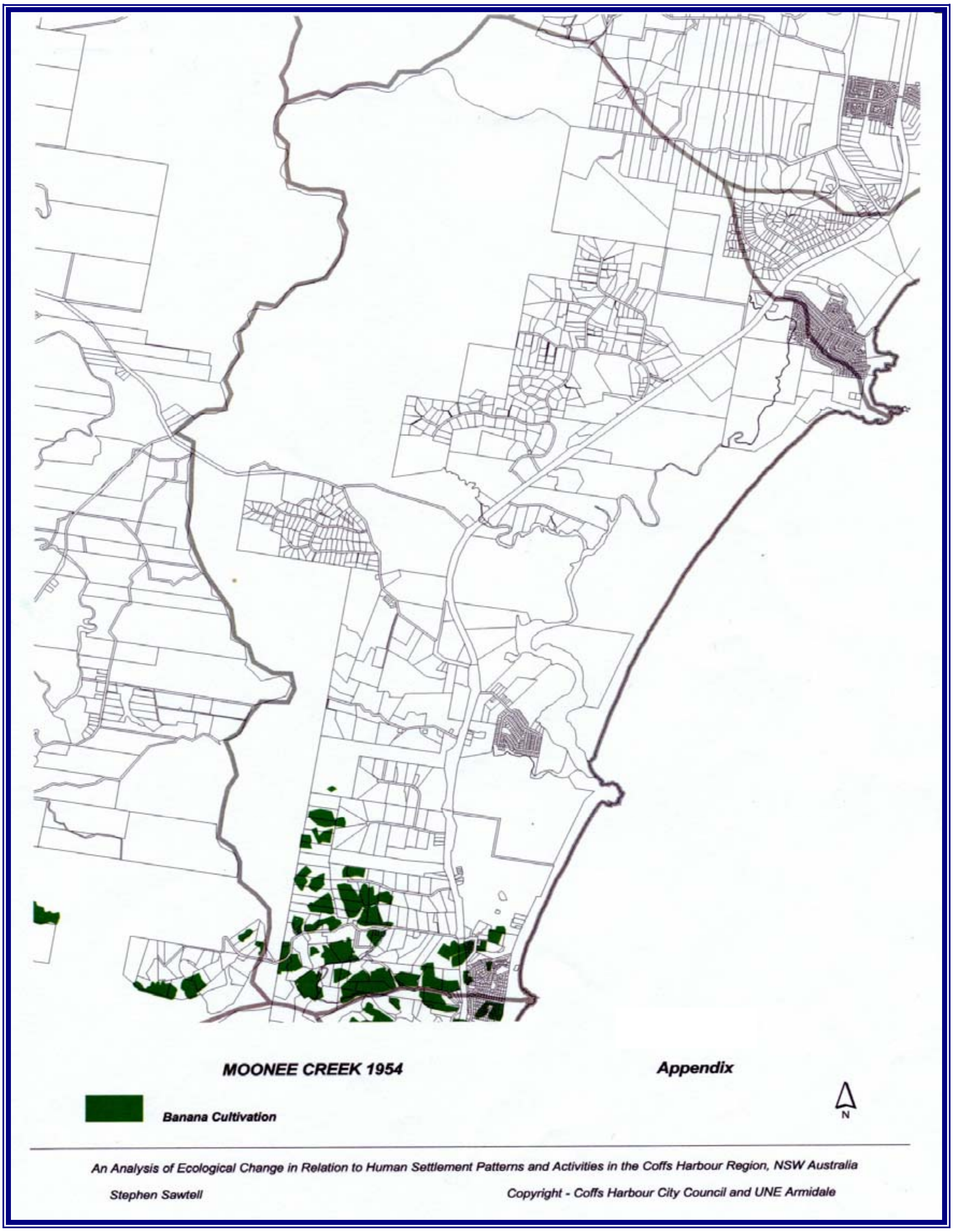


Figure 5-58 - Banana cultivation - Moonee Creek 1954

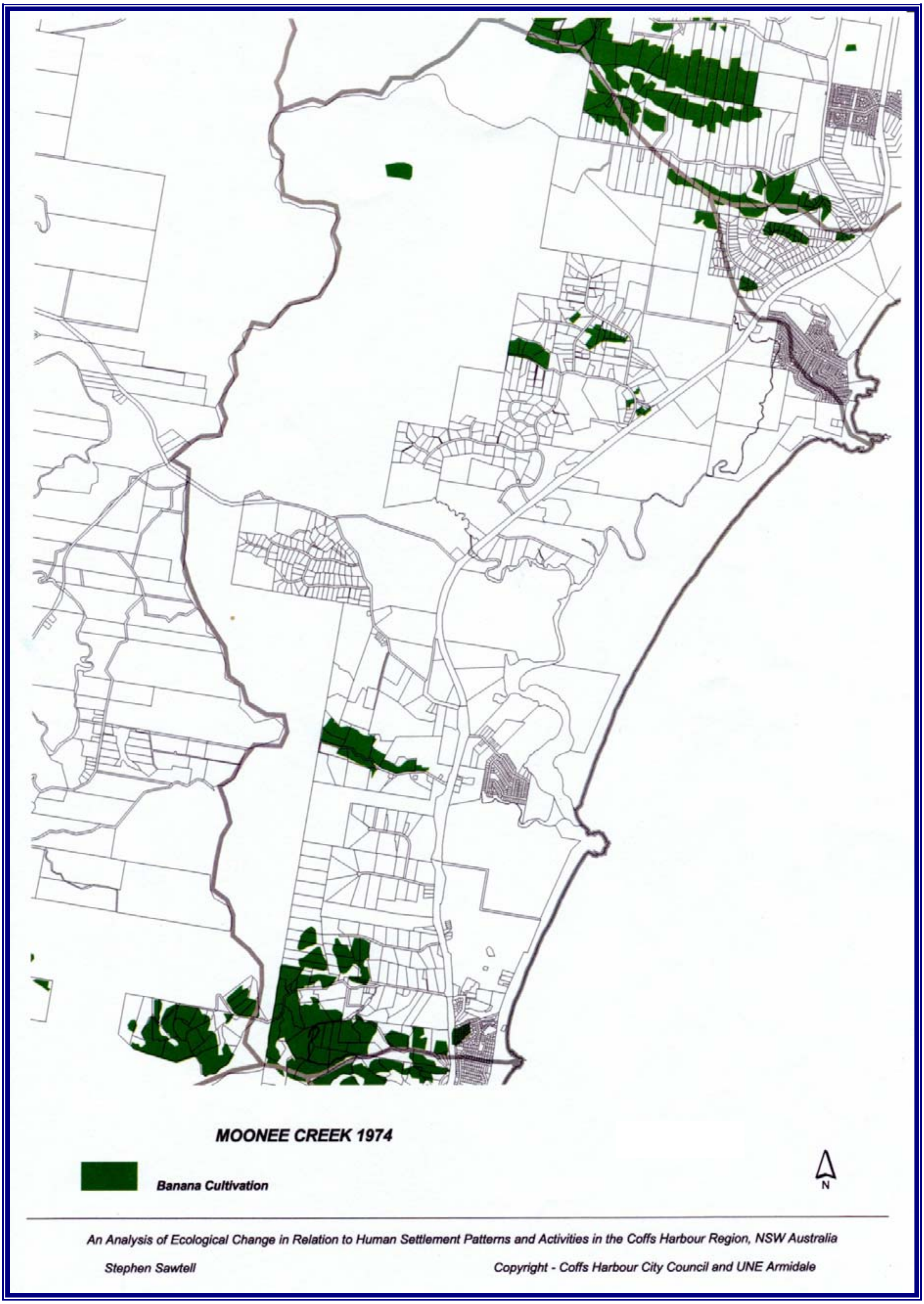


Figure 5-59 - Banana cultivation - Moonee Creek 1974

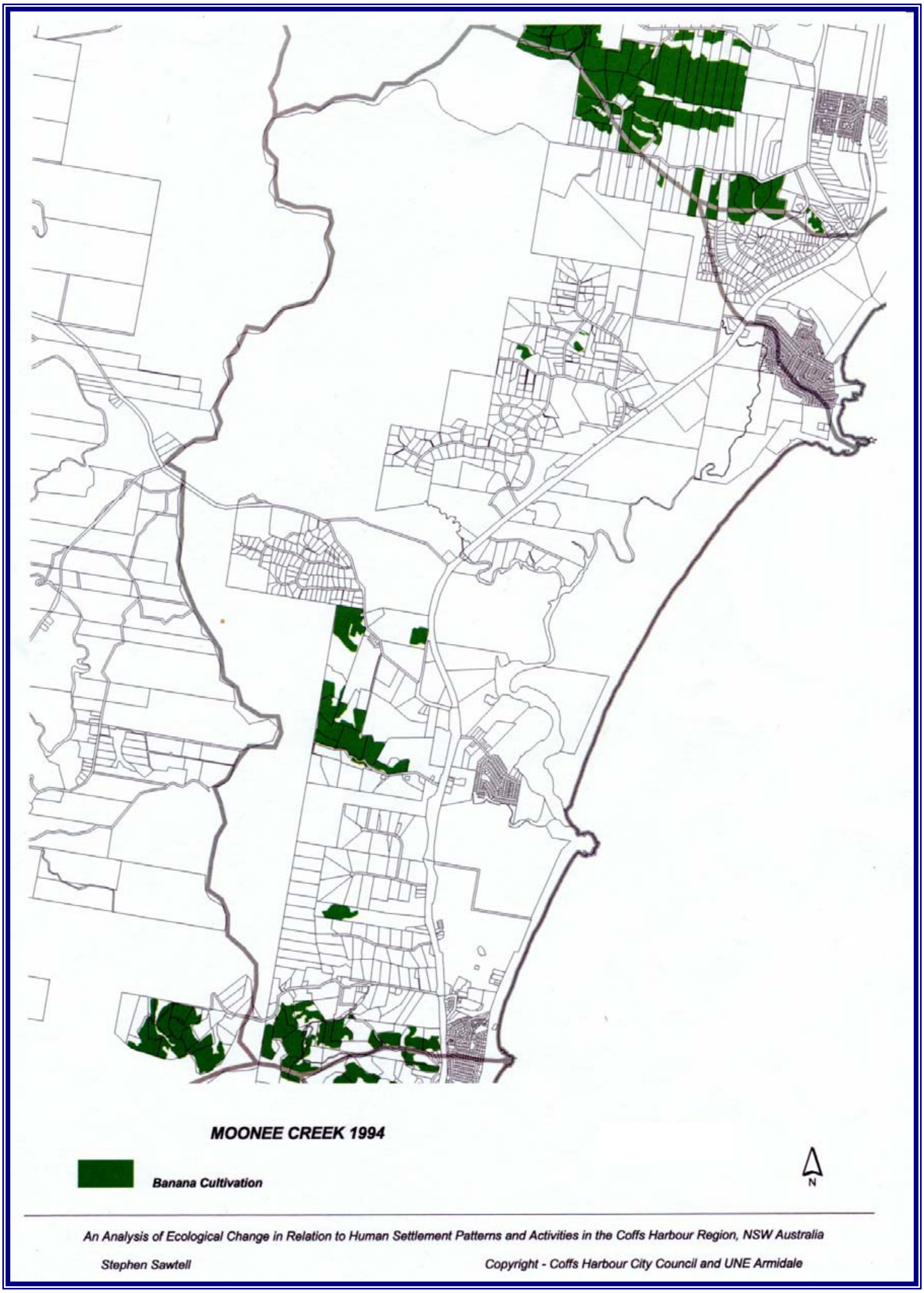


Figure 5-60 - Banana cultivation - Moonee Creek 1994

5.6.3 PHYSICO/CHEMICAL VARIABLES, WATER QUALITY AND GRANULATION

5.6.3.1 WATER QUALITY - MOONEE CREEK

The 1997 pH fluctuated at both surface and depth rising from a pH of 8.4 to 8.8 and then dropping to 7.7 at site 4, 1999 samples remained constant at a pH of 7.8. Differences in depth occurred from site 1 at 0.8 metres to site 4 at 1.8 metres in 1997, the 1999 pH varied with a depth of 0.5 metres at site 1 to 2.5 metres at site 4. Conductivity was constant across the four sites for 1997 (50 mS/cm), similarly 1999 conductivity was constant at 50 dropping off approaching site 3 and site 4 to 45 ms/cm. In 1997 the turbidity was low for sites 1 and 2 evidencing 15, slowly rising to 20 - 25 at site 4, the 1999 period evidenced nil turbidity at sites 1 and 2, site 3 turbidity became evident and increased to 8 at site 4. In 1997 dissolved oxygen had a drop-off from site 1 to site 4, with both surface and bottom changing from 6.5 mg/L at site 1 to 4.2 mg/L at site 4. This indicates a degree of mixing, a similar trend occurred in the 1999 sampling period with a DO of 5.5 mg/L fluctuating for sites 1 and 2, a DO reading at the surface at site 4 was 4.5 mg/L and at depth was 3.5. Salinity was constant for the 1997 period at 3.5‰, 1999 this was constant at sites 1, 2 and 3 at surface and at depth with 3.5‰, this dropped to 3‰ at site 4. Temperature in 1997 evidenced a marked drop from 21ºC at site 1 to 17ºC at site 4, the temperature for 1999 sampling period was constant at sites 1, 2 and 3 both at depth and surface with at 24ºC, this increased at surface at site 4 to 25ºC.

5.6.3.2 FAECAL COLI FORMS

Faecal and total coliform levels dropped from 1997 to 1999, 1997 evidenced 140.22 faecal coliforms with a decrease to 64.87/100 ml. Total coliforms dropped from 185.47 in 1997 to 131.65/100 ml in 1999 (n=24 per annum).

5.6.3.3 GRANULOMETRY

Interpretation using the Wentworth grading classification indicates a category of fine sand (140.92 Um) for sites 1, 2 and 3 with very fine sand experienced at site 4 (122.1 Um).

5.7 ANALYSIS OF COMPARISONS BETWEEN CREEKS

5.7.1 ESTUARINE VEGETATION

Absolute changes are assessable, and are more informative with respect to the relative coverage of vegetation within each creek and between creeks, standardising, in this case would remove some of this relative information. Refer Appendix 6 for all raw data.

5.7.1.1 SEAGRASS

Bonville Creek has a greater area of seagrass compared to Boambee and Moonee Creek with Coffs presenting the least total area of the four creeks. All creeks except Boambee have shown an increase in seagrass since 1984 (Figure 5-62).

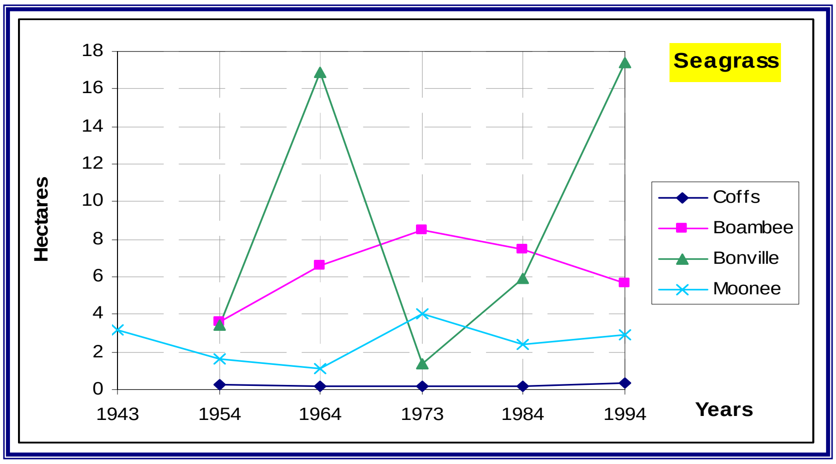


Figure 5-62 - Seagrass - all creeks for the time period 1954 to 1994

5.7.1.2 SALTMARSH

Boambee and Bonville present the greatest change in saltmarsh each declining across time. Saltmarsh cover in Moonee has been constant with Coffs experiencing a greater decline in this vegetation type (Figure 5-63).

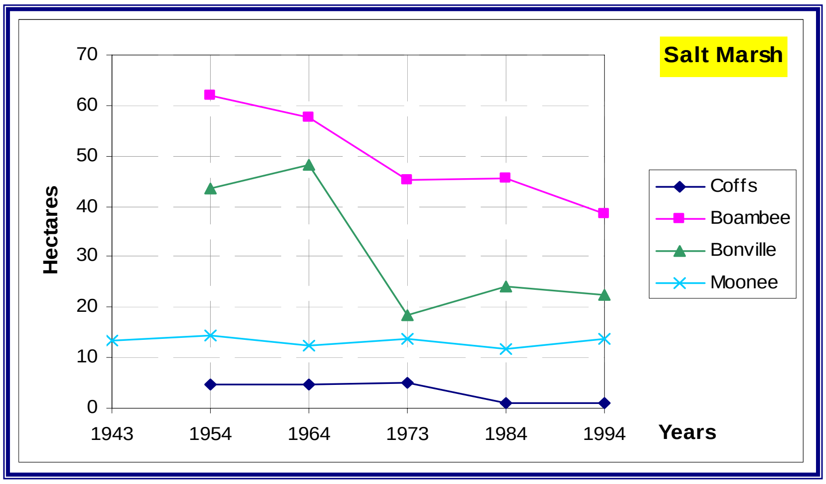


Figure 5-63 - Saltmarsh - all creeks for the time period 1954 to 1994

5.7.1.3 MANGROVE

Each creek has undergone an overall increase in the total area of mangroves. Boambee creek supported a higher cover of mangrove than other creeks, Coffs Creek is second in total abundance, Moonee and Bonville evidenced similar lower levels. Total areas of mangroves must be interpreted in proportion to the creek and catchment size (Figure 5-64)

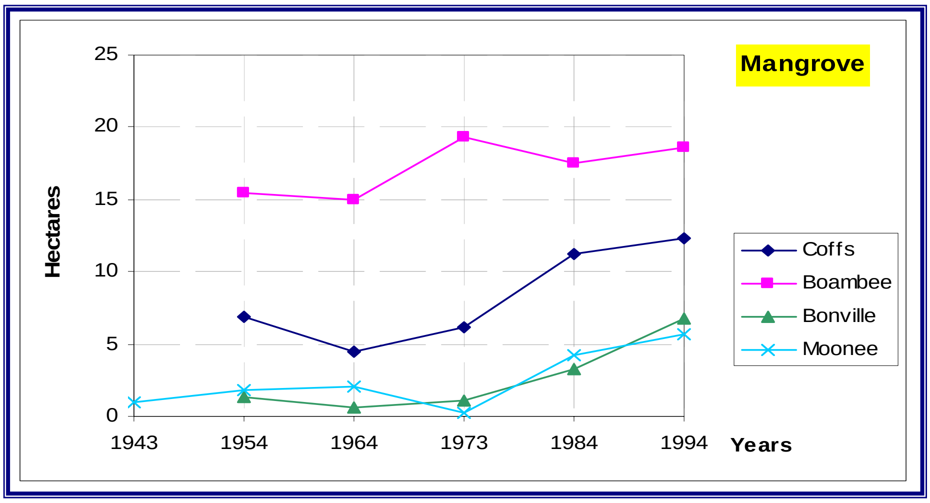


Figure 5-64 - Mangrove - all creeks for the time period 1954 to 1994

5.7.1.4 SEDGE/COASTAL HEATH

Moonee has the largest area of sedge, which includes the Moonee Nature Reserve, Boambee has experienced a high level of fluctuation in this vegetation type due to clearing, regrowth then further clearing in the airport precinct. Coffs Creek has declined from 78 ha in 1954 to negligible levels in 1994, a greatly reduced cover remains in the Bonville Creek system. The area of sedge/coastal heath has decreased in all creeks (Figure 5-65).

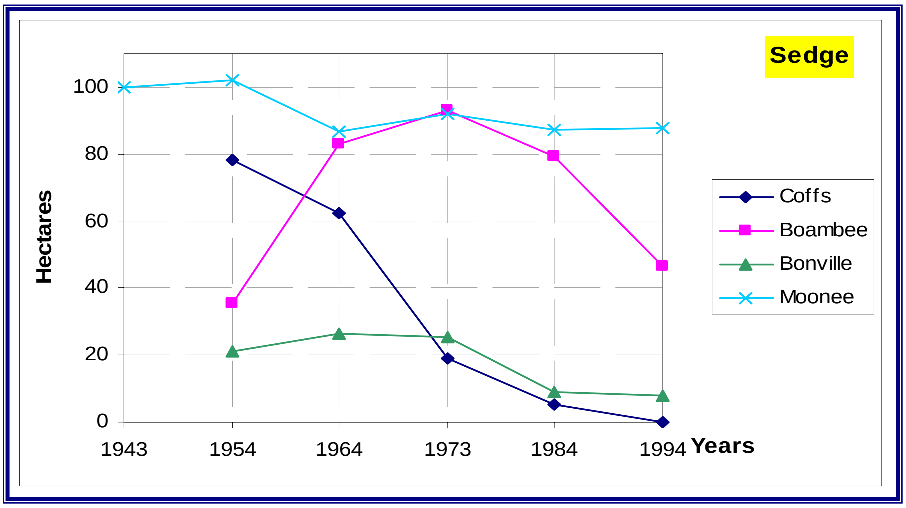


Figure 5-65 - Sedge/coastal heath - all creeks for the time period 1954 to 1994

5.7.2 HUMAN SETTLEMENT PATTERNS AND CATCHMENTS

5.7.2.1 HOUSING

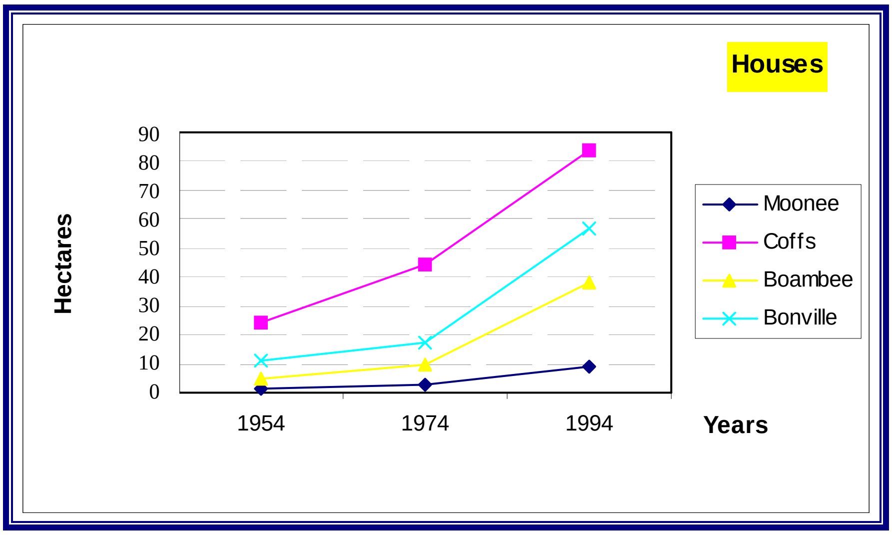


Figure 5-66 - Housing - all creeks for the time period 1954 to 1994

All creek catchments have undergone an increase in housing with the growth in the Coffs catchment producing the highest level (Figure 5-66). Refer Appendix 6 for all raw data.

5.7.2.2 PAVED AREAS

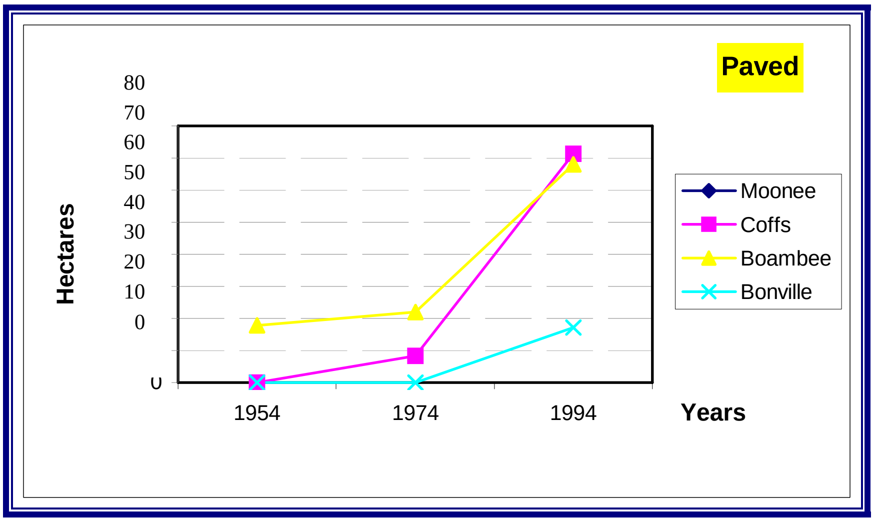


Figure 5-67 - Paved area - all creeks for the time period 1954 to 1994

The paved areas represent industrial development, Boambee is the only catchment with evidence of paved areas since 1954. Coffs has marginally higher levels in 1994 than Boambee whilst Moonee catchment has nil area recorded (Figure 5-67).

5.7.2.3 SEALED ROADS

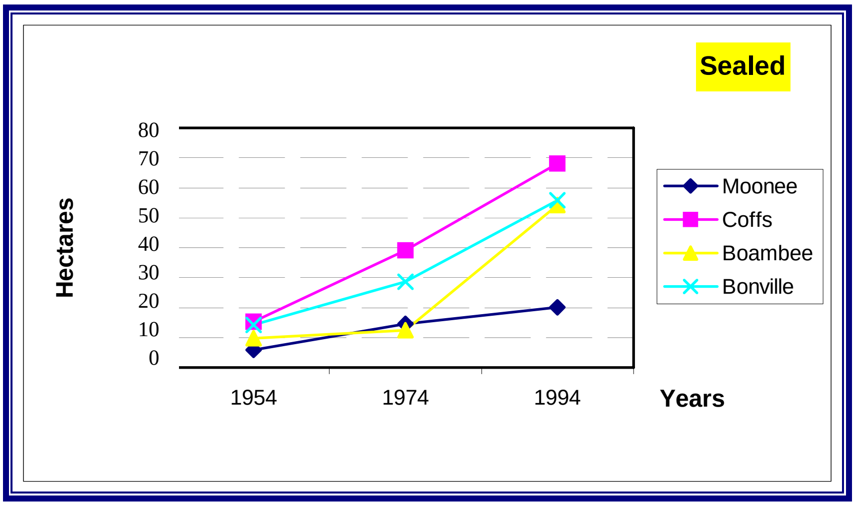


Figure 5-68 - Sealed roads - all creeks for the time period 1954 to 1994

All creek catchments have experienced an increase in sealed roads, Coffs having the highest total area, followed by Bonville and Boambee at almost similar levels, whilst Moonee evidenced the lowest area in sealed road surfaces (Figure 5-68).

5.7.2.4 UNSEALED ROADS

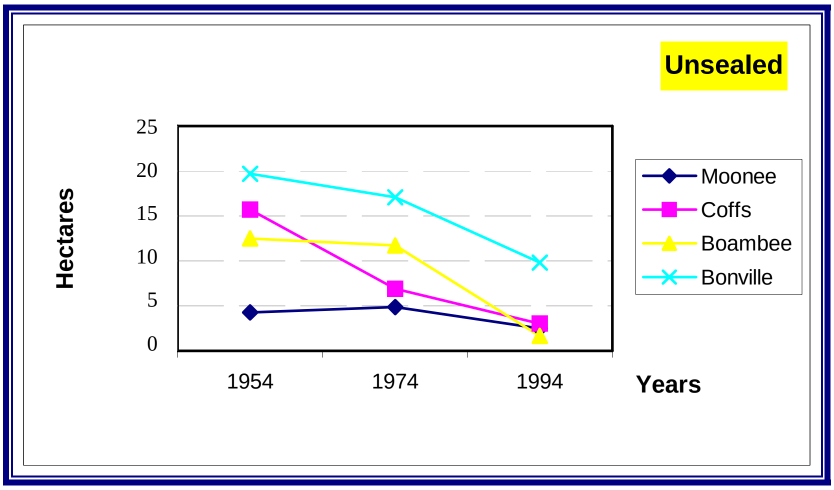


Figure 5-69 - Unsealed roads - all creeks for the time period 1954 to 1994

All catchment have undergone a distinct decrease in unsealed roads, obviously proportional to an increase in the sealing of roads. Boambee has the least unsealed roads with Bonville catchment evidencing the largest area of unsealed road. Coffs and Moonee have similar levels (Figure 5-69).

5.7.2.5 TRACKS

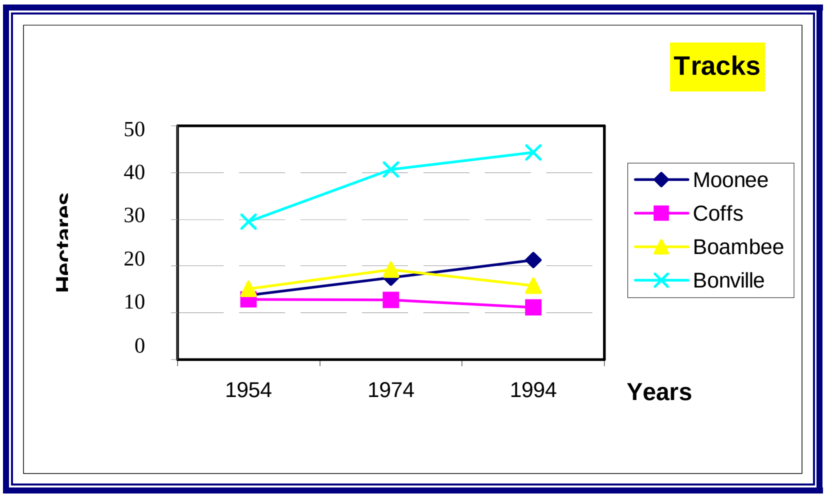


Figure 5-70 - Tracks - all creeks for the time period 1954 to 1994

Bonville catchment has the largest area of tracks together with the highest recorded increase, Moonee tracks have increased whilst Coffs and Boambee have both declined (Figure 5-70).

5.7.3 CATCHMENT COVERAGE OF HUMAN SETTLEMENT

Table 5-25 - Human Settlement Patterns
coverage change within the creek catchments between 1954 and 1994

YEAR	CREEK (% of catchment covered)			
	Bonville	Boambee	Coffs	Moonee
1954	0.76	1.46	17.44	2.8
1974	1.65	3.2	23.9	4.75
1994	2.21	4.96	25.76	3.8

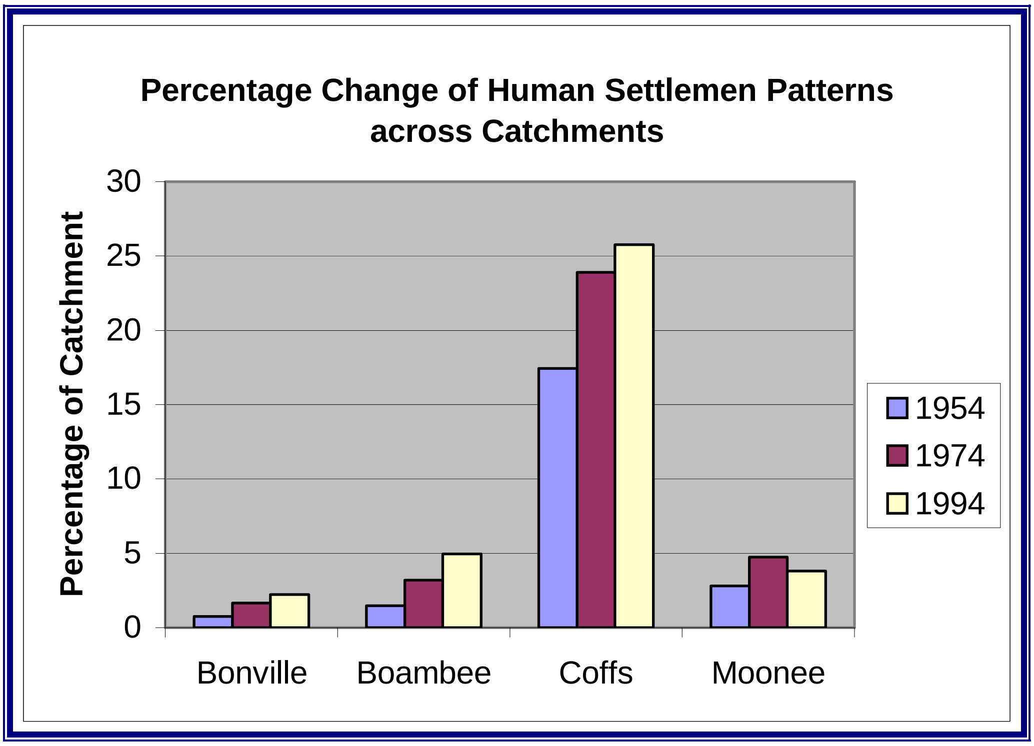


Figure 5-71 - Comparative change in catchments between 1954 and 1994 for Bonville, Boambee, Coffs and Moonee

The amount of catchment taken up by human settlement patterns in Bonville has increased from 0.76% in 1954 to a total of 2.21% in 1994. Boambee experienced a net increase from 1.46% in 1954 to 4.95% in 1994 relative to total catchment area. Coffs has experienced a change from 17.44% in 1954 to 25.76% in 1994. Moonee has experienced a marginal increase from 2.8% in 1954, to 4.75% in 1974 with a reduction to 3.8% in 1994. This is attributed to a decline in banana cultivation. Coffs evidences the greatest percentage increase and the highest catchment coverage which indicates that Coffs Creek catchment has the highest level of Human Settlement Patterns (Table 5-25 and Figure 5-71). Refer Appendix 7 for raw data.

A trend of increasing human settlement patterns across time is apparent for the Bonville, Boambee and Coffs Catchments with Moonee the exception.

5.7.4 CORRELATIONS OF ESTUARINE VEGETATIONS AND HUMAN SETTLEMENT PATTERNS

5.7.4.1 REGRESSION ANALYSIS

Regression analysis was carried out on changes in estuarine vegetation (dependent variable) and Human Settlement Patterns (independent variable) to determine if changes in HSP could explain the observed changes in vegetation patterns across the four creeks. All data were standardised as percentage of catchment for human settlement patterns (HSP) and percentage of creek area for all estuarine vegetation (Est Veg). Prior to analysis data were transformed (log), where necessary to improve homoscedasticity.

Catchment was calculated from ridge line to high tide at the ocean (Figures 2-5, 2-7, 2-9 and 2-11). Creek area was achieved by calculating high tide limits down to creek entrance.

Summary statistics were achieved by Regression Analysis and ANOVA using Excel statistical package. Biological populations normally appear as exponential or as a curvilinear function, log transformation reduces this expression to a linear function or linear relationship which assists in interpretation, correlation of these variables creates a line of best fit, this tells how closely the data points fit the model, the test is perfect when $r = 1$.

The data were aggregated across the four creeks. Table 5-1 displays the various highest coefficients of determination as outcomes against the dependant and independent variables, this is a summary of 16 different correlations (refer Appendix 7). The method yielded the best r^2 value and results are reported in Table 5-1.

Table 5-16 - Estuarine vegetation and human settlement patterns correlations Aggregated across all creeks

DEPENDANT VARIABLE	INDEPENDENT VARIABLE	R^2
Seagrass	Human Settlement Patterns	0.378
Saltmarsh	Human Settlement Patterns	0.4500
Mangrove	Human Settlement Patterns	0.429
Sedge	Human Settlement Patterns	0.162

5.7.4.2 SEAGRASS

From the theory covered in Chapter 1, it would seem reasonable to assume that seagrass cover may respond to human settlement patterns (HSP) hence seagrass cover is used as the dependent variable. Seagrass data has been transformed as the dependent variable, calculated as log seagrass (R^2=0.3775).

The line of best fit for the relationship between seagrass and HSP was the log-log model which explained 38% of the variation between the two, a significant result ($P \leq -0.05$).

SUMMARY OUTPUT

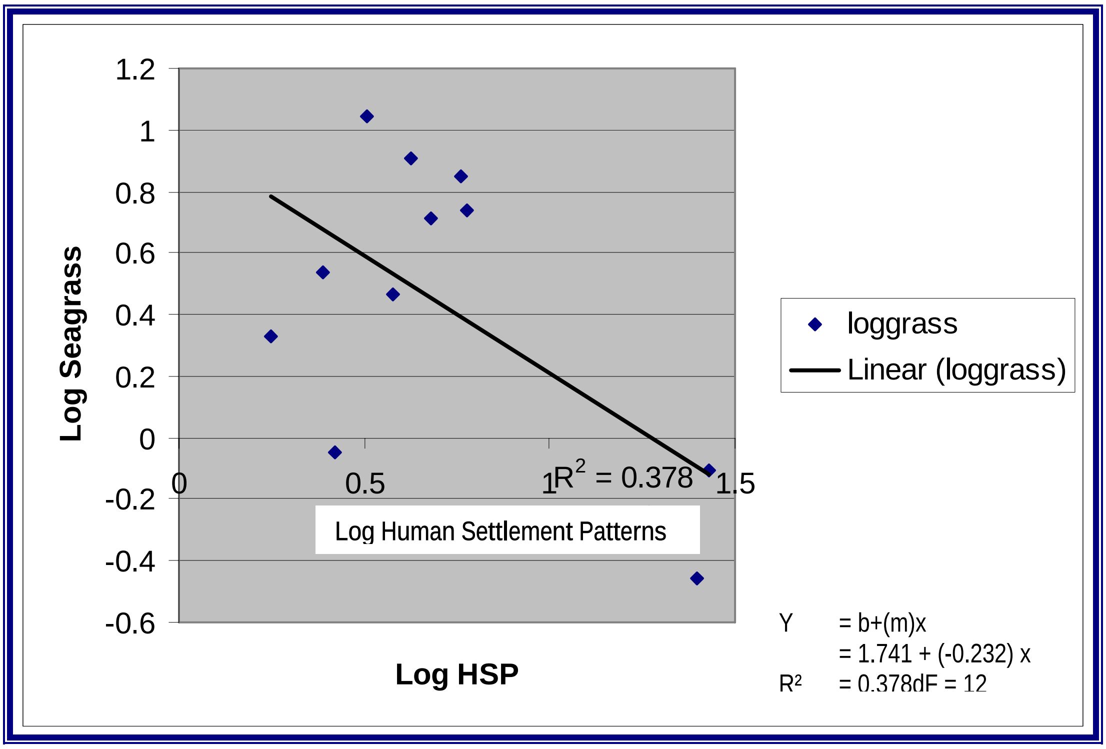


Figure 5-72 - Correlation of log seagrass, log human settlement patterns (HSP) As human settlement patterns increase seagrass has declined.

5.7.4.3 SALTMARSH

Saltmarsh has been log transformed in order to interpret the data in a lineal relationship, the R^2 value is 0.4998. The line of best fit for the relationship between saltmarsh and HSP was log-log model which explains 50% of the variation between the two, a highly significant results (($P \leq - 0.01$). This indicates that as human settlement patterns increase, saltmarsh decreases ().

SUMMARY OUTPUT

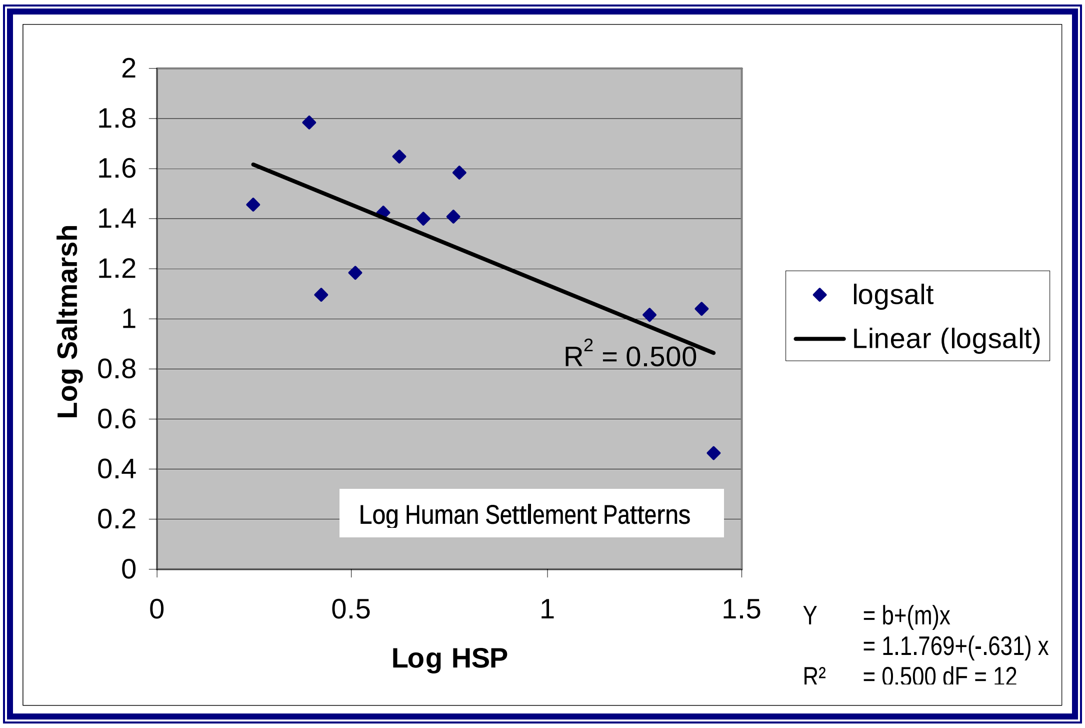


Figure 5-73 - Correlation log saltmarsh log human settlement patterns (HSP)

5.7.4.4 MANGROVE

Both mangrove and human settlement pattern (HSP) data sets have been log transformed (R^2=0.429). The line of best fit for the relationship between mangroves and HSP was the log-log model which explained 43% of variation between the two, a highly significant result (($P \leq -0.05$). This indicates that as HSP increases so too have mangroves. (Figure 5-74)

SUMMARY OUTPUT

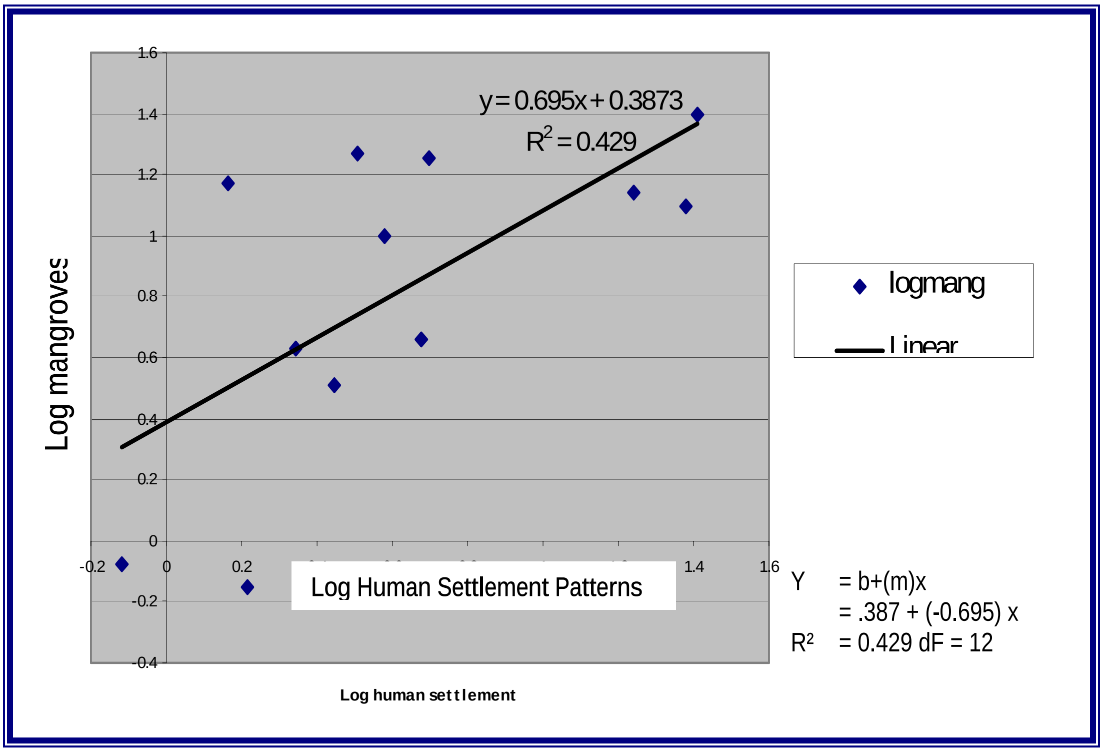


Figure 5-74 - Correlation log mangrove log human settlement patterns (HSP)

5.7.4.5 SEDGE

Both sedge and HSP data sets have been log transformed (R^2=0.162). The line of best fit for the relationship between sedge and HSP was the log-log model which explained 16.2% of the variation between the two. This is a very low interpretation and indicates that there are other variables involved, however interpretation indicates a loss of sedge as human settlement patterns increase (Figure 5-75).

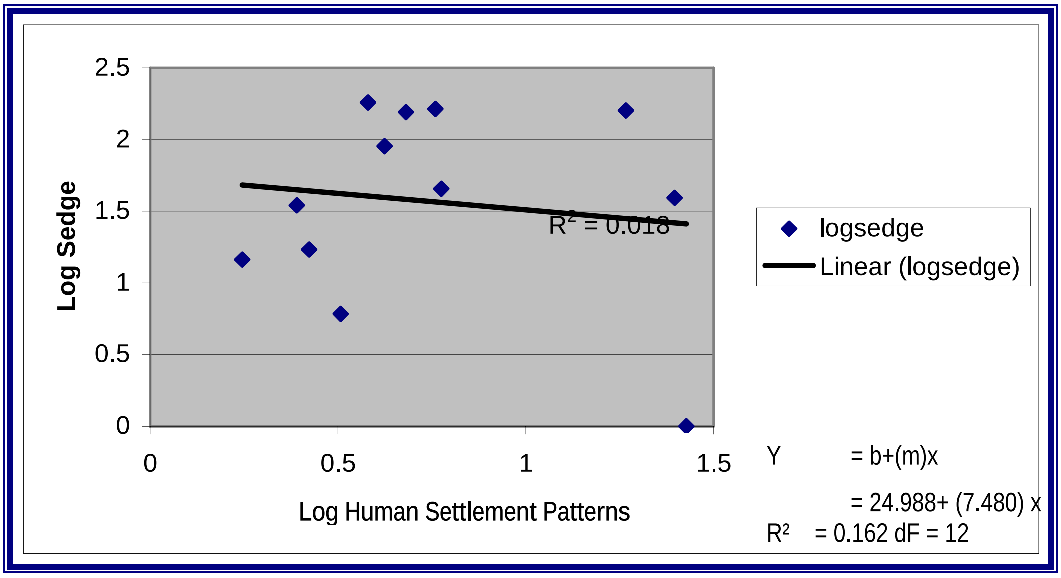


Figure 5-75 - Correlation log sedge log human settlement patterns (HSP)

6 DISCUSSION

6.1 BENTHIC COMMUNITIES AND STRUCTURE

There have been few studies undertaken in the mid north coast area concerning the investigation of benthic infaunal communities in estuaries. Johnstone (1997) undertook a study of benthic macro-invertebrates in the Yarrawarra/Arrawarra and Darkum Creek system and concluded that there are discernable differences in community composition between the three creeks of the study, a range of polychaetes, bivalves and amphipods dominated at different sites along the creeks. Davey (1998) undertook a study of seagrass macrofaunal communities in the Coffs Harbour region utilising the creeks of this study, Bonville, Boambee, Coffs and Moonee. The study concluded that the macrofaunal species associated with the seagrass of the four creeks is typical of those found in other estuaries in NSW and that there were significant differences both within and between creeks, and that typical macrofauna consisted of polychaetes, bivalves and amphipods.

Smith and Parker in Jelliffe (1997) undertook macrobenthic studies of Hearnes Lake, Willis Creek and Station Creek and found a range of polychaetes, bivalves and amphipods along the creek systems. Patterson et al. (2000) have undertaken macrobenthic analysis of the Bonville Creek system with previous analysis being undertaken by the Department of Land and Water Conservation with bivalves, polychaetes, amphipods as the major taxonomic groups detected. These were classified into groups ranging from rare to common.

A gradation of species along the length of an estuary can usually be found. (McLusky, 1989). This has been confirmed by the findings of this study where species of amphipods, bivalves and polychaetes are also evident at different locations along the creek length. Smith and Paterson in Jelliffe (1997) further confirms seriation patterns of benthic macro-invertebrates from the upper reaches to the mouth of each of the estuaries studied.

Knowledge of the spatial patterns of organisms is a necessary pre-requisite in establishing what processes might underlie the observed arrangement of organisms. (Andrew and Mapstone, 1987). The trophic shift towards dominance by shallow subsurface deposit feeders in contaminated habitats may have dire implications for fisheries (Gaston et al. 1998).

Changes with respect to seasonality, that is the time of the year samples were taken, are offset by the findings of Burchmore et al. (1984), who found significant correlation between autumn and spring benthos sampling results that indicated the benthic invertebrate community, like the fish community, was relatively constant on a seasonal basis. This contrasts with the findings of this study in that variations in abundance and diversity were apparent between 1997 and 1999, species richness was less for all sites in 1997 than in 1999. These considerations need to be viewed with respect to the limited number of sample periods.

Jones (1987) found that the overall number of species and number of individuals showed significant seasonal and annual differences. The aspect of seasonality in this study needs to be considered. The 1996 sample period was carried out from July to September, the 1997 sampling was carried out in September of that year and the 1999 sample period was conducted in March and April of that same year. Thus, the first two sample periods were carried out in spring and the 1999 sample period was carried out at the onset of winter, this may in itself give reason for community variance. Due to the limited number of sample periods and the confounding of year and season, caution is required in this interpretation.

Monitoring of benthic infauna is necessary to establish the magnitude, spatial distribution and temporal distribution of anthropogenic impacts in the receiving environment (Hartley (1982) cited in Bilyard (1987). Bilyard (1987) states that benthic infauna are superior to many other biological groups that could be monitored, (eg., plankton, fish and marine birds) because they are sedentary and must adapt to environmental stress or perish.

The response of benthic infauna to sediment contamination facilitates the spatial definition of impacts (Bilyard, 1987). Benthic organisms are very sensitive to habitat disturbance including organic enrichment of the sediments and contamination of the sediments by toxic substances (Pearson and Rosenberg, 1978). The aim of community ecology is to explain the patterns of natural assemblages of organisms, patterns can be detected by making comparisons among features of natural communities within or between those systems (Ardisson and Bourget, (1990)), as in the comparative analysis of within and between creeks of this study. Highly significant differences in community structure were detected for all sites and creeks across each time period.

Ardisson and Bourget, (1990) go on to state that biotic structures are seen as a series of nested and non-nested mosaics in time and space where complexity comes from the non linearity and asymmetry of the interactions between biological entities and their environment. This "environment" will later be broadened to include the "built environment" as a register of Human Settlement Patterns. These settlement patterns will be interpreted into human activities and consequent impacts.

McLusky (1989) divides estuaries into discreet areas, the upper area closest to freshwater is characterised by fine sand and high organic content within the sediment (as in Site 4 of this study). The mid estuarine region is subject to fluctuating salinities and supports mixed communities dominated by polychaetes, bivalves and amphipods, (as in sites 2 and 3 of this study). This is reflected in this study where a range of bivalves, polychaetes and amphipods varied in both abundance and species richness across sites, creeks and different time periods.
The opening, or the mouth of estuaries, are subject to higher salinities and intense tidal flushing which reduces the availability of organic matter within sediments. Species profile in this area is different to that of the upper reaches, one reason being the high salinity levels. Resident species are drawn mainly from within the families of polychaetes, molluscs and crustacea (amphipod) (Barnes, 1974). Gastropod molluscs such as mud welchs, proliferate in these areas. This study revealed low species richness at Site 1, usually composed of amphipods. Urohaustorid sp. 1 tended to dominate, gastropods molluscs were present in Boambee and Moonee Creek.

From the literature it becomes obvious that models of benthic community structure can be quantified and shown to have some predictive or theoretical application, though each creek requires individual assessment. In order to examine the effects of enrichment or pollution (or other anthropogenic impacts) the use of any indicator scheme must be accompanied by a detailed knowledge of both the abundance and range of species in the area concerned (Pearson and Rosenberg, 1978). This study has now established this important baseline data. Pearson and Rosenberg (1978) further discovered that species changed along a gradient of increased organic enrichment which took the form of a continuous succession, rather than a series of distinct groupings.

Collett et al. (1984) further confirm the dominance of polychaetes, crustacea and molluscs in estuarine fauna and identified clear representative feeding categories; shredders and grazers were rare (5%); filter and deposit feeders (49%), were dominant with a high percentage of carnivores (21%). Collett et al. (1984) further observed that characteristic estuarine sites supported larger numbers of deposit feeders, namely polychaetes, whilst at the more marine sites (towards the entrance) herbivores, filter feeders and carnivores were of relatively greater importance. These observations are further supported by the findings of Jelliffe (1997) and the outcomes of this study which found a concentration of carnivorous molluscs (gastropods) with amphipods and polychaetes at the mouth of estuaries.

The number of species of true estuarine animals in the sea or freshwater is low and at times absent but increases within estuaries with a maximum number of species in the 5-18 parts per thousand regions, ie. towards the centre, as evident in this study around Sites 2 and 3. This again is reflected by Figures 16 and 17 (Nix and Elliot, 1975).

It is often difficult to distinguish actual modifying variables, such as water depth and sediment type (grain size) from those which influence community structure via anthropogenic disturbance (Warwick, 1993). Thus, studies of benthic macroinvertebrate community structure in relation to the detection of pollution effects has often provided equivocal results.

One of the most confounding problems associated with detecting anthropogenic disturbance is finding suitable control treatments. To mitigate this problem during interpretation, theoretical expectations of community change in relation to anthropogenic activities can be used (Warwick, 1993). These expectations act as internal controls. Initial questions with respect to disturbance, population and impacts were: would Coffs Creek be the most impacted? Boambee could possibly be the second most impacted, followed by Moonee with Bonville being the least? It was assumed Coffs and Boambee Creeks to be putatively impacted. Community differences were expected to be observed on that basis. An interpretation of expected community representation was that the most impacted creeks would offer the lowest species richness, together with the highest abundances (Pearson and Rosenberg, 1978).

Both univariate and multivariate analysis showed that there were high levels of spatial and temporal variability within the four estuarine systems. Comparisons resulted in significant differences within and between creeks, illustrating both variation in community structure and composition, and generally little similarity between sites and creeks.

Significant differences were detected between sites at each sampling time as well as between samples collected at each site during separate sampling rounds, that is, both spatially and temporally. These differences relate to the number of species present (S) and their abundance (N).

Interpretation of the analyses for abundance (N) indicated a trend in the interaction terms being a high significant difference between time, creeks and sites across time. Post hoc tests using least significant difference to detect where the differences lie indicated the highly significant difference between Bonville and Moonee and Coffs and Moonee. Moonee was significantly different from all other creeks.

Further determination of where these differences lie revealed highly significant differences between sites 1 and 2, 1 and 4 and 2 and 4. The trends with respect to species richness (S) indicated a high level of significant difference between subject effects for time, creek and site. Multiple comparisons using least significant difference between creeks indicated highly significant differences between Bonville and Moonee and Boambee and Moonee and in determining further where differences lie, highly significant differences between 1 and 3, sites 2 and 3 and sites 3 and 4. Site 3 is significantly different from all other sites. LSD and pairwise comparisons indicate high variability across all creeks, sites and times.

Non-metric multi dimensional scaling (nMDS) indicated the 1999 sample period supported much tighter grouping than the previous sampling period of 1997 and 1996, which can indicate greater similarity between samples. This introduces variables that may be influencing composition other than seasonality and recruitment, particularly applicable to Coffs at all sites, which stood separate from the 3 other creek systems. This may have implications in relation to pollution and the impact of external variations over this site, natural variation may not be occuring.

Multivariate analysis comparisons showed the most similarity between Coffs and Boambee sites at Site 4. Observations at sampling time indicated a thick anoxic mud in Boambee (then Site 7, 1996, now near Site 4) which required relocation of the upper estuary site; and very thick, almost anoxic sediment at the upper estuary site (then Site 7, 1996, now near Site 4) in Coffs Creek. Birch (1996) claims that the most polluted parts of estuaries are the upper regions.

Each Site 4 also supported not only *Notomastus estuarius*, but the amphipod Hadziidae together with the bivalve mollusc *Lasaea australis*. The polychaete worm *Capitella capitata* is a common inhabitant of both polluted and unpolluted estuaries (McLusky, 1989).

The species most responsible for differences between creeks for the period were:

Site 2, *Tellina deltoidalis,* Urohaustorid sp. 1 and *Scoloplos simplex*; Site 3, Hadziidae, *Scoloplos simplex* (except in the Boambee/Bonville dissimilarity index) Sabellid sp 1 and *Tellina deltoidalis* (except in the Coffs/Bonville dissimilarity index); Site 4, Hadziidae, *Scoops simplex, Tellina deltoidalis, Notomastus estuarius* and *Owenia* (Bonville only).

Amphipods, molluscs and polychaetes were found at most sites in all estuaries, these species appeared at different abundance and diversity throughout all sites and all creeks, for example, gastropod molluscs were particularly observed in the lower reaches of Boambee and Moonee at Site 1.

All estuaries supported a lower diversity of species at Site 4, with Boambee, Coffs and Moonee supporting the least species, generally a mixture of polychaetes (*Capitella*, bivalve and amphipods). The variation of amphipods, bivalves and polychaetes contributed to variations in community structure across all sites, creeks and time periods.

Estuaries with the greatest change in human settlement patterns offered least abundance and diversity, such as Coffs and Moonee. Those outside of catchments subject to the greatest change, such as Boambee and Bonville, provided a higher level of abundance and species diversity.

Jelliffe (1997) also found that the upper reaches of estuaries tend to support fine silt with a high organic component and the faunal communities are dominated by polychaete worms, particularly f. *capitellidae*. The mid estuarine regions support a more mixed community which is dominated by worms (polychaetes), bivalve molluscs and amphipods (Family Hadziidae). The lower reaches which are under a strong marine influence and where sandy sediments predominate, supported a different suite of species in the same three taxa (polychaete, bivalve and amphipod), this may also include moderate densities of carnivorous (dog whelks) and deposit feeding (mud whelks) gastropod molluscs.

The species *Notomastus estuarius* of the Family Capitellidae, has a wide distribution in the upper reaches of estuaries in New South Wales and is particularly common in areas which experience low salinities (Hutchings and Murray 1984). Members of this family are known for their tolerance to organic enrichment and physical disturbance and proliferate in polluted conditions (Pearson and Rosenberg, 1978; Gray, 1981). This species was found in the upstream areas of Hearns Lake, Willis Creek and Station Creek (Jelliffe, 1994) and was the only species present in Willis Creek. It must also be noted that *Capitella* sp. and *Notomastus estuarius* were present at Site 4 in all creeks, in this study with the highest abundance in Coffs and Boambee Creeks.

Are macro-invertebrates, in isolation, the best indicators of estuarine health?

Various recommendations have been made to use *Capitella capitata* as a pollution indicator, however it is now clear that they are by no means confined to polluted situations, and this species once proposed as an indicator has now been incorporated into a much longer list variously described as transgressive "opportunist" or "r" strategists (Pearson and Rosenberg, 1978, Kramer, 1994). The ability of "r" strategists to quickly take advantage of vacant niches and prosper, if only temporarily, can change a community structure and is the basis for their inclusion as possible pollution indicators. The greater precision with which we specify the relationship between an organism and its environment, the better the biological indicator will be. *Capitella*, often the first to recolonise a disturbed area are considered opportunistic species (Hutchings, 1984), their rapid response and quick colonisation may be a function of the fact that *Capitella* is a typical "r" strategist species which can reproduce both as subplanktonic and benthic larvae (Gray, 1981).

Seventy one macrofaunal species were found across the four estuaries in this study using grab samples, which compares to the seventy macrofaunal species found by Davey (1998) using corers and is in comparison to the average number of species for NSW which in previous studies ranged from twenty three to one hundred and sixty three species (Rainer and Fitzharding, 1981; Davey, 1998) .

Many physical factors are involved in the structure of communities of benthic organisms in estuaries ranging from grain size and sediment composition, through to organic enrichment and pollution. These physical factors are also affected by human settlement patterns (HSP) and activities and can be a register of impacts. Benthic community structure is also influenced by physical, chemical and environmental processes, local disturbances, recent evolutionary history of the community and recruitment and settlement dynamics (Deeley and Paling, 1999). Substrate characteristics generally explain the variability observed in animal communities in natural marine environments where pollutants do not play a significant role,

The principal characteristics are water depth, sediment grain size and type and conductivity of overlying water. (Patterson and Britton, 2000). Of relevance in this study is the findings that DO, pH and salinity decreased from the lower reaches, site 1 (creeks entrance) to the upper reaches, site 4. Increased stability of the sediment surface either through physical or biological agents can increase the diversity of fauna. For example, the tubes of polychaetes or crustaceans have been observed to stabilise sediment and cause a concomitant increase in species diversity.

Orth et al. (1984) state that sediment size is an important factor governing the kinds of infaunal species that occupy the substrata, studies in south eastern Australia also show patterns of invertebrate occurrence and density change with fluctuations in salinity, depth, substrate structure, temperature and other environmental parameters. (Horwitz and Blake, 1992).

The biological and environmental data matching of this study found that pH and DO were responsible for 22% of the variation in community structure at site 2. Turbidity for 13% of variation at Site 3 and DO, salinity, depth and grain size responsible for 25% of variation in community structure at site 4.

Grain size ranged from fine sand at all sites in Bonville Creek, in Boambee Creek, fine sand at Site 1 through very fine sand to silty clay at Site 4. Both Coffs and Moonee Creek each had fine sand at Site 1 to very fine sand at Site 4.

Water quality tests indicated common trends for all estuaries in the sampling period of 1997 and 1999, in that pH, conductivity and dissolved oxygen (DO) all decreased when progressing from Site 1 to Site 4 (upper reaches). Faecal coliforms and total coliforms increased in all creeks from 1997 to 1999, excepting Moonee which showed a reverse trend for the sample period of 1999. This also coincided with the provision of reticulated sewer to the township. Turnbull (1978) found that water temperature normally increases downstream, consistently supported by the *insitu* temperature readings of this study, that is lower water temperatures in the upper reaches.

Salinity readings in the study decreased towards the upper reaches. Salinity is a major controlling factor determining the distribution of organisms within an estuary, and thus the character of estuarine ecosystems. (Hammond and Synnot, 1994). Lower salinity in the upper reaches of all estuaries of the study is coincident with the findings of low benthic species diversity and mud substrates. Conversely, higher species diversity occurred in the sandy substrates located midway in the estuaries at sites 2 and 3.

Austen and Warwick (1989) found that there may be a species zonation up the estuary relative to salinity which is not reflected in the diversity of assemblages. Figure 1-3 and 1-5 (p. 7 and p. 9 respectively) and the previous discussion by McLusky (1989) outlines the different zones with respect to salinity. A point of consideration with respect to the diversity of assemblages between seagrass and open stratum areas could be the fact that seagrass beds are the most studied structural habitats in shelf sediment environments (Constable, 1999). Mechanisms to explain the abundance and species richness associated with seagrass beds include such variables as food abundance, sediment stability, protection from predation and habitat complexity (Orth et al., 1984).

Turbidity or clouding of the water through sediment run-off proves to be another problem for some macrobenthic fauna, particularly those that are filter feeders. The disposal of effluent and runoff significantly increases soluble nutrient concentrations within an estuary.

Organic enrichment also occurs naturally within estuaries through the decomposition of fauna and leaf litter forming detritus. Increased organic enrichment can lead to problems of eutrophication, which can have profound effects on fauna, altering habitats and food webs, and more directly from reducing oxygen concentrations in the water (McComb and Davis, 1993; Pearson and Rosenberg, 1978).

Aquatic sediments especially those rich in organic matter have a very low concentration of dissolved oxygen. Infaunal deposit feeding invertebrates must accommodate two potential bioenergetic limitations due to the inherent physical and chemical nature of aquatic sediments, relative to many habitats, the sedimentary environment is both oxygen and food poor (Forbes and Lopez, 1990).

Pearson and Rosenberg (1978) state that it would appear that the majority of species associated with the early stages of succession following gross organic enrichment of an area are those also associated with succession following any major environmental disturbance which has resulted in the elimination or significant reduction of the normal fauna. Species particularly associated with the early stages of succession in organically enriched areas, that is, those which might be termed enrichment species, appear to be very limited in number, in this case the Capitellid sp., which were evident in the upper reaches (Site 4) of the estuaries of this study. Present in the sites of the upper reaches were the Capitellid sp. *Notomastus estuarius.*

Reduction of oxygen as a result of eutrophication or other oxygen demanding processes can result in high benthic mortalities. Similarly, periodic hypoxic or anoxic events produce the same result. Macrobenthos, which generally live deeper within the sediment cannot survive to become biomass dominant, or establish themselves in the sediment depth, therefore the community is dominated by short lived, shallow dwelling species. The total density of individuals may actually be higher in stressed areas due to adaptive strategies of opportunistic species that allow rapid local recruitment (Dauer et al. 1992). Oxygen consumption in the sediment occurs as a consequence of oxygen respiration, chemosynthesis and chemical oxidation (Graf, 1987). Sample sites 4 in the upper reaches of Coffs and Boambee presented dark anoxic muddy silts (and to a lesser extent the upper reaches of Moonee).

Numerous sources of nutrients occur, particularly from fertiliser applications (in catchments) rural industries and from sewage overflow and individual on site wastewater runoff into estuarine waters (McComb and Davis, 1993). Site 4 in each creek was the first site affected by runoff from the upper catchment.

Rainer (1981) raises a very important point in that the effects of severe environmental stress are usually obvious, whether judged by low diversity or the presence of particular indicator species. When the stress is relatively mild the possible reduction of the diversity by biological interactions and the existence of ecotone points in pollution gradients suggests that measures of community structure may often be of limited usefulness. The data of this study indicated benthic community structure had significant variation between all sites, within and between creeks across time. That is high variation both spatially and temporally.
In summary, Constable (1999) states that the major physical factors thought to influence the distribution of macroinvertebrates and soft sediment habitats are sediment, nutrients, food supply and water movement, with some recent studies identifying the importance of hypoxia and substratum chemistry which are particularly important in understanding the environmental effects of pollution. (Moonee is an example of low diversity in species.)

The previous factors give an accounting for changes in spatial patterns of community composition and distribution (Morrisey et. al. 1992). Within these patterns there can be other smaller temporal and spatial scale changes that may be a combination or result of biotic, abiotic factors or a combination of both. Sediment grain size can vary substantially within a metre of a sample, which then in turn influences community structure. An example of this scale of variation is the 0-4 mm aggregate of blue metal fines sampled off Carrolls Creek (a tributary of Coffs Creek) across a 150 metre zone, benthic life was absent for that extent of the creek. The fines were downstream from the adjacent stormwater discharge points, its source being the gravel fines from the untarred shoulder of adjacent roads draining into the stormwater discharge points. Incursions of this nature from stormwater have the impact of:

1. Disturbing benthic communities
2. Potentially raising the creek bed which has further ongoing impacts in relation to stormwater retention and flooding.

With respect to the specific questions of the study: The estuaries of the study are characterised by a range of bivalve, polychaetes and amphipods; these species vary within and between creeks both spatially and temporally; through the detrital food chain the benthic communities have a direct association with estuarine vegetation communities.

In order to broadly address ecological change and impacts from Human Settlement Patterns, research into estuarine vegetation communities and interpretation of human settlement patterns and activities (as this study does over 40 years) has been undertaken. This provides a history for establishment, change and impacts (long term trends) whilst benthic community analysis provides an interpretation of current estuarine health.

6.2 VEGETATION COMMUNITIES AND STRUCTURE

The significance of considering estuarine vegetation is due to its direct relationship with the formation of detritus for the estuarine food chain; any changes to the productivity of the related estuarine vegetation eventually impacts on the benthic community of the estuary. West and Larkum (1981) define production as the capacity of a biological system to form organic matter and the rate of this formation is called productivity.

Seagrass beds are among the most biologically diverse and productive components of coastal systems serving as important habitats for nursery species (Livingstone et al. 1998). Stoner (1980) further identifies seagrass meadows as having long been recognised as an important source of food and shelter for benthic invertebrates and a nursery ground for fish.

General trends indicate that seagrass, saltmarsh and sedge/coastal heath communities have declined across all creeks. Seagrass has undergone the greatest fluctuations across the time periods of the study. Mangrove communities have undergone an increase in area across all creeks.

Interpretation of the Bonville creek data indicates significant fluctuation and impact in the period 1964 to 1974 where a reduction in seagrass, sedge and saltmarsh occurred.

This could have been a result of an environmental impact such as dredging or possibly increased nitrogen fertilisation of estuarine waters since that time (Patterson et al. 2000). This impact may also coincide with the construction of the Bonville Waters Estate housing development or various sand extraction industries over the years.

Patterson et al. (2000) in a study of seagrass based on 1996 aerial photography mapped an almost identical distribution pattern as the results for this study with only slight to moderate infilling and/or extension of beds.

Trends in the cover of estuarine vegetation indicate that fluctuations have occurred with respect to seagrass across all creeks, except in Coffs where cover is very low. Mangroves have increased across all creeks whereas saltmarsh and sedge have decreased across all creeks.

This study identifies that from 1974 in Bonville Creek there has been an increase in mangrove, seagrass, and a levelling out or slight decrease in saltmarsh and sedge. Based on 1964 figures there has been an overall increase in seagrass and mangrove with an overall decrease in saltmarsh and sedge.

Boambee Creek presented a decline in sedge, saltmarsh and seagrass since 1974 with a small increase in mangroves. Mangroves have increased based on 1964 figures. Further increase in seagrass occurred, together with a net decline in saltmarsh. Fluctuation has occurred in the sedge which would appear related to a regrowth and clearing in the airport precinct.

Coffs Creek experienced a disappearance of sedge and coastal heath. Saltmarsh has also declined with mangrove and seagrass having both increased. Loss of sedge and saltmarsh relates to urban and industrial development, particularly in the Lawson Crescent/Park Beach area where broad expanses of sedge coastal heath (80 ha) have been filled and raised for development. Loss of sedge areas would aggravate flooding issues as these areas act as temporary stormwater reservoirs in peak times of high seas and intense rainfall.

Moonee Creek displayed the least variation or fluctuation in estuarine vegetation. There has been an overall increase in mangrove and seagrass with a small decrease in saltmarsh and sedge over the 40 years of the study.

Shepherd et al. (1989) indicate that seagrass in various estuaries in previous times used to grow at 10 to 12 metres depth but is now restricted to less than 3 metres due to the attenuation of light. Light intensity will decrease as a result of increased turbidity, which is associated with sediment and erosion runoff.

Walker and McComb (1992) further hypothesised that increased turbidity can be a result of: discharge of the re-suspension of foreign material in the water column, for example, sludge dumping or dredging with indirect effects from nutrient concentrations from discharge of sewage and industrial waste, or from agricultural activity in catchments and increasing phytoplankton biomass. The results of an increase in seagrass in some creeks since 1984 in this study are contrary to other State and National findings (Zann, 1995), which, for example indicate a 60% loss in seagrass in the Clarence River.

Further impacts can occur due to sediment runoff, particularly from uncontrolled development or agricultural areas. These changes could explain the dispersal of areas of seagrass evident throughout Bonville and Boambee creeks, though overall areas may have increased in recent times, the location of seagrass beds has changed across time.

Regression analysis determining correlation between changes in estuarine vegetation relative to changes in human settlement patterns indicated a distinct correlation between increases in human settlement patterns and the loss of seagrass, saltmarsh and sedge/coastal heath, with a positive correlation between increases in human settlement patterns and an increase in mangroves.

As saltmarsh is one of the highest intertidal habitats in estuaries, often forming a buffer between land and sea (Connelly, 1999), its loss can have substantial impacts. Connelly (1999) further states that the conservation value of saltmarsh is a result of five important factors:

1. Filtering of fresh water surface overflow
2. Stabilisation of substrate
3. Biodiversity
4. Export of energy and nutrients that sustain production elsewhere in the estuary
5. Direct use by fauna.

Other forms of loss of saltmarsh have occurred due to the invasion of saltmarsh by mangrove (Mitchell and Adam, 1989; Saintilan and Williams, 2000), as documented in the Bonville and Boambee Creek systems.

A growing body of evidence suggests that incursion of mangroves into saltmarsh is a consistent trend across temperate south east Australia and is a potential threat to the extent and biodiversity of saltmarsh (Saintilan and Hashimato, 1999; Saintilan and Williams, 1999).

Mangrove leaf detritus is the most important element in the food web (Hutchings and Recher, 1981) and increases in mangrove cover, by extrapolation, could potentially mean greater availability of detritus into the estuarine food chains. Saintilan and Williams (2000) indicate that the occupation of the upper intertidal environment by mangroves may be ephemeral, but this could also be cyclical in nature and could be a result of elevated nutrient levels and increased siltation.

Saintilan (1997) puts forward four hypothese for the incursion of mangroves in a landward direction:

1. Higher rainfall
2. Higher nutrient
3. Higher temperatures
4. Sea level change

McTainsh et. al. (1986) suggest an alternative view in studies in south eastern Queensland where that area between the mangroves and the mud flats, (parts of which are sparsely vegetated with saltmarsh grasses and other halophilic species), evidenced salinity measurements of intertidal water ranging from 80 parts per thousand (ppt) on the mud flat margins at low tide to in excess of 110 (ppt) in the centre of mud flats. The conclusion was drawn that extremely high salinity levels can inhibit the growth of estuarine vegetation, including salt tolerant mangroves.

The changing sediment environment, or the build up of both land based and marine derived sediment into banks allows an opportunistic response, by way of the proliferation of the mangroves, this process is apparent in each of the estuaries, as a cycle of sand accumulation and subsequent colonisation is occurs. Mangroves begin a succession of colonisation promoting further sand build up and bank formation.

Catchment erosion induced by anthropogenic activities has dramatically increased sedimentation rates in many wetlands (Adam et. al. (1985). Further impacts on wetlands can come from clearing, grazing, infilling, erosion, extractive industries, pollution and introduced species. Adam et. al. (1985) further suggests that wetlands are slowly changing because of sedimentation. Stream bed raising of the estuaries of this study could be an outcome of this process.

As an example, the gradual increase in mangroves over the past 40 years in the Bonville catchment corresponds to a period of development within the catchment. Sediment could well have been added to the estuary forming mud/sand banks along margins of the creeks and lower estuary (Patterson et. 1.(2000). This is also the case for Boambee, Coffs and Moonee Creeks.

Dispersion of vegetation has occurred in respect to mangroves colonising and creating new sand banks and in some areas overtaking saltmarsh. Shifting patterns of seagrass communities, particularly in Bonville and Boambee creeks have also occurred in the same time period.

6.3 HUMAN SETTLEMENT PATTERNS, ACTIVITIES AND IMPACTS

The Coffs Harbour area has had a history of human activities and changes ranging from the period of forestry commencing in 1860 (Fisher et al. 1996), and the commencement of banana horticulture in the 1880's (Centre for Coastal Management, 1995).

Urban development began with the establishment of villages around Bucca and Coramba in 1851, with the Coffs Harbour population beginning with 500 people in 1905. Urbanisation has increased from that time with a population of 4,000 people in 1945 (Fisher et. al., 1996) rising to 62,000 people in 2000. (CHCC 2000). The intent of studying the changes in human settlement patterns (HSP) and activities from 1954 to 1994, with the particular parameters of housing, paved areas, roads, sealed, unsealed tracks and horticulture, is to gain an indication of the anthropogenic effects that may have been occurring across this time period. That is the understanding of human settlement patterns and activities leads to the interpretation of impacts.

The application of these data to the estuarine system is most important with respect to changes in estuarine vegetation with consequent changes in detrital food chains and important dependent communities.

Cairns (1994), states that the opportunities to study ecosystems that have suffered no anthropogenic effects probably disappeared at least two decades ago, this relates to the difficulties in finding controls for analysis. Very few studies on changes in human settlement patterns other than landuse, agriculture, catchment boundaries or population and demographics have been carried out and no studies in this area have been undertaken with respect to changes in human settlement patterns.

Birch (1996) in investigating the Parramatta River, Port Jackson, the Georges River and Botany Bay, reports that these waterways have been major repositories for urban and industrial waste and are heavily impacted by anthropogenic influences particularly in regard to heavy metal contamination of benthic communities and sediment.

Trends indicate that across all four catchments with respect to human settlement patterns there has been an increase in housing, paved areas and sealed roads with a decrease in unsealed roads. Tracks for Bonville and Moonee have increased, though tracks have decreased for the Coffs and Boambee catchments.

Coffs Harbour catchment displays the highest coverage of human settlement at 25.76%, this is well above the next closest, Boambee at 4.96%, Moonee at 3.8% and Bonville at 2.1%. Of relevance is the size of catchments between each estuarine area, Coffs catchment being the smallest. Moonee is the only catchment that has experienced a reversal in catchment coverage from 1974, this is a result of a decline in banana cultivation. Increase in hard surfaces as previously shown has dramatic impacts on sediment and stormwater runoff. As hard surfaces increase, less infiltration occurs by surface waters to ground water, high velocity runoff is experienced with an increase in sediment yields entering estuarine systems (Day et. al 1994; Corbett et. al. 1997)

This is added to by urbanisation with the construction of impervious surfaces and hydrological improvements, such as stormwater drains which promote surface runoff and reduced infiltration into the groundwater table, resulting in flash flooding at one extreme and lowered dry weather flow at another (Preston, 1995).

Regression analysis indicates direct correlation between the loss of seagrass and the increased cover of human settlement patterns. This was also mirrored with salt marsh and sedge/coastal heath, though the trends for sedge were less distinct. Mangroves have increased with an increase in human settlement patterns.

The current research data reveals that human settlement patterns and particularly the increase in human settlement patterns, has had an impact on estuarine vegetation (Adam, 1983; Saintilan and Williams, 2000). These impacts would result in changes in overall net production, which in turn would affect the structure of benthic communities through each of the estuaries of the study.

With the increase of mangroves on estuarine sandbanks, it is quite obvious that the sand banks themselves have increased over the decades (pers. obs), this is very hard to measure in that aerial photography cannot easily pick up the creep of sand banks within estuaries, particularly when considering tidal influences with respect to the interpretation of this aerial photography. The effect of increased mangroves within newly formed sandbanks creates stabilisation, this stabilisation has the effect of what may be termed land build up, or "the choking of the creek".

The secondary and tertiary impacts from this relate to stormwater flow and flooding potential. It is proposed that as stream bed lowering occurs in the upper freshwater reaches of rivers and creeks, the opposite occurs in estuaries, that is, stream bed raising which is largely a result of landbased sediment run off and accumulation with marine sand infilling. This in turn can have impacts on flow, channel changes, bank stability and consequent erosion.

The hydrological flows of the coastal estuaries needs to be investigated. It would appear that prior to development within a catchment, stormwater events created a hydraulic head adequate to remove land based sediments and marine sands from the lower to middle reaches of estuaries.

In some manner or form the hydrological flows have changed in that it appears that there is not the scouring and consequent movement occurring today as has happened around the 1960' and 1970's, hence estuaries are becoming shallower in their lower reaches. This in turn has impacts upon temperature of the water, water flow, flushing and access of dependent life forms such as benthic communities and fish, particularly in relation to spawning and juvenile habitat protection and changes in estuarine vegetation communities.

In summary, as human settlement patterns increase across all catchments there appears to be a direct relationship with an increase in mangroves and a decrease in seagrass, saltmarsh and sedge/coastal heath.

The settlement history of the Coffs Harbour area provides further insight into the presence of organo-chlorines in the estuarine system and hence impacts for activities. From 1960's to mid 1980 organo-chlorines were widely used in both pesticide use for banana borer control in banana cultivation areas and sub floor termicide treatment in housing construction. Of note is the previous rubbish tip located under a section of the Coffs Harbour Botanic Gardens which would have experienced uncontrolled chemical container dumping. The containers would have residual amounts of the chemicals within. Corrosion across time, infiltration by ground and surface waters could have led to run-off problems into the Coffs Creek.

Lower levels of dieldrin and chlordane residues were found in fish from Moonee Creek, residues of dieldrin and chlordane also evidenced in fish from Boambee Creek, with some aldrin present. The dieldrin residue in fish in Bonville Creek was low, but was not significantly different from those in fish from Moonee or Boambee Creek. The residues of dieldrin in fish from Coffs creek were probably caused by urban use of dieldrin and by erosion of banana soils into the creek, high levels of dieldrin and arsenic have been reported in banana soils (McDougal and Dettman, 1989; Sawtell, 1994). Further investigation should include taking samples of resident biota such as bivalves, oysters and crabs to test for chemical residues.

The bio-availability of contaminants in estuarine and marine waters depends on biological, chemical and physical processes. When the chemical uptake by an organism surpasses the elimination rate bioaccumulation can take place. (Kenish, 1992). Scanes et al. (1993) suggests a degree of chemical contamination of water and sediment may not always be an accurate reflection of acute impact on biota and that different components of the biota can show different reactions to the presence of the toxic chemical. The sampling of fish only, that is a single indicator, can lead to the mis-interpretation of results due to unknown variables such as the resident time of the fish within that estuary.

Chemical residue testing in Coffs Creek in the past has only been carried out on fish species and sediment. A number of problems occur with these parameters:

1. How long have the fish resided in the creek?
2. How recent has the sediment been deposited?. Is it a newly eroded bed, or is it a new layer of sediment washed down or washed in?

   Deep core sediment profiles should be tested for chemical residues. Water sampling should also include tests for the breakdown products of arsenic and dieldrin which are known locally to be persistent chemicals in soils.
3. The use of resident biota, such as bivalves, oysters or crabs should be tested for chemical residues and included in an ongoing sampling regime.

Sediment analysis could provide further data, however sediment cores rather than sediment grabs would be necessary as an interpretation of sediment placement across time. A distinction needs to be made between the placement of recent sediment and sampling, or the access to older sediment; e.g, was it deposited in 1960 or in 1990?

To avoid further increases in stream bed height changes, sediment and erosion control measures should not only be referenced as guidelines, but should be enforced on all site opening activities whether building platforms for houses, agricultural areas or road building exercises.

The depth of sediment sample and its exposure to anoxic conditions also impacts on the bioavailability of the chemical to the food chain, when chemically contaminated sediments become anoxic there degradation is diminished. This can, when considering future erosion and sediment movement, if re-exposed makes the chemical bio-available at a future time to the estuarine food chain.

Mileikovsky (1970) states very clearly that the influence of different kinds of pollution on niches or on estuarine waters such as urban oil products, domestic sewage, industrial waste, including effluent and pesticides in these waters is resulting in qualitative and quantitative changes in the composition of littoral and sublittoral benthic communities to the extinction of many species on the one hand and through the mass development of a few other species, for example polychaetes such as *Capitella,* on the other.

To understand the impacts from runoff, it is important to consider that agriculture has the greatest impact on water resources of all sectors of the Australian economy (McCelland and Valiela, 1998). It is the largest consumer of water and the largest non point source of water pollution from nutrients, pesticides, salt, suspended solids and sediment, for example, it is estimated that 77,000 tons of nitrogen, 11,000 tons of phosphorus and 15 million tons of sediment are washed onto the Great Barrier Reef annually from Queensland's coastal catchments. (McClelland and Valiela, 1998). Alexandra and Eyre (1993) identify the need to control sources of pollution runoff, such as the minimisation of fertiliser usage.

This also relates to chemical usage as it is most important to: minimise the distribution of chemicals prior to rain events; sediment and erosion control devices to all relevant areas including housing and agriculture; use of cover crops in agriculture; minimisation or the cessation of the use of chemical adjacent to stream; keeping in mind that 90% of the food chain is microbiological in nature and can be impacted by chemical application. The provision of litter and sediment traps to stormwater discharge points would be of considerable benefit to the estuarine ecosystems of Coffs Harbour.

Some of the major impacts on estuaries in the Coffs Harbour area commenced with the beginning of the forestry industry around the 1880's and relate to previous clear felling, where off-site migration of soils would have been considerable. This followed through into the agriculture and horticulture periods, and is carried right up to the present day with respect to clearing and preparation of sites for housing, civil works, horticulture and broad acre farming (Lyons, 1993).

Creation and maintenance of roads is no different to the opening up of soil ready for agricultural purposes except that roads are directly linked to drainage channels having direct discharge into coastal estuarine systems or marine environments. It is imperative that stormwater, sediment and erosion controls are applied to all road building and road renewal exercises.

Observation of estuarine photographs particularly for Bonville and Boambee indicate a degree of fragmentation both in relation to seagrass beds and mangrove areas. This fragmentation displays obvious patterns of mangroves incrementally overtaking saltmarsh and the shifting patterns of seagrass (Saintilan and Williams, 1999; Saintilan and Hoshimoto, 1999).

Of high priority is the protection of the detrital food chain, avoidance of impact upon this foodchain and the sustenance of the estuarine food webs. It is interesting to note that most legislation either relates to fauna protection of large and discernable size, animals, for example, bandicoots or birds, or habitat protection from the point of view of large scale zoning or protection, e.g. SEPP 14; Local Government Zoning.

There is currently no legislation to protect the macrofauna down to microscopic level which are the underpinning factors for survival of estuarine food chains and hence commercial fish stocks. One essential fact is that of every food chain, up to 90% of that food chain is at a microscopic level (Phillipson, 1966), hence changes in habitat, influx of nutrients, changes in related environments, impacts such as chemical spraying adjacent to habitat areas will all tend to have a disturbing or destructive effect on the microbiota.

Impacts from human activities are not limited to estuarine vegetation or sedimentation. Herman et. al. (1999) states the evaluation of the consequences of anthropogenically induced changes in the system will likely include the possible responses of the benthos. Hence the pathway or link from human activities through estuarine vegetation to detrital food chains in estuarine systems is established. The assessment of environmental disturbance by humans is a matter of increasing concern but remains an area of primitiveness in terms of the designs of programs of monitoring and evaluation. (Green, 1979; Underwood, 1981, 1991). This then calls for a rethink of the way we monitor and manage the estuarine environment.

Human Settlement Patterns have increased across all catchments, particularly by way of housing, paved areas (industrial) and sealed roads. As Human Settlement Patterns have increased, there has been a corresponding decrease in seagrass, saltmarsh and sedge and an overall increase in mangroves. This then, must have an impact on benthic communities by way of an increase, or decrease in detrital matter, which in turn will affect the growth or the diminishment of benthic organisms, dependant upon the availability of detritus.

Water quality has deteriorated in three of the four creeks with DO, conductivity, and salinity decreasing from the estuary opening to the upper reaches. One identified trend is the presence of amphipods, bivalves and polychaetes across most sites in all estuaries. These, in turn, may prove to be possible indicators for estuarine health. Those estuaries in catchments with the lowest percentage growth, and human populations (Bonville and Boambee) support the highest species abundance and diversity. Initial assumptions of Coffs and Boambee Creeks being the most impacted have not held true. Moonee Creek, based on limited diversity could be assumed as "impacted" though a high level of diversity does not always mean health.

The aims and objectives of this study have been fulfilled by the provision of baseline data on benthic communities, estuarine vegetation and human settlement patterns. The uses and activities of each catchment have been compared and contrasted and human activities and impacts have been assessed.

The specific questions associated with the aims and objectives have also been answered in that estuaries are characterised by certain macrobenthic species, in particular, polychaetes, bivalves and amphipods. These species do change both within and between creeks and across time. The estuarine vegetation communities have been established and have identified differences both within and between creeks, across time have been identified. There has been distinct changes in estuarine vegetation in the period 1954 to 1994, and there is a direct association between the estuarine vegetation and the benthic communities. Human settlement patterns have been documented for each estuary from 1954, together with the establishment of the multiple factors that create impact and change within the catchments of the estuaries. One outcome is the direct association between human settlement patterns and activities and changes in relation to estuarine vegetation.

The issues facing estuaries remain clear. These are: chemical residues, bio-accumulation and bio-magnification; changes to benthic communities and related food chains and food webs; fertilisers; erosion and sediment runoff; development and civil works; paved areas and non-absorption of rainfall; stormwater runoff and discharge; nutrient runoff and pollution; loss of vegetation and loss of habitat, sediment build up and sand bank formation together with an increase in mangroves and development areas encroaching on estuarine habitats.

The question of impacted or non impacted creeks is important. This study began with the prediction that Coffs or Boambee Creek may be the most impacted. It is clear that Site 4 in both Boambee and Coffs Creek may be influenced by either organic enrichment or human settlement activities, particularly evidenced by the presence of the polychaete Capitellid sp.

However, assessing the overall combination of data including benthic organisms, estuarine vegetation and human settlement patterns, Moonee would appear to be the more impacted than the other estuaries of Coffs and Boambee and Bonville, particularly based on abundance and species richness data.

A review of the history of Moonee creek will be required in order to interpret these findings. The urban area of Moonee up until 1999 was dependant upon on-site effluent disposal. This also included a rather large caravan park at the end of Tiki Road at the confluence of Skinners Creek and Moonee Creek (no longer operating). Considerable discharge of effluent has been experienced from this site over the years (pers. Comm; A Schaeffer). Improvements have occurred with respect to runoff and on-site wastewater management and sewage discharge. Recent legislation changes require compulsory inspection of all on-site wastewater systems, which should improve the functioning of the septic systems and minimise any run-off potential. The faecal coliform and total coliform readings in Moonee indicate a decrease across the 1997 - 1999 period rather than an increase, which is probably related to the provision of reticulated sewer. There has also been an intense history of chemical application to the intertidal zone from Moonee Escapades (halfway up the creek), to Stingray Creek in the lower reaches for biting midge control.

As in all environmental issues the social economic and environmental parameters must be considered in order to correctly address the problem and provide solutions to the future.

7 CONCLUSION

In summary, with respect to bio-indicators, the arguments for and against are many. Interpretation of the previous benthic data is just that, interpretation. To solely rely on a single indicator is fraught with possible future errors of judgement. Factors such as seasonality, the stages of population growth. that is, is it in a state of growth, or in fact, is it in a state of decline? What ramifications could come from misinterpretation of this data? There are other factors not considered by this study, such as: prey/predator interrelationships; longer term natural fluctuations and cycles; undefined anthropogenic influences.

The solution is to look at benthic analysis wholistically. Such an interpretation and projection requires an understanding of the whole "data set" and analysis of "interrelationships", which is the true definition of ecology. In this study, the integration of benthic data with the consideration of estuarine vegetation changes and human settlement patterns provides a more sound interpretative and predictive tool.

Through the process of Agenda 21, Ecological Sustainable Development (Socio-economic and environmental considerations) and State of the Environment reporting, uniform indicators are now being required. These indicators need to address the ecological interrelationships within suitable time frames and provide answers to managers, scientists and the community.

"Core" environmental indicators for estuaries can be defined as that minimum set of indicators, which when properly monitored, will provide information on major trends and impacts on estuarine ecosystems. There must be sufficient background or baseline data for these indicators in order to describe departures from normal behaviour within natural variability and to provide an understanding of the range of natural biophysical processes and relationships contributing to ecological systems (Deeley and Paling, 1999). This is the utilisation of ecological data in resource management.

This study has identified the need for data at larger scales and incorporating indicators of potential stress, at the scale of the catchment, in order to put benthic biological data in perspective.

Estuarine managers require a rigorous evaluation of the statistical power and application of these indicators to underpin the difficult task of assessing the early onset of adverse changes in the ecological health of an estuary (Deeley and Paling, 1999), this is not being done.

Ecologists have a limited ability to provide predictions about how estuarine assemblages will respond to a variety of influences including anthropogenic ones (Constable and Fairweather, 1999). Of high priority is to establish baseline data on all natural resources, particularly those within and related to estuarine systems.

The term, bio-indicators is commonly used for application to estuarine environments that are subject to rapid change. Monitoring and management strategies have not evolved to accommodate these variables, or to include indicators of anthropogenic impacts and change in estuaries and turn them into corrective management tools. It is important that research and management broadens the view from estuarine health into ecosystem management, or to what may now be termed, integrated environmental management.

Effective indicators of ecosystem health must be cost effective, be based on the ecological health of biota and include an understanding of historical and current behaviour. They should apply to a narrow geographical group of organisms in a limited area and should be sensitive enough to indicate anthropogenic stress, whilst incorporating natural variation (Deeley and Paling, 1999).

The indicators need to be broad enough to encompass not only changes in the ecology of the estuary but also the changes to the built environment which delivers the impacts to an ecosystem and can therefore be monitored and act as a trigger or early warning system of change.

What can be learned from this study in terms of day to day management requirements?

Detritus is a key driver of the estuarine ecosystem. The results have shown a link or interrelationship between human settlement patterns, activities and impacts and changes in estuarine vegetation. Estuarine vegetation changes in turn can create changes to the macrobenthos, though in longer time scales.

Therefore changes in human settlement patterns and estuarine vegetation can be incorporated with biological indicators as “core” indicators and act as a trigger for further investigation.

It is suggested that core indicators for estuarine assessment include human settlement patterns, estuarine vegetation together with biological (benthic) analyses. Use of benthos alone would be inadequate, as this study shows, that the patterns of benthic macro-invertebrate communities are sensitive and exhibit high levels of variation in space and time. As such they might be too sensitive to natural change to be used, singularly, as a reliable tool to gauge anthropogenic impacts.

Any indicator must be achievable and depends upon: costs, funding, availability of resources, community wants, scientific achievability and management needs.

It is the goal of environmental management efforts to protect natural ecosystems, human health and ecosystem health (Cairns Jr. et al. 1993), it is quite obvious that these goals are sadly forgotten or lacking.

Amir and Hyman (1993) clearly state that health has been identified to relate to two major features:

1. An ability to resist external pressures - resistance or inertia
2. An ability to rebound and recuperate from irrestable pressures - resilience.

Fairweather (1990) asked a most important question: Are we doing the research that is important for habitat protection and ecological management and is it readily available to interested parties?

As management decisions and considerations taken in isolation are generally based on a lineal format, then the true inter-relationships that are required by ecology will fail to be observed or implemented.

Current scientific and management thinking dwells all too often around the comments put by Bilyard (1987) in that management decisions are based on scientific information that exhibit three characteristics:

1. The information should be quantative and it’s inherent variability should be able to be estimated.
2. It should also be site specific to aid in defining impacts in space and time and attributing them to individual point sources of pollutants

3. Finally, the scientific information should characterise at least one biological community benthic infaunal data not three characteristics.

The preponderance on a single indicator organism, rather than integrated management as a whole, defies the true and scientific definition of ecology, which is in the study of inter-relationships. Integrated environmental management needs to step out into the understanding and consideration of interrelationships between social, economic and environmental needs and pressures of society.

The need of legislation and the required establishment and use of data are obvious for the protection of estuaries relative to “ecosystem management”. If this legislation and data is not rationalised between the scientific and academic sectors in partnership with the management sector, (both government and private), if we cannot create understandable definitions and tools that are easily interpreted by the end user, that is, the public, then resource management will relate only to resource deterioration.

7.1 FUTURE STUDIES

In general terms, to ensure estuarine health into the future, the following broad considerations are important:

- Establish baseline data, which is both valid and reliable;
- Expand the parameters of biological indicators to include resident biota such as crabs, oysters and bivalves;
- Consider interrelationships;
- Identify the key factors, such as benthos, estuarine vegetation and human settlement patterns and their interrelationships with a reference estuary;
- Establish (short term) emergency response and (long term) strategies such as development control, monitoring, education, ecological awareness, improved strategic planning and sustainability responses and practices, and
- Education campaigns in respect to the sensitivity of estuaries and the minimisation of impacts, such as runoff, chemical and fertiliser usage is also important.

The identification of future studies relates to the establishment of data for benthic communities estuarine vegetation communities and human settlement patterns. The further assessment of human activities and consequent impacts is essential if estuarine environments are to be protected and any impact to be assessed, limited or reversed.

To incorporate the previous considerations future studies would need to include the following:

1. The assessment of detritus as biomass, its increase or decrease and its direct role in estuarine food chains:

   In reviewing the outcome of estuarine vegetation analysis, it appears that there could be a net increase in detritus available to the estuarine systems as a result of the high percentage increase in mangroves. Specifically has this been balanced by the loss of seagrass, saltmarsh and sedge? Does this then: improve benthic communities by way of (N) and (S) or foodchains; is the excess removed in flushing and not available to the food chains? or does it confound the food chain by too much partial treatment such as ingestion and thence removal prior to further digestion by other microbiota and the consequent necessary micro colonisation that is required?

2. Ongoing benthic sampling would be required to add to this database and should include physico/chemical means such as granulometry, water and faecal coliform results, nutrients testing for nitrogen and phosphorus would also be important.

3. The inclusion of biomass (wet weight) of organisms would provide an important addition to the benthic data development.

4. The inclusion of resident biota such as crabs and oysters for chemical residue testing should be an important factor, and the testing for breakdown products of arsenic and dieldrin based chemicals would be important.

5. Human impact assessment. This study barely commences the assessment of human settlement patterns. Future studies would include; audits of pollution, industry, stormwater and waste disposal, particularly looking at the triple bottom line components of social, environmental and ecological interaction.

6. Chemical residue testing. Looking at transect analysis along the creek systems and identification of potential hot spots such as the old tip along Coffs creek.
7. Sedimentation. Addressing the question of infill or cyclical? There would need to be a review of historical data related to the depth of the estuaries, together with the estimation or quantification of tidal flows in the estuary. This hydraulic analysis should be linked to long term rainfall studies.
8. Sediment analysis. This would include bore logs at depth with consideration of the slip slope and sediment build-up relative to the cut off slope, including assessment of the broad range of chemicals that have been used in the catchment together with their derivatives with concentration based on the arsenics and organochlorines.

   Interpretation of the results whether biota or sediment, particularly needs an understanding in levels of detection (LOD), eg, parts per thousand (ppt) or parts per million (ppm) and the interpretation of none detected (ND), and the confusion that this creates in the misinterpretation through the comment that “nil residue is evident”, when in fact correct interpretation means none detected at that level, whether it be ppt. or ppm.

9. Water analysis would typically include bacteriological, chemical and nutrient analysis. It could also include a new parameter of faecal sterols which differentiates between faecal contamination sourced from animals or from humans.
10. Environmental audit of both industrial and potentially polluting practices, including stormwater and sewer overflow points.

8 ECOLOGICAL CHANGE AND ESTUARINE HEALTH ”SCIENCE IN MANAGEMENT”

A review of the literature indicates a preponderance with observation, documentation, policy review and adjustment relating to a theoretical response that may be achieved some time in the future. Indicators and bio-indicators are discussed as methods of interpreting change within our ecosystems. Most of this research lacks, with respect to very few initiatives, an involved and integrated management approach. An integrated management approach:

1. Documents the nature of the environment, habitats and ecosystems and their important interrelationships.
2. Reviews policies in relation to activities and changes regarding those habitats.
3. Provides an active integration of all attributes regarding those interrelationships, for example, the inclusion of research data, much of which never reaches management areas whether in government or private levels. This message is at times conveyed in a language that is not discernable or unable to be assimilated into policy decisions. If this occurs then there is a failure to instigate change or protect the natural resource currently in place.
4. Science must generate data that becomes a management tool.

The use of a geographic information systems (GIS) as a management tool can fulfil some of these needs. The attached CD “Science in Management” offers an interactive display of spatial and temporal changes in both estuarine vegetation and human settlement patterns within the four estuaries of the study, together with photographic interpretation of the benthic organisms of this study.

This CD, “Science in Management”, as an integrated management tool presents a bridge between science, government and the environment. It provides desktop access for ecologically sensitive areas based on Local Government property information and coordinates. This provides an interactive tool which can:

1. identify sensitive areas relative to current and future development;
2. provide a tool to observe historical change in the vegetation communities of the 4 major estuaries in the Coffs Harbour area;

3. overlay changes in human settlement patterns, such as housing, road networks, industrial areas, agriculture, paved areas, tracks and unsealed roads;

4. provide a basis for the understanding and interpretation of the complex interrelationships between human settlement and estuaries;

5. provide the location, nature and abundance of biological data; and

6. provide the basis to assess some human activities and their consequent impacts.

The integrated approach offered by GIS can relate to sensitive natural resource areas, to human activity or to development areas. It can display data such as: biological data, proximity of roads and development areas to creeks, stormwater discharge lines and points, septic tank locations, sewage pump stations. I would like to suggest that it also has the potential for integration with emergency response such as the provision of HAZMAP (Hazardous Materials Mapping), a new concept.

The HAZMAP initiative can locate all dangerous goods and potentially contaminating sites or storage areas in an overlay system and has particular relevance and value to emergency response and spillage incidents, for example, 10,000 litres of petrol stored on a block of land adjacent to a stormwater drain 50 metres from a creek. The programme can offer positive protection to estuarine and human health. There is currently a lack of well developed ecological models of estuaries that can indicate future issues for the management of estuaries.

Current estuarine management does not achieve integrated management due at times to confusion, lack of communication, lack of identification of roles and responsibilities, lack of resources and funding.

Decisions are usually presided over by a community/interagency committee. To achieve tangible, ecological and resource management outcomes this committee structure needs to be analysed, refined and redirected. The Estuary Care concept is relevant.

8.1 COMMUNITY BASED APPROACH TO MANAGEMENT

A further example of an Integrated Management approach is the fostering of community groups in line with academic institutions and government agencies. These partnerships would be called Estuary Care Groups. Data gathered by these groups would need to include baseline data, verification and monitoring. Data gathered can be improved by scientific input which would then assist government and the community in decision making processes. Through education and awareness it is hoped to remove the question "drains or estuaries?" and change the common attitude of "out of site, out of mind".

The provision of baseline data, the interpretation of that data, its interactions in estuaries and the associated human settlement patterns and impacts that has been undertaken by this study has been both complex and costly with respect to time and financing. It is unlikely that a study such as this would be carried out very often. As such, the estuary care initiative could continue the data gathering and management required that comes from this study.

The combination of community groups, academic institutions and government, (both state and local), offer distinct advantages with regard to strategic planning, sharing of costs, networking, generation and interpretation of data, linking to a data management tool such as a geographic programme (GIS). Correct implementation of this system does not require the community to become scientists.

Initially, clear objectives would be required to be set, such as the monitoring of catchment ecology including human settlement patterns and activities as well as the estuarine ecology, including estuarine vegetation; regular assessment of benthic fauna and water quality sampling; and the application of correct scientific procedure in data gathering and analysis. Implementation of this program would include training, identification of roles, responsibilities and assessing the needs and capabilities of both the stakeholders and participants as well as the programmes.

Breakdown of some roles and responsibilities could be as follows:

- *Academic Institutions*: providing student assistance, such as Honours, Masters and PhD, sample design and methodology, establishment of baseline data, correct sampling and monitoring procedures together with scientific interpretation of data.

- *Community*: training in and implementation of environmental audit, training and monitoring in vegetation assessment utilising current GIS and Global Positioning technology, training in biological monitoring, such as transect analysis and capture, sorting and identification techniques.

- *Government - Local*: compilation of data and provision of GIS tools, education, overview of audit and assessment, establishment of programs and guidelines such as stormwater management or HAZMAP, co-ordination and facilitation of funding opportunities, legislation; interpretation and enforcement.

- *Government - State*: regional assessment and provision of resources, access to Federal Government funding and guidelines and legislation, interpretation and enforcement.

A model such as this can begin to address issues such as storm events and run-off, response times, costs, accessibility, partnership and cost sharing, data gathering and assessment, application of data to policy change and legislation enforcement.

Problems that could arise from such a system or model include: matters of responsibility sharing; legislative responsibilities; implementation of the various acts and ordinances; funding; ongoing commitment; providing the ongoing costs for research; co-ordination and facilitation; and proper project planning, both in scale and time.

A program or model such as this has the potential to provide an integrated management approach. The estuary care model could follow a simple methodology of:

1. Initial assessment providing baseline data. This can be a combination of academic and community input, for example, thesis completion from Honours, Masters or Doctorates and community group sampling. Agencies responsible would include, community groups, local government and academic institutions.

2. Ongoing monitoring for change. Agencies responsible would include community groups such as Estcare, academic institutions, local government and state government such as Council, Department of Land and Water Conservation (DLWC) or the Solitary Islands Marine Park Authority (in this area).

3. Corrective action, for example, enforcement of sediment and erosion control guidelines, stormwater guidelines, pollution control which would rely upon:
    a) environmental audits of industry and any potential polluting practices, which then arrive at a hazard index for HAZMAP application;
    b) corrective actions such as physical works, which would cover issues of erosion control in development works, roadworks, subdivisions and upgrade of existing roadworks, chemical usage. Responsible agencies would include local and state government.

Various terms are now coined such as catchment management, integrated catchment management, strategic environmental planning or sustainability. Irrelevant of the term, it is the issues involved that require address. It is a logical step in relation to any existing problem to also plan to avoid those problems that may occur in the future, hence strategic planning has a primary role in environmental and ecological issues.

However, Atkins et al. (1993) indicates that catchment management alone may not be able to achieve scientific and community objectives for waterway management within the required timeframe, and it is usually necessary to treat the symptoms as part of an integrated management strategy. Pressures need to be assessed and relieved with future impacts minimised or made non-existent.

Global issues such as changes in sea level and changes in long term rainfall patterns may also tend to impact on local estuaries. Jones (1994) states that whereas a rise in sea level in the open ocean would be of negligible significance, along the sea land interface it would be pronounced with respect to estuaries. As the sea level rises so estuaries would become wider and deeper, this trail of penetration extending further upstream. Saintilan (1999) indicated a minimum 1.5mm rise per annum over the last 50 years has occurred in the coastal area.

Bio-indicators of estuarine health are not sufficient as stand alone management tools. An integrated approach should involve, not only the preparation of research, but the dialoguing of that research into interpretable and useable data, whereby management, both government and private, is more able to utilise that data in a proactive sense and incorporate ramifications into policy formation.

Science has to transform its' research into more usable data which is easily applied and interpreted. Science needs to integrate with management.

It could be commonly put "no data, no management", thence resource deterioration. This is confirmed by Cooper et al. (1994) who state that coastal zone management is often hampered by ineffective collection of multidisciplinary information and even when adequate data is available, there is ineffectual transfer of information from scientists to end user.

There are obvious inadequacies and obstacles to rational environmental management, such as an inadequate understanding of the full complexity of interaction between physical, chemical and biological processes, a lack of identifying adverse impacts and their source. It would appear that the first step, which is normally overlooked, is to determine the present condition of the environment.

The suggested approach enables the selection, implementation and interpretation of indicators of the current state of the estuarine environment as an early warning system.

The answer to Integrated Management is to begin to unravel the links between all sectors/levels; agencies, education institutions and community groups and improve pathways of communication, identification of roles and responsibilities and commitment to action. To do this a number of models need to be understood and then links (or relationships) both within the models and between need to be forged.

Currently all the processes, wants, needs and considerations of the groups exist in a confusion of demands and competing resources with very little outcome. Collectively gathered in such a group are various needs, wants, demands and responses (Figure 8.1).

8.2 AN INTEGRATED MANAGEMENT MODEL: A MODEL FOR THE FUTURE

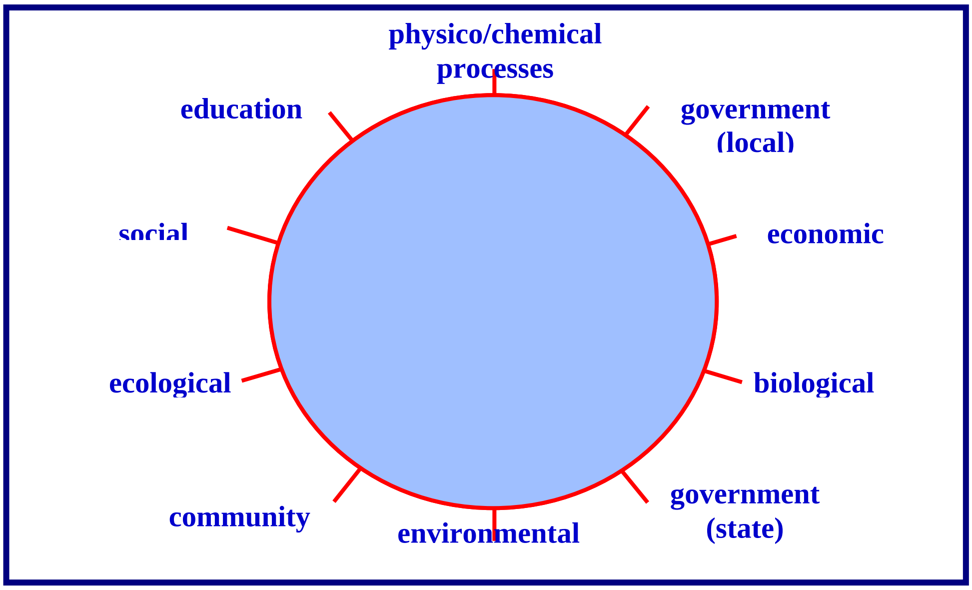


Figure 8-1 - Stakeholders in integrated management

I would like to conclude this thesis by proposing an overall management model that has the potential to produce tangible outcomes and decisions toward higher goals of ecological and resource management.

Ecologically Sustainable Development (ESD) principles are founded in the use, conservation and future improvement of community resources so that ecological processes are maintained and improved (AIEH, 1993). The most familiar model associated with this is that which considers the social, economic and environmental considerations and impacts, the triple bottom line (TBL) (Figure 8-2).

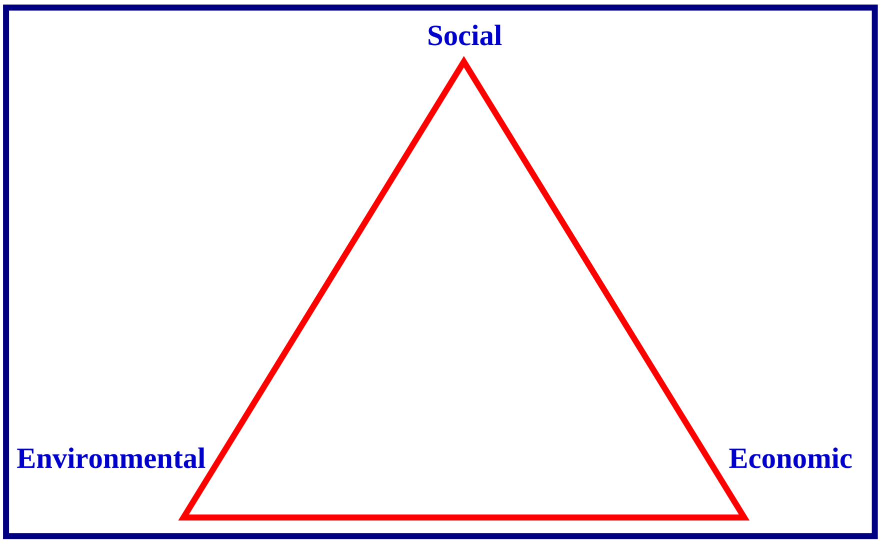


Figure 8-2 - The triple bottom line (TBL) process involves socio-economic and environmental considerations and impacts

Previous socio-economic imbalance, now considered in primary, secondary and tertiary impacts (level of order and significance 1, 2, 3) relating to the interplay and balance within the tripatite relationship. Particularly applicable in all government activities and compliance requirement.

Two other layers of relationships need to be integrated with this ESD level. The next layer or model is that of the physio/chemical, biological and ecological processes which again can be expressed as a tripartite relationship (Figure 8.3).

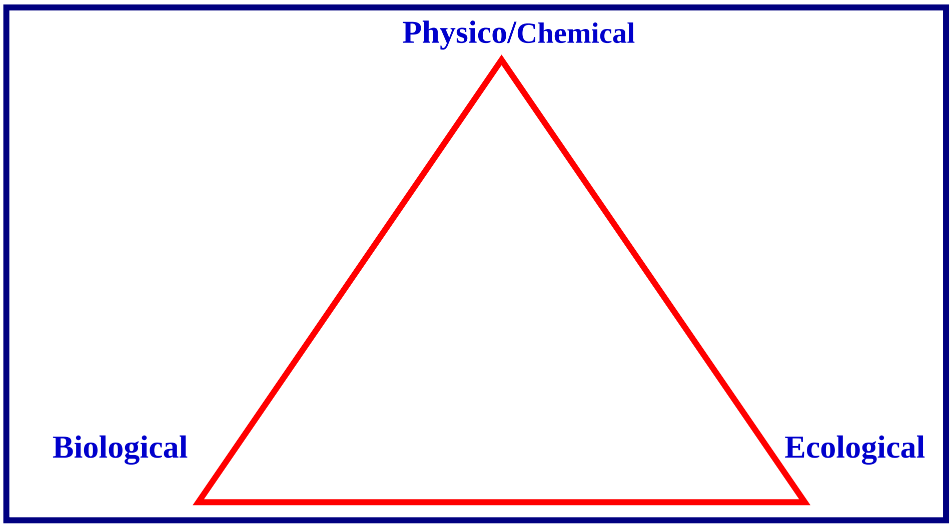


Figure 8-3 - Integrated Management Model - Structure
Physico-chemical, geological and ecological considerations and impacts
Generally fits as a prior consideration to TBL and a basis for TBL. This considers the ecological and biological environment with the physico/chemical variables that are responsible for this structure, e.g. estuary dynamics and biological dependencies such as fauna, macrobiota and fish and thence ecological considerations of interrelationships between all biotic levels

A third model integrates community groups, government and semi-government agencies (state and local) with educational institutions (Figure 8-4).

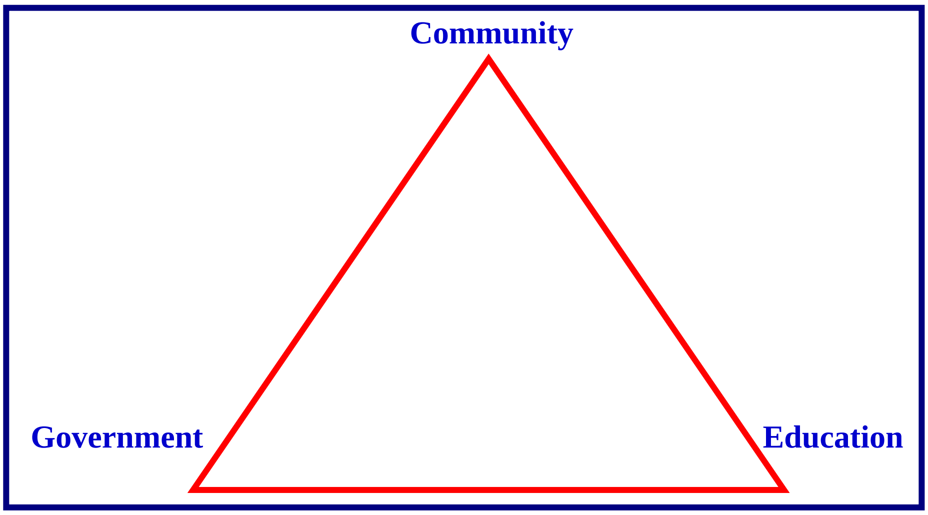


Figure 8-4 - Integrated Management Model - Action/response. Community, Government (local and state) and educational institution response to ecological and TBL considerations and impacts

Links or relationships have to be achieved both within and between these models (Figure 8-5, 8-6)

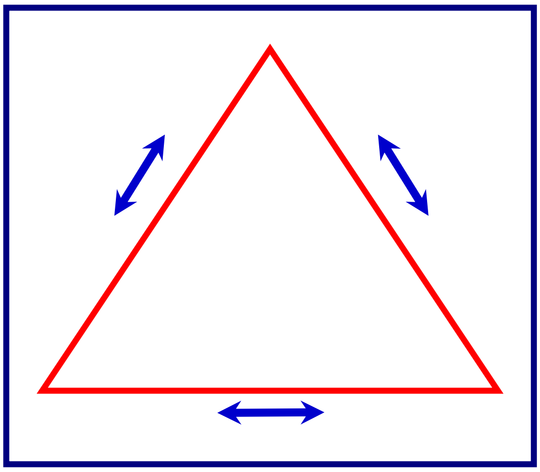


Figure 8-5 - Links or relationships within the model or level

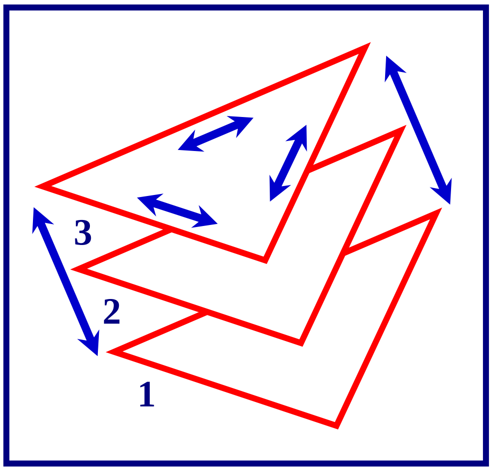


Figure 8-6 - Links and relationships between the models or levels

1. Structure; 2 Indicators and assessment (TBL), 3 Action/response mechanisms

This can be done through education, understanding and then awareness. If the interrelationships are understood then a more refined model is possible. The key is data management and sharing.

This process enables communication, identification of roles and responsibilities, engenders commitment and will present a refined decision making tool.

In each level the tripartite relationship must be understood and fulfilled. For example:

1. Structure: Without proper understanding of the physico/chemical, biological and ecological parameters of the environment and the dependant interrelationships associated, then an incomplete understanding will be the inevitable outcome, which will provide flawed interpretation and decision making (Figure 8-3).

2. Indicators and assessment: The TBL considerations and impacts now require a balance of socio - economic and environmental considerations and impacts. Previous interpretations have related to the socio-economic parameters only (Figure 8-2).

3. Action/Response: By proper involvement and assessment of community, government and education roles, responsibilities and limitations, commitments can be realised as tangible outcomes not “wish lists” (Figure 8-4) and act as a mechanism for implementation.

4. Policy change: The fourth level to the Integrated Management Model is a feedback mechanism that allows for policy change, implementation and at times enforcement. This will range through, for example, habitat protection guidelines, erosion and sediment control guidelines to statutory responsibilities in legislation, implementation and enforcement, e.g., Protection of the Environment Operations Act (P.O.E.O. Act, 1997).

The key to this Integrated Management Model is data management, sharing and education. The expected outcomes will not only provide a trigger for response and action, but should also affect policy, guideline and legislation implementation, enforcement and change.

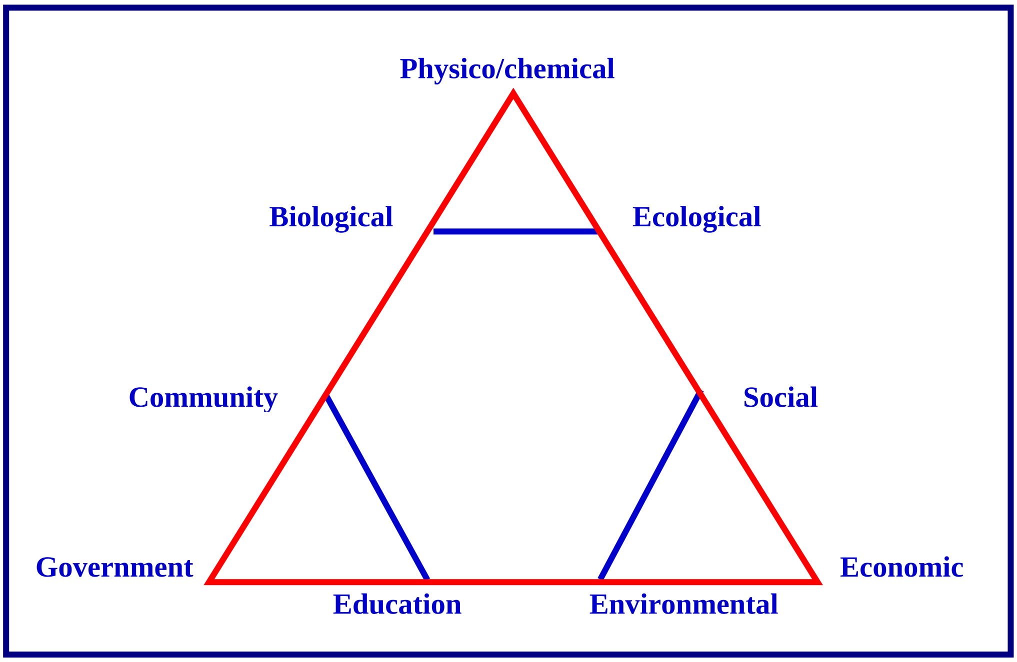


Figure 8-7 - Parameters of the Integrated Management Model

With each response area understood by the stakeholders with respect to roles and responsibilities, the levels, planes or parameters can be brought together through a process of assessment, consideration and response (Figure 8-7).

This then forms an Integrated Management Model (IMM). (Figure 8.8).

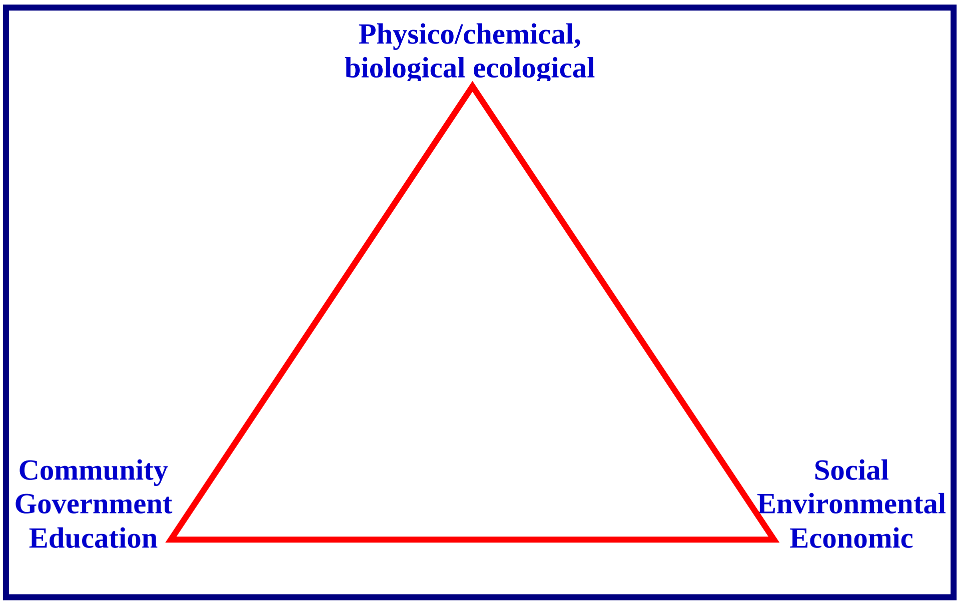


Figure 8-8 - The Integrated Management Model

This transformed model can then provide not only the answers to the questions that managers, community and scientists ask, but provide a balanced and informed approach to environmental management. This model will provide “forged relationships” which is the preferred outcome of community consultation. True integrated management produces a new paradigm of interrelationships which can then create “Science in Management”.

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APPENDICES

TABLE OF CONTENTS - APPENDICES

APPENDIX 1 BENTHIC DATA-RAW DATA OF MACROBENTHIC STUDIES

1.1 BENTHIC DATA 1999 - BONVILLE

Bonville																				
Estuarine Species List	1999																			
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5
Polychaetes:																				
Aphrodite sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arenicola sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Armandia intermedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Australonereis ehlersi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capitella capitata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ciratulid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Glycera sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbrinereis latrelli	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	0	0	1	0	0
Magellionid sp. 1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0
Magellionid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marphysa sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertean sp.1	0	0	0	0	0	0	0	0	0	0	5	0	0	1	7	1	2	1	1	3
Nepthyidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Nepthyidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
Nereididae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notomastus estuarius	0	0	0	0	0	0	0	0	0	0	2	0	3	3	7	12	2	0	2	7
Phyllodoce novaezealandiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodocid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Owenia sp.1	0	0	0	0	0	0	0	0	0	0	2	0	0	1	1	1	19	55	48	1
Sabellid sp. 1	0	0	0	0	0	0	1	0	0	0	0	4	0	1	1	0	0	0	0	0
Sabellid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scoloplos simplex	0	0	0	7	4	0	1	0	1	3	0	0	0	0	0	0	0	0	0	0
Sigalionidae sp. 1	1	2	2	3	3	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
Sipunculid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichobranchid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tubeworm sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipod																				
Hadziidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	5	1	0	5	0	0	0	1	0
Hadziidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urohaustorid sp. 1	2	21	7	0	0	7	2	0	1	0	0	0	0	0	0	0	0	0	0	0
Amphipod sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aora hebes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decapods																				
Alpheid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawn sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawn sp. 2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Callianassa australiensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hermit crab sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Halicarcinus ovatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Mysid sp. 1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Isopod																				
Sphaeromid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusc																				
Bivalves:																				
Tellina deltoidalis	1	0	3	8	6	21	2	13	15	15	15	8	8	4	0	2	0	2	5	2
Macomona deltoidalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lasaea australis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ambuscintila praemium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eumarcia fumigata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Spisula trigonella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Sollatelina donacoides	0	0	0	0	0	7	0	0	0	5	0	0	0	0	0	3	0	0	0	4
Gastropods:																				
Hydrobia buccanoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ophicardelus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nassarius sp.1	1	0	3	1	0	3	4	3	0	0	1	3	1	2	0	0	0	2	1	0
Pseudoliotia micans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Assininea tasmanica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taetia rufilabris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naticid sp.1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F. Potomodidae	0	0	0	0	0	0	0	0	0	0	3	24	0	1	2	0	0	0	9	1
Prosobranch sp. 1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish																				
Fish sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Fish sp. 2	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Fish sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Animals																				
Animal sp.1(Anenome)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Animal sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animal sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1.2 BENTHIC DATA 1999 - BOAMBEE

Boambee **Estuarine Species List**	1999 .1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5
Polychaetes:																				
Aphrodite sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arenicola sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Armandia intermedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Australonereis ehlersi	0	0	1	0	0	4	14	29	24	36	0	0	0	0	0	0	0	0	0	0
Capitella capitata	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ciratulid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glycera sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbrinereis latrelli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Magellionid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Magellionid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marphysa sp. 1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Nemertean sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nepthyidae sp. 1	1	0	0	0	3	0	0	0	0	0	0	7	4	1	1	0	0	0	0	0
Nepthyidae sp. 2	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 2	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Nereididae sp. 3	0	0	6	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notomastus estuarius	0	0	0	0	0	0	0	0	0	0	1	7	0	0	0	20	19	6	10	6
Phyllodoce novaezealandiae	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
Phyllodocid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Owenia sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 1	0	0	3	0	2	2	0	0	0	3	13	16	7	6	3	1	1	0	0	0
Sabellid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scoloplos simplex	0	0	0	0	0	2	1	4	8	5	4	0	0	0	0	0	2	0	0	0
Sigalionidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sipunculid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 1	0	0	3	0	0	0	0	2	3	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Spionid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	4
Trichobranchid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tubeworm sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipod																				
Hadziidae sp. 1	0	0	0	0	0	2	0	0	0	0	5	1	1	0	0	8	13	3	20	9
Hadziidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urohaustorid sp. 1	0	0	0	0	0	8	28	7	5	0	0	0	0	0	0	0	0	0	0	0
Amphipod sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Aora hebes	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decapods																				
Alpheid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawn sp. 1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Prawn sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Callianassa australiensis	0	0	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Hermit crab sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Halicarcinus ovatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mysid sp. 1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopod																				
Sphaeromid sp.1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusc																				
Bivalves:																				
Tellina deltoidalis	5	0	0	0	3	3	0	17	8	4	15	11	6	1	9	2	2	0	1	2
Macomona deltoidalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lasaea australis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0
Ambuscintila praemium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eumarcia fumigata	2	2	0	0	0	0	0	0	3	0	0	2	0	0	1	0	0	0	0	0
Spisula trigonella	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Sollatelina donacoides	0	0	0	0	0	0	0	7	6	2	3	7	3	0	5	0	0	0	0	0
Gastropods:																				
Hydrobia buccanoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ophicardelus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nassarius sp.1	6	0	0	2	13	1	5	2	8	8	3	0	4	0	1	0	0	0	0	0
Pseudoliotia micans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Assininea tasmanica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taetia rufilabris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naticid sp.1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
F. Potomodidae	25	28	0	23	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Prosobranch sp. 1	3	0	0	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Fish																				
Fish sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animals																				
Animal sp.1(Anenome)	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
Animal sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animal sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1.3 BENTHIC DATA 1999 - COFFS

Coffs

Estuarine Species List	1999																			
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5
Polychaetes:																				
Aphrodite sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arenicola sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Armandia intermedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Australonereis ehlersi	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Capitella capitata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ciratulid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glycera sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbrinereis latrelli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Magellionid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Magellionid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marphysa sp. 1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Nemertean sp.1	0	0	0	0	0	4	0	2	0	5	0	0	3	0	0	0	0	0	0	0
Nepthyidae sp. 1	0	0	0	0	0	4	7	15	14	4	0	0	0	0	0	0	0	0	0	0
Nepthyidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 2	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp.1	0	0	0	0	0	0	0	0	0	0	1	7	3	4	1	0	0	0	0	0
Nereididae sp.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notomastus estuarius	0	0	0	0	0	5	0	2	2	0	0	0	0	2	0	5	6	7	8	19
Phyllodoce novaezealandiae	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
Phyllodocid sp. 1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaete sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 1	0	0	0	0	0	0	0	4	3	1	10	2	1	0	3	0	0	0	0	0
Sabellid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scoloplos simplex	0	0	0	1	3	0	1	0	0	1	14	19	17	11	1	0	0	0	0	0
Sigalionidae sp. 1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sipunculid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 2	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Spionid sp. 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichobranchid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tubeworm sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipod																				
Hadziidae sp. 1	0	0	0	0	4	4	0	2	8	6	23	15	20	15	45	1	0	7	1	0
Hadziidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urohaustorid sp. 1	4	3	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipod sp. 3	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aora hebes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decapods																				
Alpheid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawn sp. 1	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Prawn sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Callianassa australiensis	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Hermit crab sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Halicarcinus ovatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mysid sp. 1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopod																				
Sphaeromid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusc																				
Bivalves:																				
Tellina deltoidalis	23	11	7	17	11	20	6	17	21	27	5	4	9	8	2	0	0	0	0	0
Macomona deltoidalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lasaea australis	0	0	0	0	0	0	0	0	0	0	2	4	1	3	0	0	0	3	9	0
Ambuscintila praemium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eumarcia fumigata	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spisula trigonella	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Sollatelina donacoides	1	0	0	0	0	4	0	4	3	9	0	0	0	0	0	2	0	0	0	0
Gastropods:																				
Hydrobia buccanoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ophicardelus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nassarius sp.1	0	0	0	0	0	11	5	10	2	4	0	0	0	1	0	0	0	0	0	0
Pseudoliotia micans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Assininea tasmanica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taetia rufilabris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naticid sp.1	1	1	0	0	2	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0
F. Potomodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prosobranch sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish																				
Fish sp. 1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Fish sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animals																				
Animal sp.1(Anenome)	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Animal sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animal sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1.4 BENTHIC DATA 1999 - MOONEE

Moonee **Estuarine Species List**	1999																			
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5
Polychaetes:																				
Aphrodite sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arenicola sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Armandia intermedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Australonereis ehlersi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capitella capitata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ciratulid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glycera sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbrinereis latrelli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Magellionid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Magellionid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marphysa sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Nemertean sp.1	0	0	0	0	0	0	1	1	0	0	0	2	0	0	1	0	2	0	0	2
Nepthyidae sp. 1	0	2	0	0	0	0	2	0	0	0	1	7	2	1	2	1	0	1	0	0
Nepthyidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 2	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notomastus estuarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	3
Phyllodoce novaezealandiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodocid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaete sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 1	0	0	0	0	0	0	0	0	0	0	0	6	2	1	3	0	0	1	1	0
Sabellid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scoloplos simplex	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Sigalionidae sp. 1	0	0	3	3	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0
Sipunculid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichobranchid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tubeworm sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipod																				
Hadziidae sp. 1	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	2	2	1	0
Hadziidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urohaustorid sp. 1	8	26	14	13	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipod sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aora hebes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decapods																				
Alpheid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawn sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawn sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Callianassa australiensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hermit crab sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Halicarcinus ovatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mysid sp. 1	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Isopod																				
Sphaeromid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusc																				
Bivalves:																				
Tellina deltoidalis	2	7	3	6	3	14	17	4	10	5	8	12	24	116	59	19	11	5	8	4
Macomona deltoidalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lasaea australis	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0
Ambuscintila praemium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eumarcia fumigata	2	3	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spisula trigonella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sollatelina donacoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Gastropods:																				
Hydrobia buccanoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ophicardelus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nassarius sp.1	0	0	0	2	1	0	0	0	0	0	2	2	1	2	0	0	0	0	1	0
Pseudoliotia micans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Assininea tasmanica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taetia rufilabris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naticid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F. Potomodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prosobranch sp. 1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish																				
Fish sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animals																				
Animal sp.1(Anenome)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Animal sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animal sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1.5 BENTHIC DATA 1997 - BONVILLE

Bonville																				
Estuarine Species List	1997																			
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5
Polychaetes:																				
Aphrodite sp.1	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Arenicola sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Armandia intermedia	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	1	0
Australonereis ehlersi	1	3	3	0	0	0	2	0	1	3	0	0	0	0	0	0	0	0	0	0
Capitella capitata	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Ciratulid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glycera sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbrinereis latrelli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Magellionid sp. 1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Magellionid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marphysa sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertean sp.1	2	0	0	0	1	0	0	0	0	0	0	9	3	1	0	2	4	7	2	5
Nepthyidae sp. 1	0	0	0	0	0	2	0	1	0	1	3	2	3	2	0	0	0	0	0	0
Nepthyidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Nereididae sp. 1	4	1	6	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notomastus estuarius	0	0	0	0	0	0	0	0	0	0	7	6	5	0	0	0	4	4	2	3
Phyllodoce novaezealandiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodocid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Owenia sp.1	0	0	0	0	0	0	0	0	0	0	0	5	14	10	0	14	121	113	228	15
Sabellid sp. 1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	2	0	2	2
Sabellid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scoloplos simplex	0	0	0	3	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
Sigalionidae sp. 1	0	0	0	2	1	4	1	3	0	0	0	0	0	0	2	0	0	0	0	0
Sipunculid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Spionid sp. 2	3	0	0	4	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichobranchid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tubeworm sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipod																				
Hadziidae sp. 1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hadziidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urohaustorid sp. 1	41	4	10	2	6	0	36	9	5	32	0	0	0	0	0	0	0	0	0	0
Amphipod sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aora hebes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decapods																				
Alpheid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawn sp. 1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Prawn sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Callianassa australiensis	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Hermit crab sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Halicarcinus ovatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mysid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Isopod																				
Sphaeromid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusc																				
Bivalves:																				
Tellina deltoidalis	0	5	0	2	3	13	8	6	3	4	3	4	2	3	9	0	0	1	0	9
Macomona deltoidalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lasaea australis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ambuscintila praemium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eumarcia fumigata	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	2	1	0	2
Spisula trigonella	0	0	0	0	0	0	0	0	0	0	0	1	2	1	1	0	0	0	0	0
Sollatelina donacoides	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1	0	1
Gastropods:																				
Hydrobia buccanoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ophicardelus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nassarius sp.1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	1
Pseudoliotia micans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Assininea tasmanica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taetia rufilabris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naticid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F. Potomodidae	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Prosobranch sp. 1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish																				
Fish sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animals																				
Animal sp.1(Anenome)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	4	3	0
Animal sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animal sp.3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1.6 BENTHIC DATA 1997 - BOAMBEE

Boambee
Estuarine Species List 1997

	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5
Polychaetes:																				
Aphrodite sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Arenicola sp.1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Armandia intermedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Australonereis ehlersi	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Capitella capitata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ciratulid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glycera sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbrinereis latrelli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Magellionid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Magellionid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marphysa sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Nemertean sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0
Nepthyidae sp. 1	2	0	0	0	0	0	0	0	0	0	0	2	2	3	3	1	1	0	0	0
Nepthyidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 2	0	0	0	0	0	0	0	1	0	5	3	0	1	0	0	0	0	0	0	0
Nereididae sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notomastus estuarius	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	1	1	3	6	2
Phyllodoce novaezealandiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodocid sp. 1	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaete sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 1	0	4	0	0	0	0	0	0	0	0	3	7	5	6	7	0	5	8	9	4
Sabellid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scoloplos simplex	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	2	8
Sigalionidae sp. 1	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Sipunculid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 1	6	0	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Spionid sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichobranchid sp. 1	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
Tubeworm sp. 1	0	1	0	0	0	1	0	0	0	0	0	0	0	6	3	0	0	0	0	0
Amphipod																				
Hadziidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	4	0	3	2	7	0	0	0
Hadziidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urohaustorid sp. 1	11	4	12	5	0	5	9	7	6	7	0	0	0	0	0	0	0	0	0	1
Amphipod sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aora hebes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decapods																				
Alpheid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawn sp. 1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
Prawn sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Callianassa australiensis	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Hermit crab sp. 1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Halicarcinus ovatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mysid sp. 1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopod																				
Sphaeromid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusc																				
Bivalves:																				
Tellina deltoidalis	24	5	10	7	0	0	9	41	13	34	13	9	9	17	11	1	3	1	5	0
Macomona deltoidalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lasaea australis	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	2
Ambuscintila praemium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eumarcia fumigata	1	0	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0
Spisula trigonella	0	0	0	0	0	0	0	1	0	0	1	0	1	1	0	0	1	0	0	0
Sollatelina donacoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Gastropods:																				
Hydrobia buccanoides	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ophicardelus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nassarius sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudoliotia micans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Assininea tasmanica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taetia rufilabris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naticid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F. Potomodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prosobranch sp. 1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish																				
Fish sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Fish sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animals																				
Animal sp.1(Anenome)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animal sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animal sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1.7 BENTHIC DATA 1997 - COFFS

Coffs

Estuarine Species List	1997																			
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5
Polychaetes:																				
Aphrodite sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arenicola sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Armandia intermedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Australonereis ehlersi	0	0	2	0	0	0	5	2	17	9	0	0	0	0	0	2	3	0	0	0
Capitella capitata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ciratulid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glycera sp. 1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbrinereis latrelli	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Magellionid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Magellionid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marphysa sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	2
Nemertean sp.1	0	0	1	0	0	0	0	0	0	0	1	0	0	5	0	0	0	0	0	0
Nepthyidae sp. 1	0	0	0	0	0	0	0	0	2	2	0	1	0	0	0	0	0	0	0	0
Nepthyidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Nereididae sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Nereididae sp.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notomastus estuarius	0	0	0	0	0	0	0	0	0	0	5	1	1	2	0	10	4	38	11	19
Phyllodoce novaezealandiae	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Phyllodocid sp. 1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaete sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 1	0	0	0	0	0	0	1	0	0	0	0	0	0	11	1	2	0	0	1	8
Sabellid sp. 2	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Sabellid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scoloplos simplex	1	4	5	3	3	9	5	15	0	3	5	8	24	2	29	0	0	0	0	0
Sigalionidae sp. 1	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Sipunculid sp. 1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichobranchid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tubeworm sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipod																				
Hadziidae sp. 1	0	0	0	0	0	0	0	0	0	0	16	5	4	2	1	13	29	24	11	16
Hadziidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urohaustorid sp. 1	0	2	7	19	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipod sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aora hebes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Decapods																				
Alpheid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Prawn sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawn sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Callianassa australiensis	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hermit crab sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Halicarcinus ovatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mysid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopod																				
Sphaeromid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusc																				
Bivalves:																				
Tellina deltoidalis	6	9	26	8	18	7	28	13	16	24	11	4	16	2	9	1	2	2	1	0
Macomona deltoidalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lasaea australis	0	0	0	0	0	0	0	0	0	0	24	4	8	4	6	27	6	26	7	14
Ambuscintila praemium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eumarcia fumigata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spisula trigonella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sollatelina donacoides	0	0	1	0	4	2	0	2	1	1	0	0	0	0	0	0	0	0	0	0
Gastropods:																				
Hydrobia buccanoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ophicardelus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nassarius sp.1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudoliotia micans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Assininea tasmanica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taetia rufilabris	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naticid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F. Potomodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prosobranch sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish																				
Fish sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animals																				
Animal sp.1(Anenome)	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Animal sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animal sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1.8 BENTHIC DATA 1997 - MOONEE

Moonee

Estuarine Species List	1997																			
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5
Polychaetes:																				
Aphrodite sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arenicola sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Armandia intermedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Australonereis ehlersi	0	0	0	0	0	0	0	0	1	0	0	0	0	1	4	0	1	1	2	5
Capitella capitata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ciratulid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glycera sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbrinereis latrelli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Magellionid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Magellionid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marphysa sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertean sp.1	0	0	0	0	0	1	0	0	0	0	0	2	1	0	0	0	0	1	0	0
Nepthyidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	1	0	0
Nepthyidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notomastus estuarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodoce novaezealandiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodocid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaete sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 1	0	0	0	0	0	0	0	0	0	1	0	2	1	0	0	1	0	0	0	0
Sabellid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scoloplos simplex	1	0	0	0	0	0	0	0	2	0	0	1	1	5	2	0	0	0	0	0
Sigalionidae sp. 1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Sipunculid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0
Spionid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spionid sp. 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichobranchid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tubeworm sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipod																				
Hadziidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hadziidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urohaustorid sp. 1	0	0	0	0	0	2	1	4	4	1	0	0	1	4	0	0	0	0	0	0
Amphipod sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aora hebes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Decapods																				
Alpheid sp. 1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Prawn sp. 1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawn sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Callianassa australiensis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Hermit crab sp. 1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Halicarcinus ovatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mysid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopod																				
Sphaeromid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusc																				
Bivalves:																				
Tellina deltoidalis	4	0	0	0	0	0	0	0	0	0	17	1	33	5	29	40	23	104	57	81
Macomona deltoidalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lasaea australis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ambuscintila praemium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eumarcia fumigata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spisula trigonella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sollatelina donacoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropods:																				
Hydrobia buccanoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ophicardelus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nassarius sp.1	0	0	0	0	0	2	0	0	0	0	0	1	1	0	0	1	0	0	0	0
Pseudoliotia micans	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Assininea tasmanica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taetia rufilabris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naticid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
F. Potomodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prosobranch sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish																				
Fish sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Fish sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animals																				
Animal sp.1(Anenome)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Animal sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animal sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

1.9 BENTHIC DATA PILOT STUDY - BONVILLE

BONVILLE CREEK - July-Sept. 1996

	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	6.1	6.2	6.3	7.1	7.2	7.3
Notomastus estuarius	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
Marphysa sp. 1	0	0	7	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Nemertean	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nepthyidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nepthyidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Australonereis ehlersi	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	5	6	0	0	0
Nereididae sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neridiidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Glycera sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodocid sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scoloplos simplex	0	0	0	0	0	1	2	0	0	0	0	0	15	6	18	0	0	0	0	0	0
Sigalionidae sp. 1	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Sabellid sp. 1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	5	4	8	0	0	0
Sabellid sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Tubeworm sp.1.	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animal sp. 2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Echiuran sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
animal sp.1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hadziidae sp.1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hadziidae sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urohaustorid sp. 1	7	5	0	0	4	0	2	12	0	0	0	0	0	0	0	0	0	0	0	0	0
Alpheid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawn sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Tellina deltoidalis	0	0	0	4	5	5	2	4	4	0	0	0	0	0	0	1	0	4	0	0	0
Bivalve sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalve sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalve sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalve sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nassarius sp. 1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sollatellina donacoides	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	3	4	0	0	1
Moon snail sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prosobranch sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Coffs Creek - July - Sept. 1996

	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	6.1	6.2	6.3	7.1	7.2	7.3
Notomastus estuarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	5	30	34	28
Marphysa sp. 1	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Nemertean	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Nepthyidae sp. 1	0	0	0	0	0	0	0	0	0	5	6	4	2	3	0	0	0	0	1	0	0
Nepthyidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Australonereis ehlersi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nereididae sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nerididae sp. 2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Glycera sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodocid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scoloplos simplex	0	0	0	0	0	0	0	0	0	0	0	0	0	2	6	0	0	0	0	0	0
Sigalionidae sp. 1	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabellid sp. 1	0	0	0	0	0	0	0	0	0	0	2	0	5	0	0	0	0	0	0	0	0
Sabellid sp. 2	0	0	0	0	0	0	0	0	0	3	8	0	0	0	0	0	0	0	0	0	0
Tubeworm sp. 1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
animal sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Echiuran sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
animal sp. 1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hadziidae sp. 1	0	1	1	14	0	2	0	0	0	0	6	1	34	29	3	6	2	10	43	40	19
Hadziidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urohaustorid	4	4	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alpheid sp. 1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Prawn sp. 1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Tellina deltoidalis	1	2	0	62	41	6	0	0	0	8	7	6	5	5	1	0	0	0	0	0	0
Bivalve sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalve sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalve sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	11	8	1	0	0	0	10	14	2
Bivalve sp. 4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
Nassarius sp. 1	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0
Sollatellina donacoides	0	0	0	1	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Moon snail sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prosobranch sp. 1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Moonee Creek - July-Sept. 1996

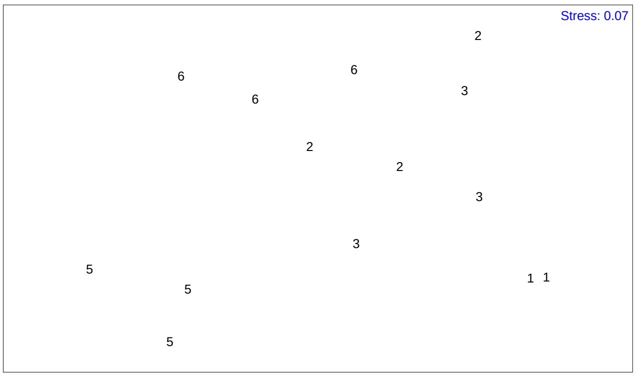
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	6.1
Notomastus estuarius	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0
Marphysa sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertean	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Nepthyidae sp. 1	0	0	0	0	0	0	1	1	0	1	0	2	2	0	2	0
Nepthyidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Australonereis ehlersi	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Nereididae sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nerididae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glycera sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodocid sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scoloplos simplex	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
Sigalionidae sp. 1	0	0	0	0	0	0	3	1	0	0	6	0	0	0	0	0
Sabellid sp. 1	0	0	0	0	0	0	0	0	2	3	6	2	0	4	0	0
Sabellid sp. 2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0
Tubeworm sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
animal sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Echiuran sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
animal sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hadziidae sp. 1	0	0	0	1	0	0	7	10	2	12	6	6	4	5	8	0
Hadziidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urohaustorid	0	0	2	0	0	9	6	0	0	0	0	0	0	0	0	0
Alpheid sp. 1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Prawn sp. 1	0	0	0	0	0	0	1	0	2	0	0	0	1	0	0	0
Tellina deltoidalis	0	0	0	0	0	0	0	0	2	1	4	1	9	3	3	0
Bivalve sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalve sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalve sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalve sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nassarius sp. 1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Sollatellina donacoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moon snail sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prosobranch sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX 2 SPECIES LIST

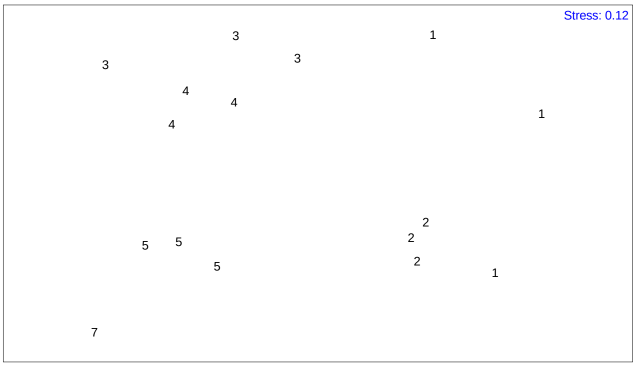
Polychaetes	Decapods
Aphrodite sp. 1	Alpheid sp. 1
Arenicola sp. 1	Prawn sp. 1
Armandia intermedia	Prawn sp. 2
Australonereis ehlersi	*Callianassa australiensis*
Capitella capitata	Hermit crab sp. 1
Ciratulid sp. 1	*Halicarcinus ovatus*
Glycera sp. 1	Mysid sp. 1
Lumbrinereis latrelli	**Isopod**
Magellionid sp. 1	Sphaeromid sp. 1
Magellionid sp. 2	**Molluscs Bivalves**
Marphysa sp. 1	*Tellina deltoidalis*
Nemertean sp.1	*Macomona deltoidalis*
Nepthyid sp. 1	*Lasaea australis*
Nepthyid sp. 2	*Ambuscinta praemium*
Nereidid sp. 1	*Eumarcia fumigata*
Nereidid sp. 2	*Spisula trigonella*
Nereidid sp. 3	*Sollatelina donacioides*
Nereidid sp. 4	**Gastropods**
Notomastus estuarius	*Hydrobia buccanoides*
Phyllodoce novaezealandiae	*Ophicardelus* sp.
Phyllodocid sp. 1	*Nassarius* sp. 1
Owenia sp. 1	*Pseudoliotia micans*
Sabellid sp. 1	*Assininea tasmanica*
Sabellid sp. 2	*Taetia rufilabris*
Sabellid sp. 3	Naticid sp. 1
Scoloplos simplex	F. Potamididae
Sigalionid sp. 1	Prosobranch sp. a
Sipunculid sp.1	**Fish**
Spionid sp. 1	Fish sp. 1
Spionid sp. 2	Fish sp. 2
Spionid sp. 3	Fish sp. 3
Spionid sp. 4	**Unidentified Taxa**
Spionid sp. 5	Animal sp. 1
Spionid sp. 6	Animal sp. 2
Trichobranchid sp. 1	Animal sp. 3
Tubeworm sp.1	
Amphipod	
Hadziid sp. 1	
Hadziid sp. 2	
Urohaustorid sp. 1	
Amphipod sp. 3	
Aora hebes	

APPENDIX 3 NON-METRIC MULTI-DIMENSIONAL SCALING (N-MDs)

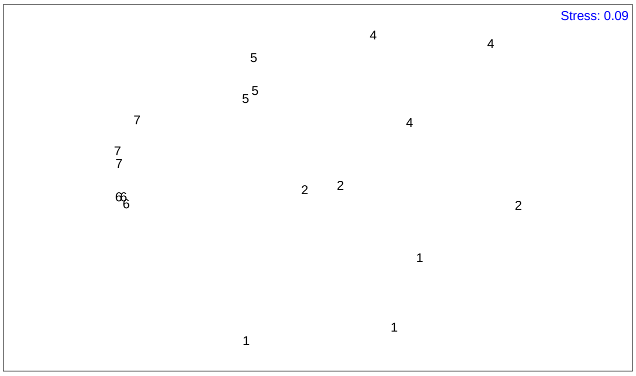
Pilot study data - Bonville 1996



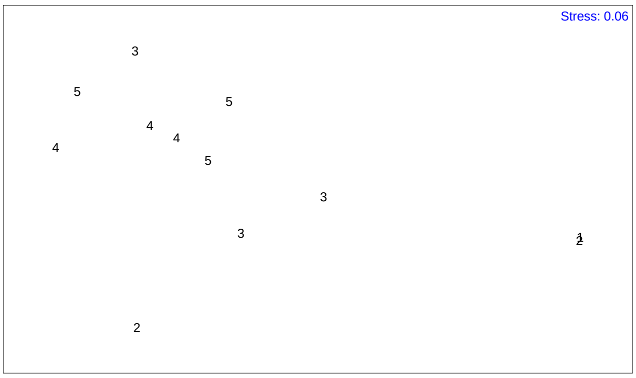
Pilot study data - Boambee 1996



Pilot study data - Coffs 1996



Pilot study data - Moonee 1996



APPENDIX 4 SIMILARITY PERCENTAGES (SIMPER) - (1997 AND 1999)

4.1 SIMPER COMPARISONS FOR DIFFERENCES ACROSS TIME WITHIN CREEKS

4.1.1 SITE 2

Table 4-1 - (Site 2) Bonville Creek

Species **Ave dissimilarity = 63.49**	**1997.**	**1999**	**Contribution %**	**Cum %**
Urohaustorid sp. 1.	50.79	7.69	15.14	15.14
Nassarius sp. 1	0.00	11.40	10.57	25.71
Sigalionidae sp. 1	7.22	0.00	9.26	34.97
Australonereis ehlersi	4.47	0.00	9.13	44.10
Scoloplos simplex	0.47	5.15	8.39	52.49

Table 4-2 - (Site 2) Boambee Creek

Species **Ave dissimilarity = 70.33**	**1997.**	**1999**	**Contribution %**	**Cum %**
Australonereis ehlersi.	0.00	35.20	16.00	16.00
Nassarius sp.1	0.00	8.22	11.02	27.02
Scoloplos simplex	0.00	6.76	10.29	37.31
Tellina deltoidalis	52.36	10.29	9.76	47.08
Sollatelina donacioides	0.00	4.41	6.05	53.12

Table 4-3 - (Site 2) Coffs Creek

Species **Ave dissimilarity = 61.19**	**1997.**	**1999**	**Contribution %**	**Cum %**
Nassarius sp.1	0.00	13.85	12.78	12.78
Australonereis ehlersi	17.72	0.33	10.35	23.12
Nepthyidae sp. 1	2.11	19.05	9.83	32.96
Scoloplos simplex	23.16	1.29	9.69	42.65
Hadziidae sp. 1	0.00	6.72	8.71	51.36

Table 4-4 - (Site 2) Moonee Creek

Species **Ave dissimilarity = 56.64**	**Group 4 Av. Abun.**	**Group 8 Av Abun**	**Contribution %**	**Cum %**
Tellina deltoidalis	0.00	71.99	21.62	21.62
Urohaustorid sp. 1	47.78	0.00	19.42	41.04
Spionid sp. 1	13.89	0.00	8.13	49.17
Nemertean sp. 1	4.17	4.61	6.52	55.69

4.1.2 SITE 3

Table 4-5 - (Site 3) Bonville Creek

Species **Ave dissimilarity = 65.44**	**1997**	**1999**	**Contribution %**	**Cum %**
F. Potamididae	0.53	14.65	7.90	7.90
Owenia sp. 1	20.70	3.60	6.88	14.78
Nepthyidae sp. 1	8.25	2.11	6.78	21.56
Nassarius sp. 1	3.33	5.82	6.58	28.14
Spisula trigonella	3.90	0.00	6.46	34.60
Sollatelina donacioides	3.37	0.00	6.25	40.85
Notomastus estuarius	14.41	14.06	6.04	46.89
Nemertean sp. 1	8.58	10.19	5.96	52.85

Table 4-6 - (Site 3) Boambee Creek

Species **Ave dissimilarity = 53.72**	**1997**	**1999**	**Contribution %**	**Cum %**
Sollatelina donacioides	0.65	10.46	9.15	9.15
Nassarius sp.1	0.00	4.87	6.69	15.85
Hadziidae sp. 1	5.57	3.07	6.56	22.40
Spisula trigonella	2.18	0.00	5.72	28.12
Notomastus estuarius	3.33	3.04	5.46	33.58
Nereididae sp. 1	3.41	1.20	5.28	38.86
Trichobranchid sp. 1	3.33	0.00	5.13	43.99
Nepthyidae sp. 1	6.72	8.31	4.63	48.62
Tubeworm sp. 1	4.54	0.00	4.58	53.20

Table 4-7 - (Site 3) Coffs Creek

Species **Ave dissimilarity = 39.26**	**1997**	**1999**	**Contribution %**	**Cum %**
Nereididae sp. 3	1.05	6.32	13.03	13.03
Sabellid sp. 1	7.86	5.79	11.44	24.47
Notomastus estuarius	4.02	0.91	10.63	35.09
Lasaea australis	18.27	3.97	9.42	44.51
Hadziidae sp. 1	11.84	44.86	8.52	53.03

Table 4-8 - (Site 3) Moonee Creek

Species **Ave dissimilarity = 56.64**	**1997**	**1999**	**Contribution %**	**Cum %**
Scolopolos simplex	9.87	0.00	12.65	12.65
Nepthyidae sp. 1	4.51	7.86	11.12	23.77
Sabellid sp. 1	4.51	6.00	9.87	33.65
Nassarius sp. 1	2.51	5.28	9.50	43.14
Nemertean sp. 1	4.51	1.50	7.17	50.31

4.1.3 SITE 4

Table 4-9 - (Site 4) Bonville Creek

Species **Ave dissimilarity = 47.58**	**1997**	**1999**	**Contribution %**	**Cum %**
Tellina deltoidalis	4.65	6.35	11.47	11.47
Notomastus estuarius	2.88	21.85	10.80	22.27
Sabellid sp. 1	2.52	0.00	10.13	32.40
Sollatelina donacioides	1.71	7.44	9.73	42.13
Animal sp. 1 (Anenome)	1.01	1.48	7.63	49.76
Eumarcia fumigata	1.45	0.74	6.87	56.63

Table 4-10 - (Site 4) Boambee Creek

Species Ave dissimilarity = 52.04	1997	1999	Contribution %	Cum %
Sabellid sp. 1	26.78	1.13	16.23	16.23
Hadziidae sp. 1	13.67	36.68	16.16	32.38
Scoloplos simplex	18.90	1.08	14.92	47.31
Spionid sp. 6	0.00	8.42	8.71	56.02

Table 4-11 - (Site 4) Coffs Creek

Species Ave dissimilarity =	1997	1999	Contribution %	Cum %
Lasaea australis	27.23	13.53	21.34	21.34
Hadziidae sp. 1	35.24	11.85	19.28	40.62
Tellina deltoidalis	2.32	0.00	14.38	55.01

Table 4-12 - (Site 4) Moonee Creek

Species Ave dissimilarity = 54.22	1997	1999	Contribution %	Cum %
Australonereis ehlersi	2.86	0.00	15.33	15.33
Hadziidae sp. 1	0.00	8.10	14.25	29.58
Nepthyidae sp. 1	0.19	3.00	9.93	51.11

4.2 SIMPER COMPARISONS FOR DIFFERENCES ACROSS TIME BETWEEN CREEKS

4.2.1 SITE 2

Table 4-13- (Site 2) Boambee and Bonville Creeks

Species Ave dissimilarity = 59.41	Boam. Av Abun	Bonv. Av Abun	Percent	Cum %
Urohaustorid sp. 1.	26.13	29.24	10.14	10.14
Australonereis ehlersi	17.60	2.23	9.69	19.82
Tellina deltoidalis	31.33	44.53	8.45	28.28
Nassarius sp.1	4.11	5.70	7.89	36.17
Scoloplos simplex	3.38	2.81	7.00	43.18
Sollatelina donacioides	2.20	3.83	5.66	48.84
Eumarcia fumigata	2.92	.00	4.66	53.50

Table 4-14 - (Site 2) Coffs and Bonville Creeks

Species Ave dissimilarity = 62.76	**Coffs Av Abun**	**Bonv. Av Abun**	**Percent**	**Cum %**
Urohaustorid sp. 1.	.00	29.24	13.09	13.09
Sollatelina donacioides	5.62	3.83	9.15	22.24
Scoloplos simplex	12.22	2.81	9.05	31.28
Nepthyidae sp	10.58	1.67	8.50	39.78
Australonereis ehlersi	9.03	2.23	8.12	47.91
Nassarius sp.1	6.92	5.70	7.42	55.32

Table 4-15 - (Site 2) Coffs and Boambee Creeks

Species Ave dissimilarity = 68.05	**Coffs Av Abun**	**Boam Av Abun**	**Percent**	**Cum %**
Urohaustorid sp. 1.	.00	26.13	14.11	14.11
Australonereis ehlersi	9.03	17.60	8.23	22.34
Nepthyidae sp	10.58	.00	8.10	30.43
Scoloplos simplex	12.22	3.38	7.67	38.10
Sollatelina donacioides	5.62	2.20	7.21	45.32
Nassarius sp.1	6.92	4.11	6.22	51.53

Table 4-16 - (Site 2) Moonee and Bonville Creeks

Species Ave dissimilarity = 69.08	**Moon.Av Abun**	**Bonv.Av Abun**	**Percent**	**Cum %**
Tellina deltoidalis	36.00	44.53	13.51	13.51
Urohaustorid sp. 1.	23.89	29.24	12.98	26.49
Scoloplos simplex	6.35	2.81	7.75	34.23
Nassarius sp.1	4.17	5.70	6.65	40.89
Nemertean sp.1	4.39	.00	5.74	46.63
Australonereis ehlersi	1.39	2.23	5.50	52.13

Table 4-17 - (Site 2) Moonee and Boambee Creeks

Species **Ave dissimilarity = 70.74**	**Moon.Av Abun**	**Boam.Av Abun**	**Percent**	**Cum %**
Tellina deltoidalis	36.00	31.33	12.12	12.12
Urohaustorid sp. 1.	23.89	26.13	11.42	23.54
Australonereis ehlersi	1.39	17.60	8.43	31.97
Scoloplos simplex	6.35	3.38	7.14	39.11
Nassarius sp.1	4.17	4.11	6.57	45.68
Spionid sp. 1	6.94	.93	5.96	51.63

Table 4-18 - (Site 2) Moonee and Coffs Creeks

Species **Ave dissimilarity = 77.24**	**Moon.Av Abun**	**Coffs.Av Abun**	**Percent**	**Cum %**
Tellina deltoidalis	36.00	42.61	10.20	10.20
Urohaustorid sp. 1.	23.89	.00	9.07	19.26
Scoloplos simplex	6.35	12.22	8.82	28.09
Sollatelina donacioides	.00	5.62	8.61	36.70
Nepthyidae sp	1.04	10.58	7.98	44.68
Australonereis ehlersi	1.39	9.03	7.32	52.00

4.2.2 SITE 3

Table 4-19 - (Site 3) Boambee and Bonville Creeks

Species **Ave dissimilarity = 64.71**	**Boam Av Abun**	**Bonv Av Abun**	**Percent**	**Cum %**
Sabellid 1	25.40	2.70	8.56	8.56
Notomastus estuarius	3.19	14.23	7.21	15.77
Owenia sp. 1	.00	12.15	6.48	22.26
Nemertean sp.1	1.30	9.38	6.27	28.52
Nepthyidae sp	7.52	5.18	5.42	33.94
Nassarius sp.1	2.43	4.58	5.14	39.09
Hadziidae sp.	4.32	3.38	5.05	44.13
F. Potamididae	.00	7.59	5.04	49.17
Sollatelina donacioides	5.55	1.68	5.02	54.19

Table 4-20 - (Site 3) Coffs and Bonville Creeks

Species Ave dissimilarity = 72.27	Coffs Av Abun	Bonv. Av Abun	Percent	Cum %
Scoloplos simplex	25.69	.59	10.48	10.48
Hadziidae sp.	28.35	3.38	8.98	19.47
Lasaea australis	11.12	.00	8.37	27.84
Notomastus estuarius	2.46	14.23	6.19	34.03
Owenia sp.1	.00	12.15	6.01	40.04
Nemertean sp.1	2.33	9.38	5.64	45.68
Sabellid l	6.74	2.70	4.86	50.54

Table 4-21 - (Site 3) Coffs and Boambee Creeks

Species Ave dissimilarity = 66.31	Coffs Av Abun	Boam. Av Abun	Percent	Cum %
Scoloplos simplex	25.69	.80	11.69	11.69
Lasaea australis	11.12	.42	8.64	20.33
Hadziidae sp.	28.35	4.32	8.52	28.85
Nepthyidae sp	.36	7.52	7.81	36.65
Sabellid l	6.74	25.40	7.74	44.40
Nereididae sp 3	3.68	.00	5.30	49.69
Sollatelina donacioides	.00	5.55	4.95	54.64

Table 4-22 - (Site 3) Moonee and Bonville Creeks

Species Ave dissimilarity = 65.69	Moon. Av Abun	Bonv. Av Abun	Percent	Cum %
Notomastus estuarius	.43	14.23	9.19	9.19
Owenia sp.1	.00	12.15	7.4Z	16.67
Nemertean sp.1	3.01	9.38	6.94	23.61
Nepthyidae sp	6.18	5.18	6.38	29.99
Nassarius sp.1	3.90	4.58	5.97	35.96
Tellina deltoidalis	65.36	24.35	5.83	41.79
F. Potamididae	.00	7.59	5.83	47.62
Sabellid 1	5.26	2.70	5.83	53..46

Table 4-23 - (Site 3) Moonee and Boambee Creeks

Species **Ave dissimilarity = 59.25**	**Moon. Av Abun**	**Boam Av Abun**	**Percent**	**Cum %**
Sabellid 1	5.26	25.40	10.12	10.12
Nassarius sp.1	3.90	2.43	6.60	16.72
Nepthyidae sp	6.18	7.52	6.57	23.29
Hadziidae sp.	2.75	4.32	6.49	29.78
Sollatelina donacioides	.00	5.55	6.27	36.04
Scoloplos simplex	4.94	.80	5.30	41.34
Nemertean sp.1	3.01	1.30	4.64	45.98
Notomastus estuarius	.43	3.19	4.38	50.36
Tellina deltoidalis	65.36	32.74	4.3	54.66

Table 4-24 - (Site 3) Moonee and Coffs Creeks

Species **Ave dissimilarity = 64.80**	**Moon. Av Abun**	**Coffs Av Abun**	**Percent**	**Cum %**
Hadziidae sp.	2.75	28.35	13.26	13.26
Scoloplos simplex	4.94	25.69	11.11	24.37
Lasaea australis	.33	11.12	10.53	34.90
Nepthyidae sp	6.18	.36	7.34	42.24
Tellina deltoidalis	65.36	13.83	6.85	49.09
Sabellid 1	5.26	6.74	6.77	55.87

4.2.3 SITE 4

Table 4-25- (Site 4) Boambee and Bonville

Species **Ave dissimilarity = 77.14**	**Boam Av Abun**	**Bon. Av Abun**	**Percent**	**Cum %**
Owenia sp. 1	.00	62.52	17.46	17.46
Hadziidae sp..	25.18	.15	10.68	28.13
Nemertean sp.1	.00	6.44	9.53	37.66
Sabellid 1	13.95	1.26	7.27	44.92
Notomastus estuarius	29.17	12.36	7.26	52.18

Table 4-26 - (Site 4) Coffs and Bonville

Species Ave dissimilarity = 79.96	Coffs Av Abun	Bonv. Av Abun	Percent	Cum %
Owenia sp. 1	.00	62.52	19.11	19.11
Hadziidae sp..	23.54	.15	11.30	30.40
Nemertean sp. 1	.00	6.44	10.38	40.79
Lasaea australis	20.38	.00	10.27	51.05
Notomastus estuarius	48.26	12.3	9.85	60.90

Table 4-27 - (Site 4) Coffs and Boambee

Species Ave dissimilarity = 50.19	Coffs.Av Abun	Boam.Av Abun	Percent	Cum %
Lasaea australis	20.38	3.03	14.98	14.98
Sabellid 1	2.00	13.95	13.46	28.44
Hadziidae sp	23.54	25.18	13.39	41.83
Tellina deltoidalis	1.16	8.37	13.05	54.88
Scoloplos simplex	.00	9.99	11.38	66.25

Table 4-28 - (Site 4) Moonee and Bonville

Species Ave dissimilarity = 80.16	Moon.Av Abun	Bonv. Av Abun	Percent	Cum %
Owenia sp. 1	.00	62.52	19.77	19.77
Tellina deltoidalis	78.93	5.50	15.27	35.04
Notomastus estuarius	3.00	12.36	9.38	44.42
Nemertean sp.1	3.43	6.44	8.77	53.19
Sollatelina donacioides	.71	4.57	5.60	58.79

Table 4-29 - (Site 4) Moonee and Boambee

Species **Ave dissimilarity = 72.40**	**Moonee Av Abun**	**Bonv. Av Abun**	**Percent**	**Cum %**
Notomastus estuarius	3.00	29.17	17.62	17.62
Tellina deltoidalis	78.93	8.37	13.63	31.24
Hadziidae sp..	4.05	25.18	12.62	43.86
Sabellid 1	1.94	13.95	9.69	53.55
Scoloplos simplex	.00	9.99		

Table 4-30 - (Site 4) Moonee and Coffs

Species **Ave dissimilarity = 81.74**	**Moonee Av Abun**	**Coffs Av Abun**	**Percent**	**Cum %**
Tellina deltoidalis	78.93	1.16	22.64	22.64
Notomastus estuarius	3.00	48.26	21.54	44.17
Hadziidae sp..	4.05	23.54	12.31	56.48
Lasaea australis	1.43	20.38	12.03	68.51
Australonereis ehlersi	1.43	1.05	5.89	74.40

APPENDIX 5 CORRELATIONS OF ESTUARINE VEGETATION AND PERCENTAGE CHANGE

5.1 CORRELATIONS OF ESTUARINE VEGETATION AND PERCENTAGE CHANGE - FROM 1954 TO 1974 ALL CREEKS

COFFS CREEK									
Year	Mangrove	Salt Marsh	Sea Grass	Sedge	Year	Mangrove	Salt Marsh	Sea Grass	Sedge
1954	68941.42	45980.68	2813.42	783730.38	1954	100.00	100.00	100.00	100.00
1974	61249.99	49420.11	1716.17	188854.51	1974	-11.16	7.48	-39.00	-75.90
1994	122840.04	9563.36	3841.77	0.00	1994	78.18	-79.20	36.55	-100.00

BOAMBEE CREEK									
Year	Mangrove	Salt Marsh	Sea Grass	Sedge	Year	Mangrove	Salt Marsh	Sea Grass	Sedge
1954	154440.99	620501.99	35994.84	351816.53	1954	100.00	100.00	100.00	100.00
1974	193032.73	452716.76	84610.06	928960.30	1974	24.99	-27.04	135.06	164.05
1994	185811.77	386461.44	56851.92	463913.15	1994	20.31	-37.72	57.94	31.86

BONVILLE CREEK									
Year	Mangrove	Salt Marsh	Sea Grass	Sedge	Year	Mangrove	Salt Marsh	Sea Grass	Sedge
1954	13307.59	434464.27	34029.84	213698.06	1954	100.00	100.00	100.00	100.00
1974	11112.67	183009.73	14073.50	255116.45	1974	-16.49	-57.88	-58.64	19.38
1994	67295.98	224394.11	173827.97	80261.12	1994	405.70	-48.35	410.81	-62.44

MOONEE CREEK									
Year	Mangrove	Salt Marsh	Sea Grass	Sedge	Year	Mangrove	Salt Marsh	Sea Grass	Sedge
1954	18574.06	145286.65	16520.10	1020737.81	1954	100.00	100.00	100.00	100.00
1974	25786.53	138771.97	40317.16	921474.44	1974	38.83	-4.48	144.05	-9.72
1994	56559.57	137896.53	29209.64	877878.20	1994	204.51	-5.09	76.81	-14.00

5.2 BANANA TABLES - TOTAL AREAS FOR EACH CREEK CATCHMENT

CATCHMENTS - BANANAS (Ha)

Catchment	1954	1974	1994
Bonville	11.95	88.48	74.43
Boambee	261.98	476.75	413.73
Coffs	394.59	490.25	409.50
Moonee	92.67	160.62	109.11

APPENDIX 6 AREAS OF ESTUARINE VEGETATION AND HUMAN SETTLEMENT PATTERNS

6.1 AREAS OF ESTUARINE VEGETATION AND HUMAN SETTLEMENT PATTERNS (HSP) - BONVILLE

Table -6-1 - Areas of Estuarine Vegetation 1954 - 1994 Bonville

BONVILLE CREEK – ESTUARINE VEGETATION (Square Metres)				
Year	Mangrove	Salt Marsh	Sea Grass	Sedge
1954	13307.59	434464.27	34029.84	213698.06
1964	5817.82	482144.17	169054.35	262688.95
1974	11112.67	183009.73	14073.50	255116.45
1984	32192.81	240696.45	59001.95	89022.11
1994	67295.98	224394.11	173827.97	80261.12

Table -6-2 - Housing 1954 - 1994 Bonville

Creek	Year	Nº	Area	Percentage Change
Bonville	54	755	113250	100
	74	1151	172650	152.4503
	94	3769	565350	399.2053

Table 6-3 - Paved areas

Creek	Year	Area	Percentage Change
Bonville	1954	0	0
	1974	0	0
	1994	171096.02	0

Table 6-4 - Sealed roads

Creek	Year	Area	Percentage Change
Bonville	54	141842	100
	74	286017	101.6448
	94	559066	294.147

Table 6-5 - Unsealed roads

Creek	Year	Area	Percentage Change
Bonville	54	196929	100
	74	170703	-13.3175
	94	98455	-50.0048

Table -6-6 - Tracks

Creek	Year	Area	Percentage Change
Bonville	54	295063	100
	74	407175	137.996
	94	443390	150.2696

Table 6-7 - Banana Cultivation

YEAR	AREA
1954	142,276
1974	217.8000
1994	367.1000

6.2 AREAS OF ESTUARINE VEGETATION AND HUMAN SETTLEMENT PATTERNS (HSP) - BOAMBEE

Table 6-8 - Estuarine vegetation 1954 - 1994 Boambee

BOAMBEE CREEK – ESTUARINE VEGETATION (Square Metres)				
Year	Mangrove	Salt Marsh	Sea Grass	Sedge
1954	154440.99	620501.99	35949.84	351816.53
1964	149675.37	576910.06	65851.50	829871.71
1974	193032.73	452716.76	84610.06	928960.30
1984	174831.50	456210.35	74913.51	72759.19
1994	185811.77	386461.44	56851.92	463913.15

Table 6-9 - Housing 1954 - 1994

CREEK	YEAR	NO.	AREA	PERCENTAGE
Boambee	54	337	50550	100
	74	628	94200	86.3501
	94	2547	382050	655.7864

Table 6-10 - Paved areas 1954 - 1994

CREEK	YEAR	AREA	PERCENTAGE CHANGE
Boambee	1954	178173.30	100
	1974	219978.92	23.46346
	1994	679238.79	281.2237

Table 6-11 - Sealed Roads 1954 - 1994

CREEK	YEAR	AREA	PERCENTAGE CHANGE
Boambee	54	97598	100
	74	124698	27.76696
	94	542129	455.4714

Table 6-12 - Unsealed Roads 1954 - 1994

CREEK	YEAR	AREA	PERCENTAGE CHANGE
Boambee	54	124944	100
	74	117057	-6.31243
	94	16829	-86.5308

Table 6-13 - Tracks 1954 - 1994

CREEK	YEAR	AREA	PERCENTAGE CHANGE
Boambee	54	151157	100
	74	192947	27.6468
	94	158861	5.0967

6.3 AREAS OF ESTUARINE VEGETATION AND HUMAN SETTLEMENT PATTERNS (HSP) - COFFS CREEK

Table 6-14 - Estuarine vegetation 1954 - 1994 Coffs Creek

COFFS CREEK – ESTUARINE VEGETATION (Square Metres)				
Year	Mangrove	Salt Marsh	Sea Grass	Sedge
1954	68941.42	45980.68	2813.42	783730.38
1964	44509.24	47571.56	1899.62	623578.23
1974	61249.99	49420.11	1716.17	188854.51
1984	112005.14	10396.45	1928.06	50286.57
1994	122840.04	9563.36	3841.77	0.00

Table -6-15 - Paved areas 1954 - 1994

CREEK	YEAR	AREA	PERCENTAGE CHANGE
Coffs	1954	0	0
	1974	82602.96	0
	1994	713294.48	0

Table -6-16 - Sealed roads 1954 - 1994

CREEK	YEAR	AREA	PERCENTAGE CHANGE
Coffs	54	152696	100
	74	391969	156.6989
	94	680792	345.848

Table 6-17 - Unsealed roads 1954 - 1994

CREEK	YEAR	AREA	PERCENTAGE CHANGE
Coffs	54	156851	100
	74	69292	-55.823
	94	30361	-80.6434

Table 6-18 -Tracks 1954 - 1994

CREEK	YEAR	AREA	PERCENTAGE CHANGE
Coffs	54	128591	100
	74	127127	-1.14
	94	111924	-12.97

6.4 AREAS OF ESTUARINE VEGETATION AND HUMAN SETTLEMENT PATTERNS (HSP) - MOONEE CREEK

Table 6-19 - Estuarine vegetation 1954 - 1994 - Moonee Creek

MOONEE CREEK – ESTUARINE VEGETATION (Square Metres)				
Year	Mangrove	Salt Marsh	Sea Grass	Sedge
1954	18574.06	145286.65	16520.10	1020737.81
1964	20965.37	123608.71	11217.79	868333.09
1974	25786.53	138771.97	40317.16	921474.44
1984	42619.01	117130.24	23890.74	870504.83
1994	56559.57	137896.53	29209.64	87787.20

Table -6-20 - Housing 1954 - 1994

CREEK	YEAR	NUMBER	AREA	PERCENTAGE CHANGE
Moonee	54	94	14100	100
	74	164	24600	74.468
	94	623	93450	562.766

Table -6-21 - Paved areas 1954 - 1994

YEAR	TIME	AREA	PERCENTAGE CHANGE
Moonee	54	Nil	Nil
	74	Nil	Nil
	94	Nil	Nil

Table -6-22 - Sealed roads 1954 - 1994

CREEK	YEAR	AREA	PERCENTAGE CHANGE
Moonee	54	58333	100
	74	146585	151.29
	94	200742	244.1311

Table -6-23 - Unsealed roads 1954 - 1994

CREEK	YEAR	AREA	PERCENTAGE CHANGE
Moonee	54	42888	100
	74	48952	14.13915
	94	25083	-41.5151

Table 6-24 - Tracks 1954 - 1994

CREEK	YEAR	AREA	PERCENTAGE CHANGE
Moonee	54	138139	100
	74	175554	127.085
	94	213449	154.5176

APPENDIX 7 CATCHMENT CORRELATIONS

7.1 CATCHMENT CORRELATIONS - PERCENTAGE ESTUARINE VEGETATION - HUMAN SETTLEMENT PATTERNS AND CATCHMENT

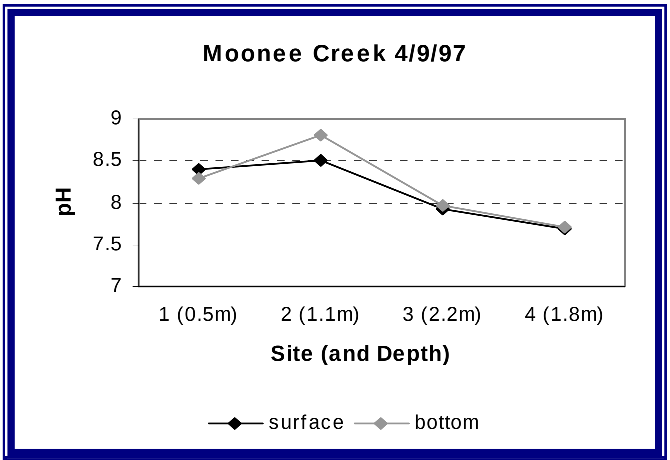
		Total % of catchment		% of creek occupied by veg type			
		Total	HSP	Mangroves	Seagrass	Sedge	Saltmarsh
Moonee	54	2.8	0	3.26	2.91	179.6	25.56
	74	4.75	1.95	4.54	7.09	162.13	24.41
	94	3.8	1	9.95	5.14	154.46	24.26
Coffs	54	17.44	0	13.95	0.57	158.61	9.31
	74	23.9	6.46	12.4	0.35	38.22	10
	94	25.76	8.32	24.86	0.78	0	1.93
Boambee	54	1.46	0	14.8	3.45	33.73	59.49
	74	3.2	1.74	18.51	8.11	89.07	43.41
	94	4.96	3.5	17.82	5.45	44.48	37.05
Bonville	54	0.76	0	0.84	2.15	13.52	27.48
	74	1.65	0.89	0.7	0.89	16.14	11.58
	94	2.21	1.45	4.26	10.99	5.08	14.19

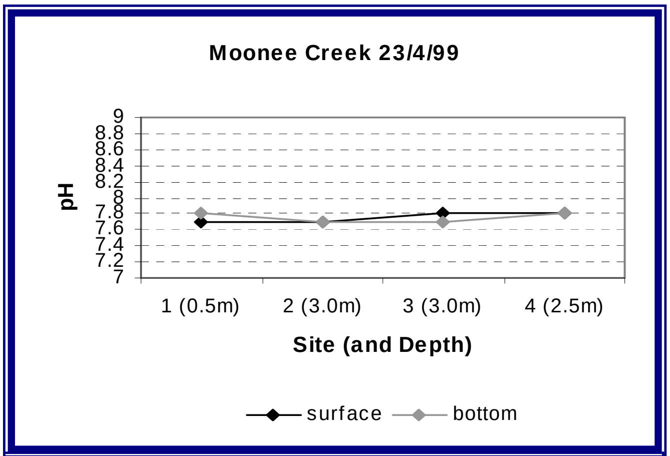
7.2 REGRESSION ANALYSIS OF ESTUARINE VEGETATION AND HUMAN SETTLEMENT PATTERNS

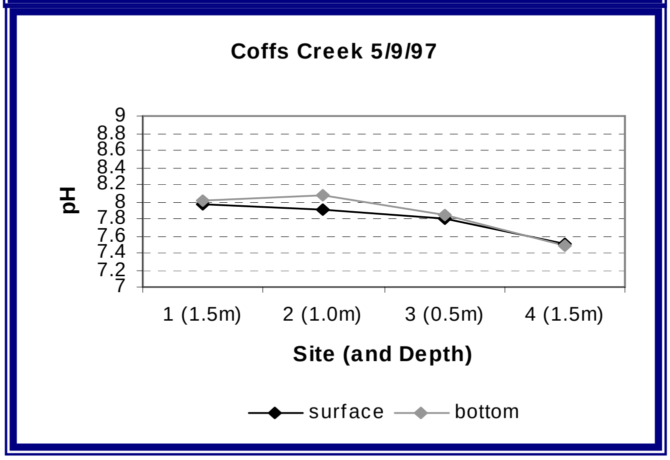
	DEPENDANT VARIABLE	INDEPENDENT VARIABLE	CO-EFFICIENT OF DETERMINATION
Seagrass	Seagrass	Human Settlement Pattern	0.0526
	Seagrass	Log Human Settlement Pattern	0.1265
	Log Seagrass	Human Settlement Pattern	0.1543
	Log Seagrass	Log Human Settlement Pattern	0.3775
Sedge	Sedge	Human Settlement Pattern	0.1621
	Sedge	Log Human Settlement Pattern	0.0180
	Log Sedge	Human Settlement Pattern	0.0027
	Log Sedge	Log Human Settlement Pattern	0.0181
Mangrove	Mangrove	Human Settlement Pattern	0.3691
	Mangrove	Log Human Settlement Pattern	0.3914
	Log Mangrove	Human Settlement Pattern	0.233
	Log Mangrove	Log Human Settlement Pattern	0.4293
Saltmarsh	Saltmarsh	Human Settlement Pattern	0.2027
	Saltmarsh	Log Human Settlement Pattern	0.3166
	Log Saltmarsh	Human Settlement Pattern	0.2908
	Log Saltmarsh	Log Human Settlement Pattern	0.4998

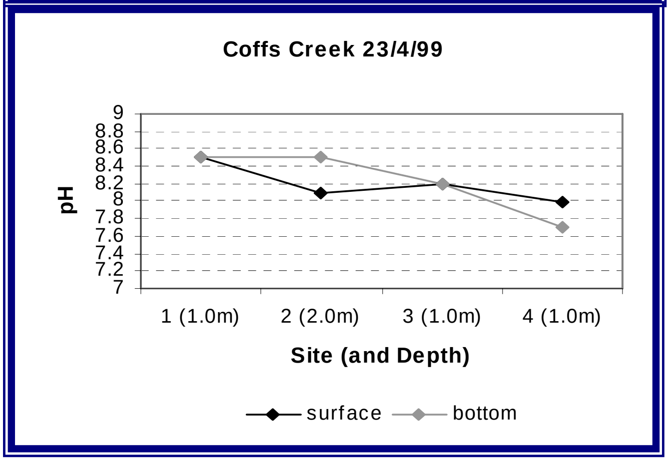
APPENDIX 8 WATER QUALITY

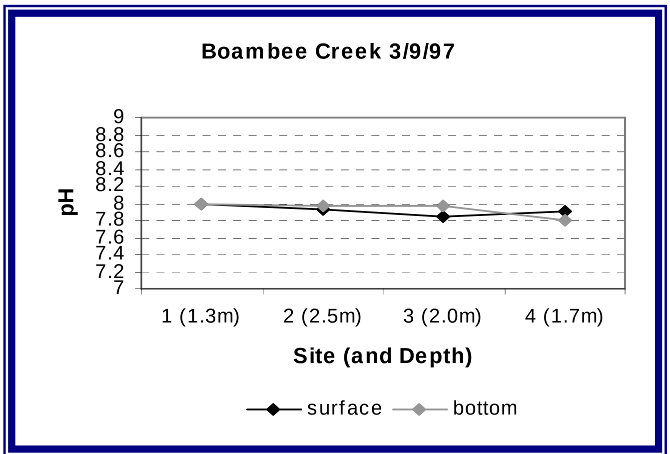
8.1 WATER QUALITY - IN SITU TESTING - pH ALL CREEKS 1997 & 1999

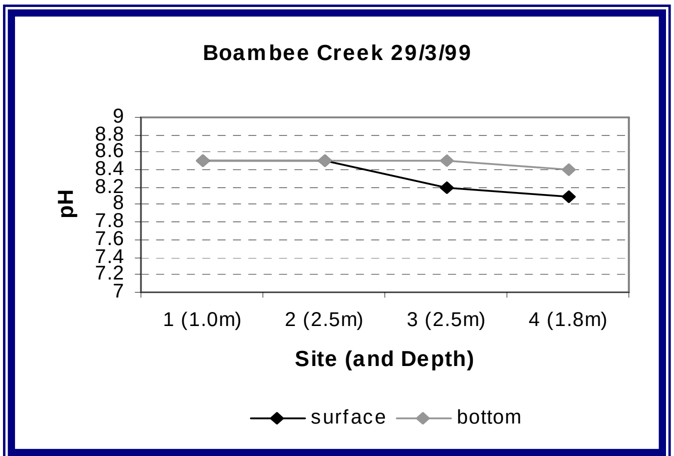


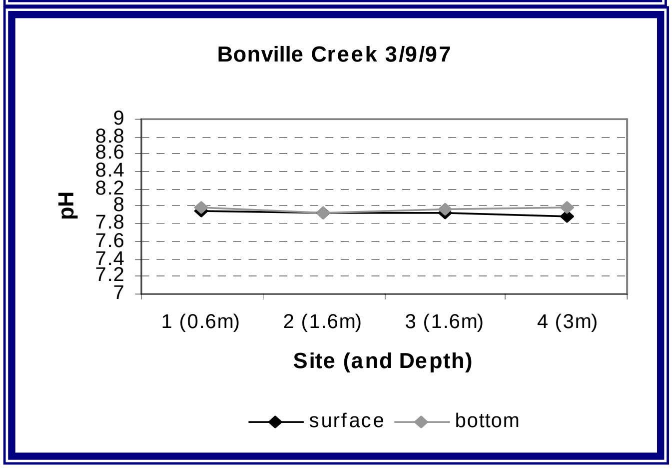


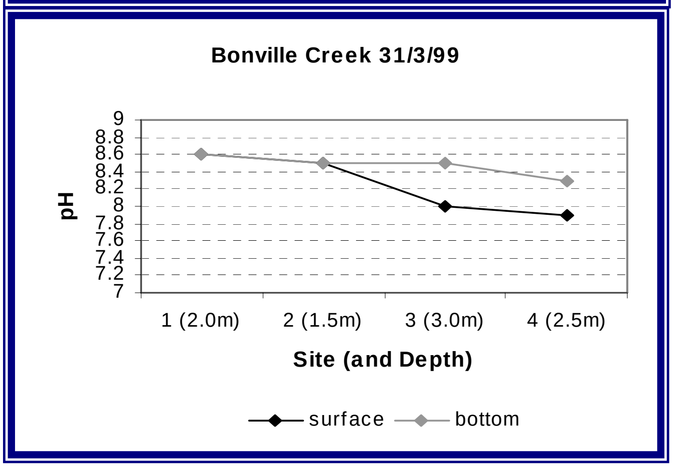




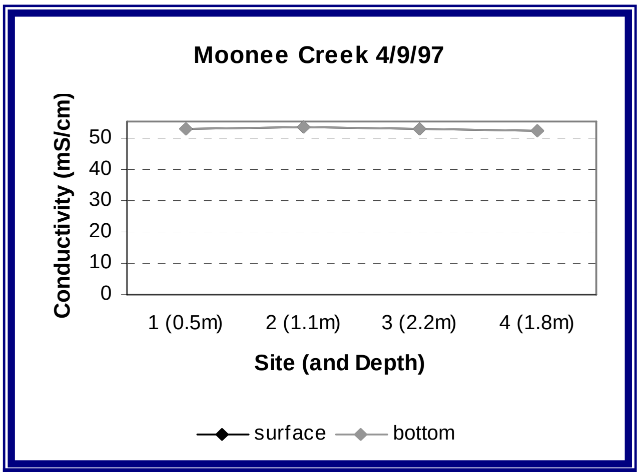


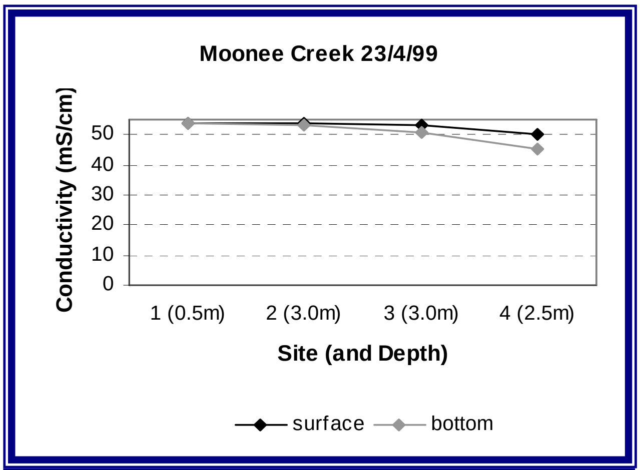


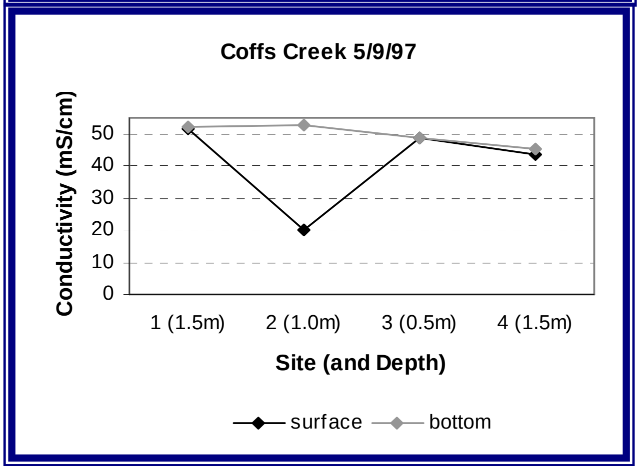


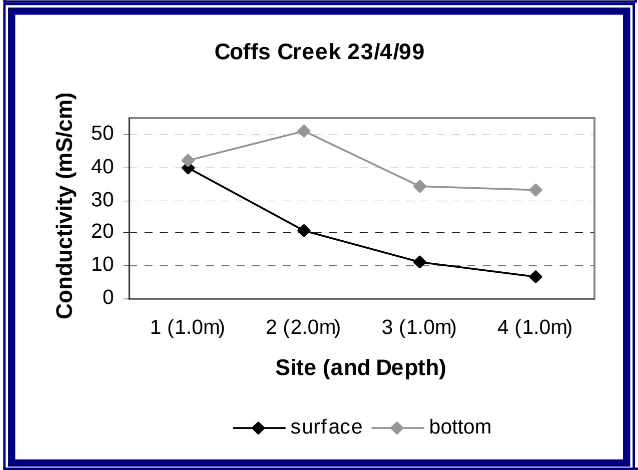


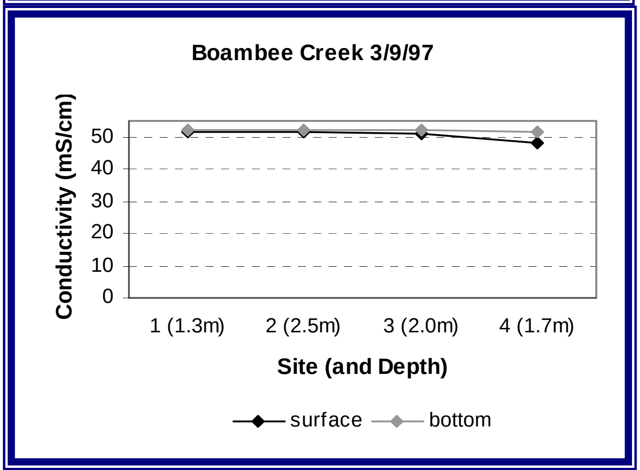
8.2 WATER QUALITY - IN SITU TESTING - CONDUCTIVITY ALL CREEKS 1997 & 1999

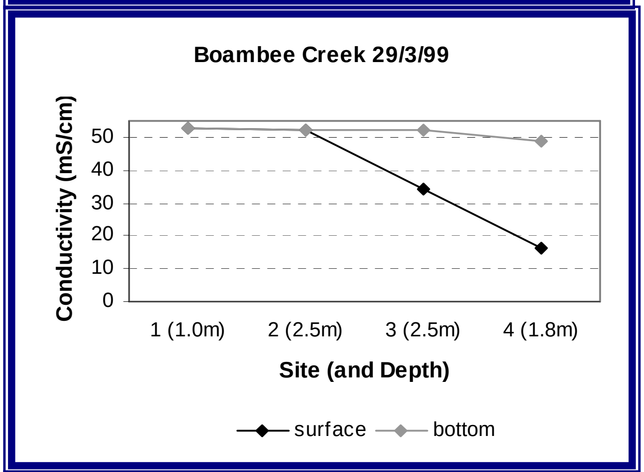


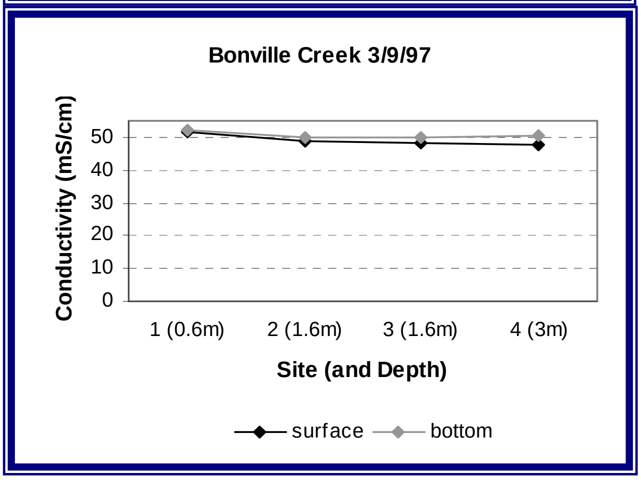


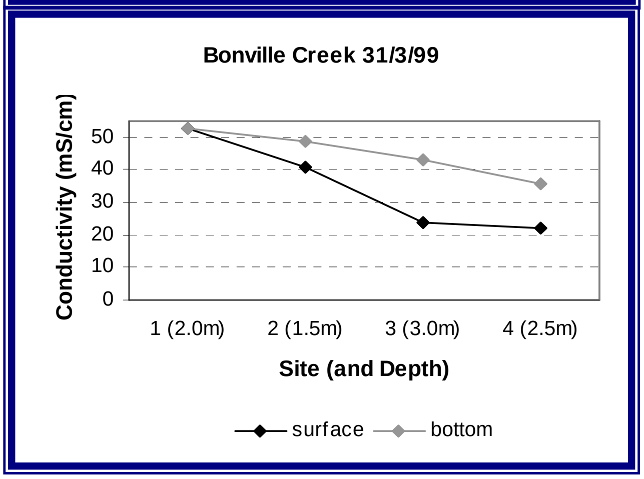




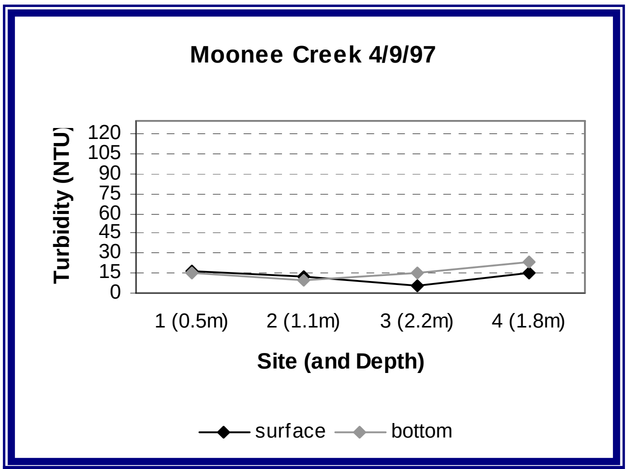


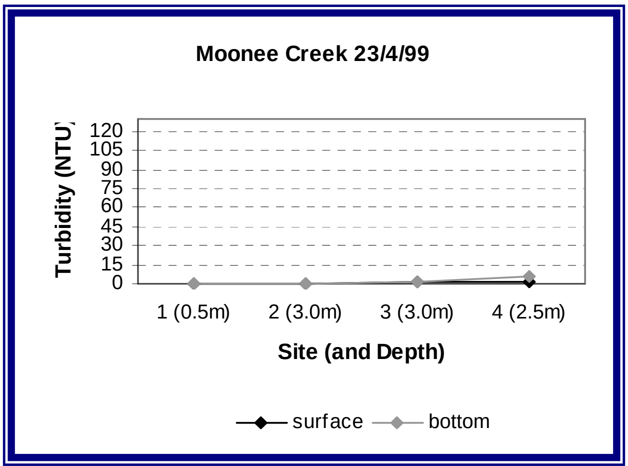


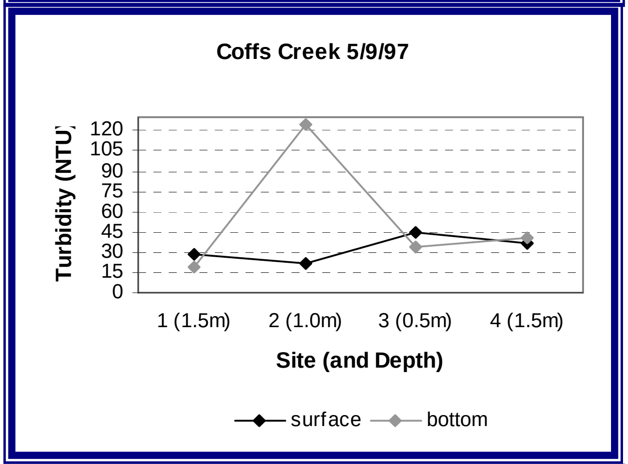


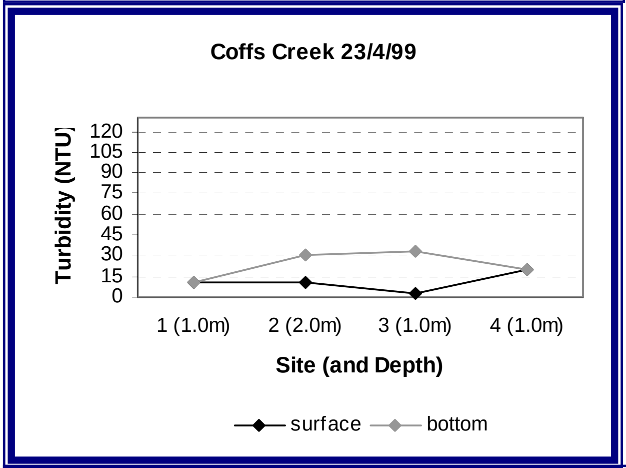


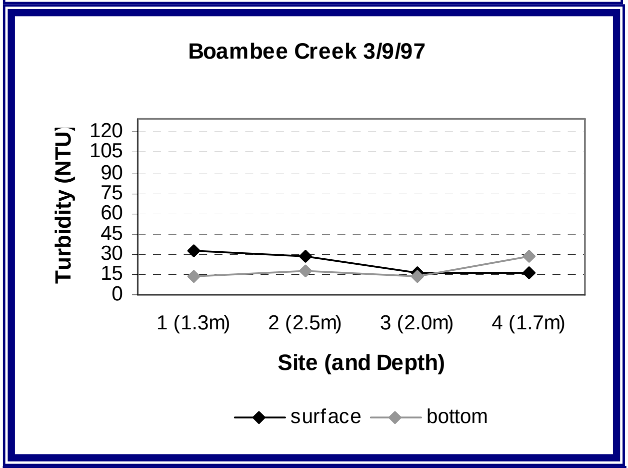
8.3 WATER QUALITY - IN SITU TESTING - TURBIDITY ALL CREEKS 1997 & 1999

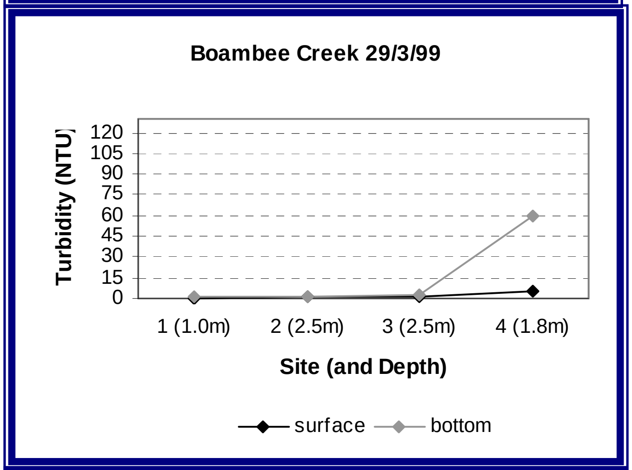


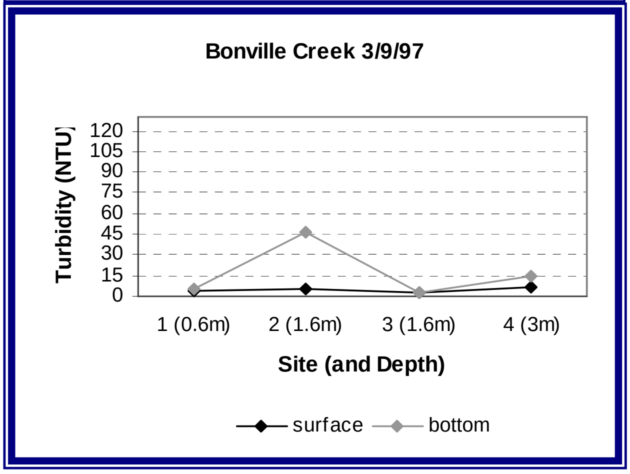


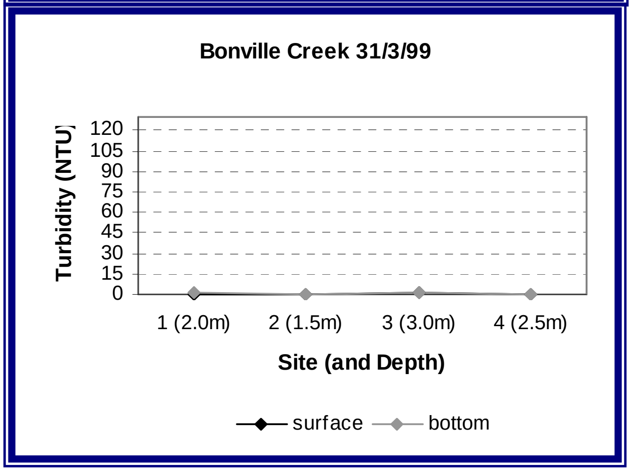




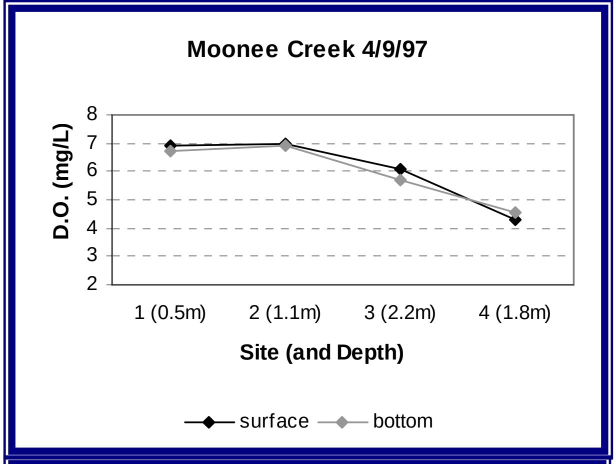


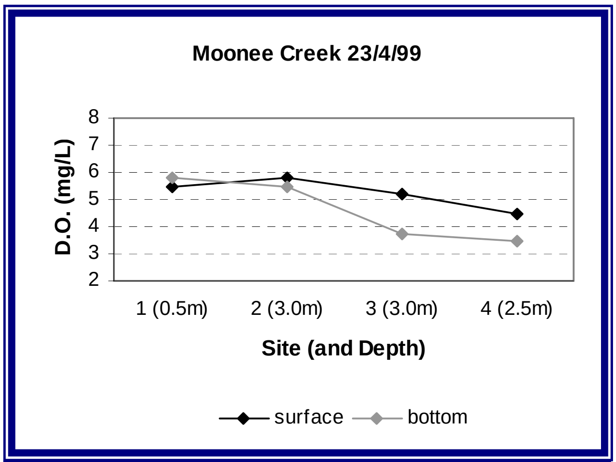


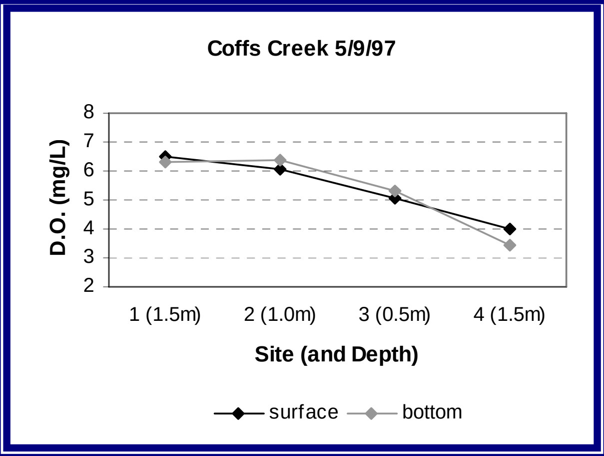


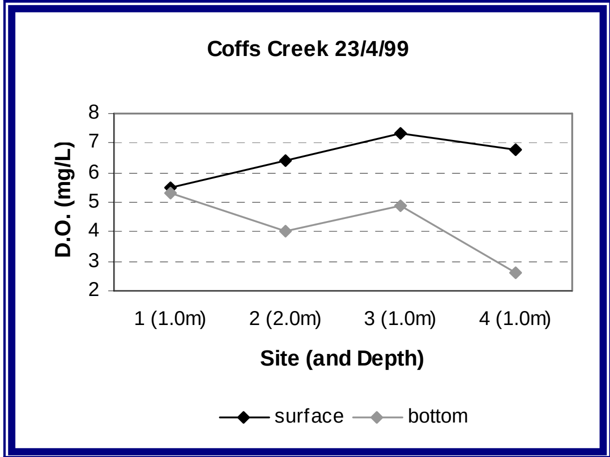


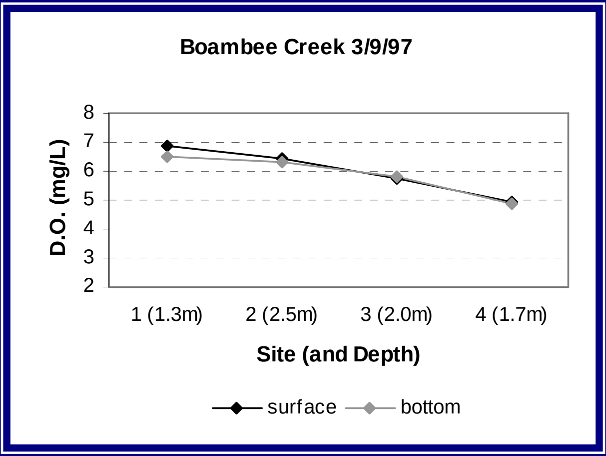
8.4 WATER QUALITY - IN SITU TESTING - DO ALL CREEKS 1997 & 1999

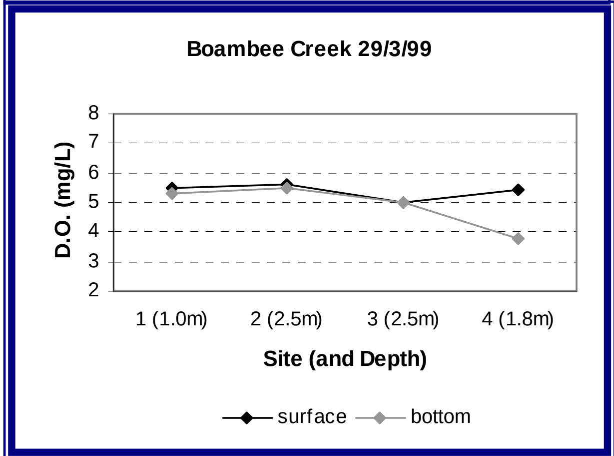


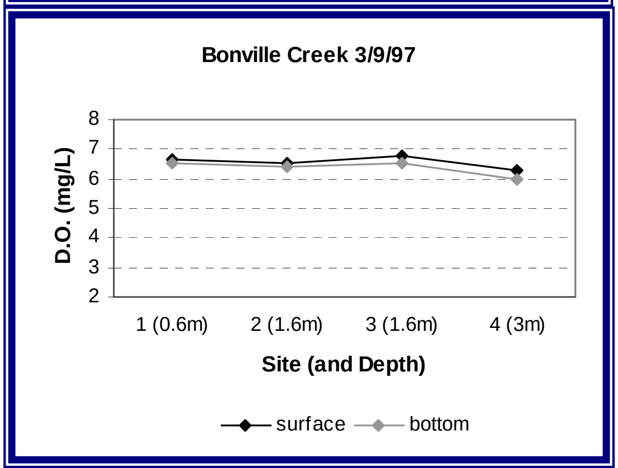


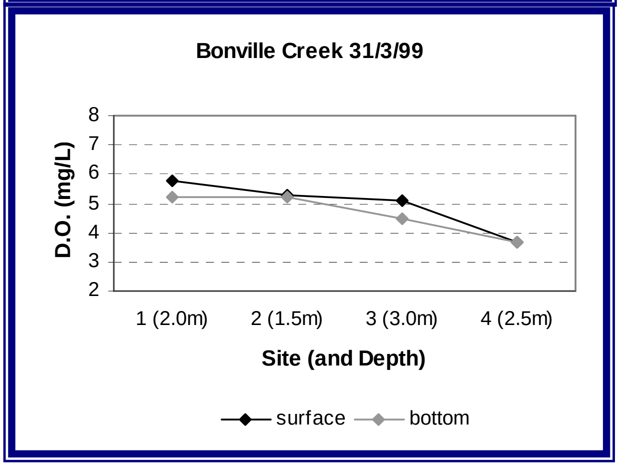




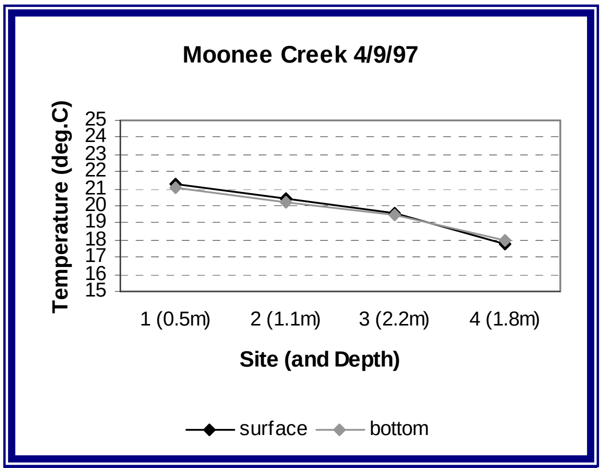


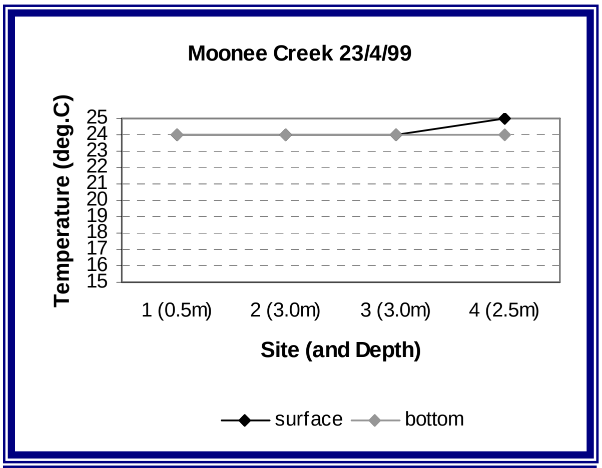


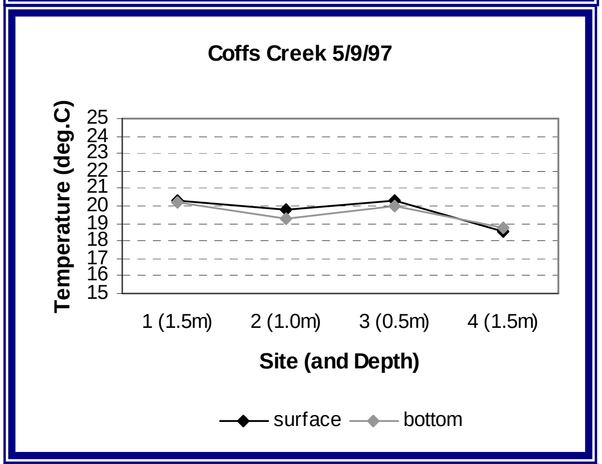


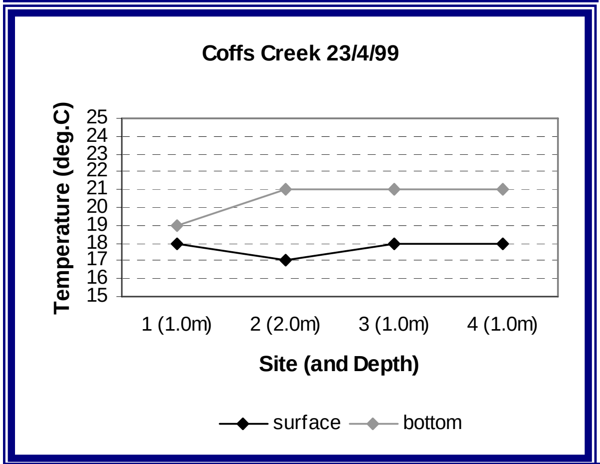


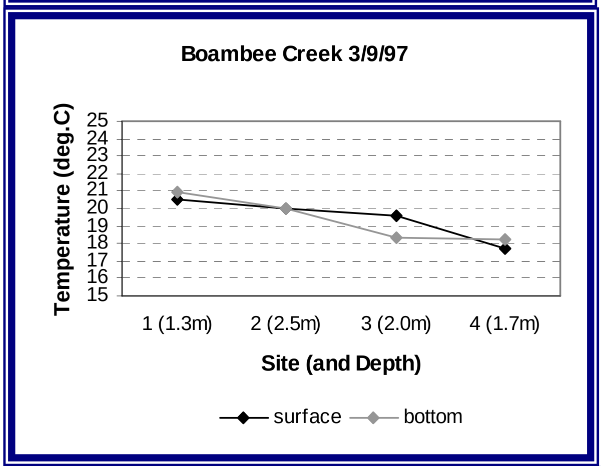
8.5 WATER QUALITY - IN SITU TESTING - TEMPERATURE ALL CREEKS 1997 & 1999

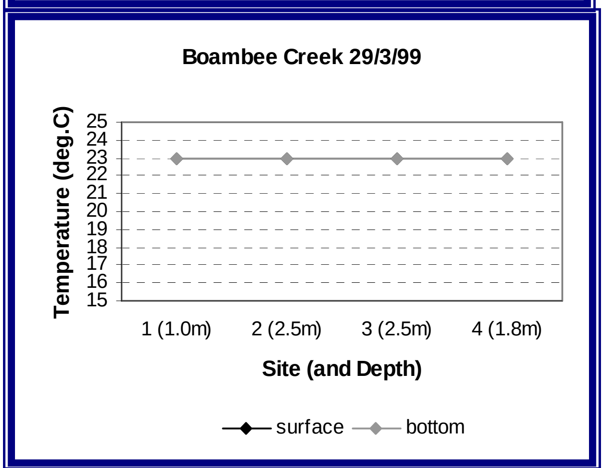


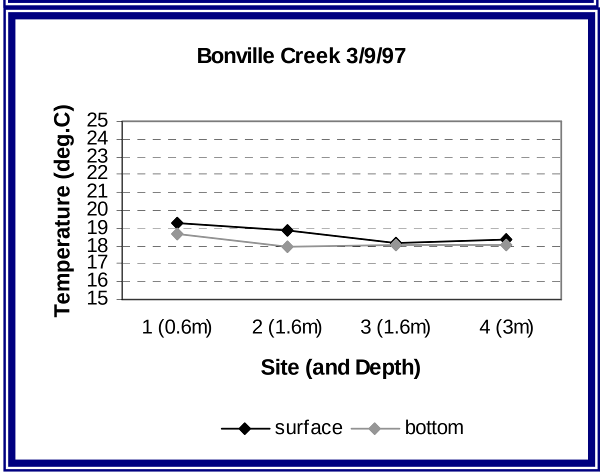


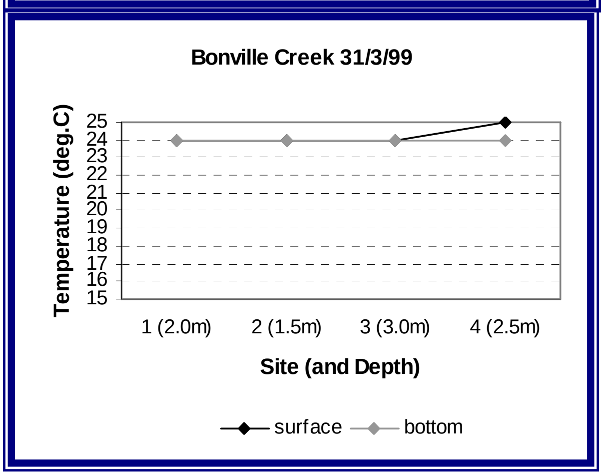




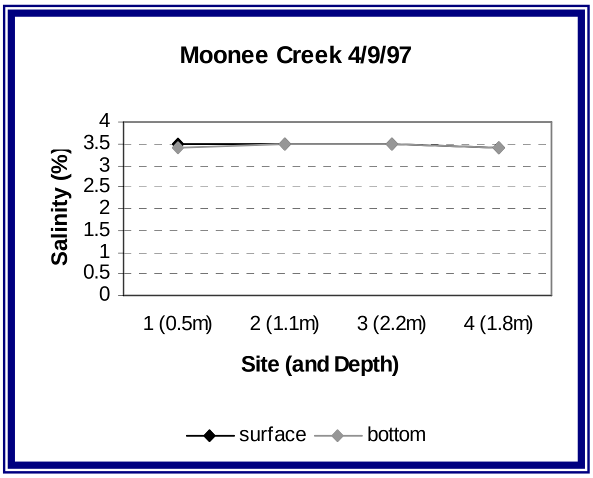


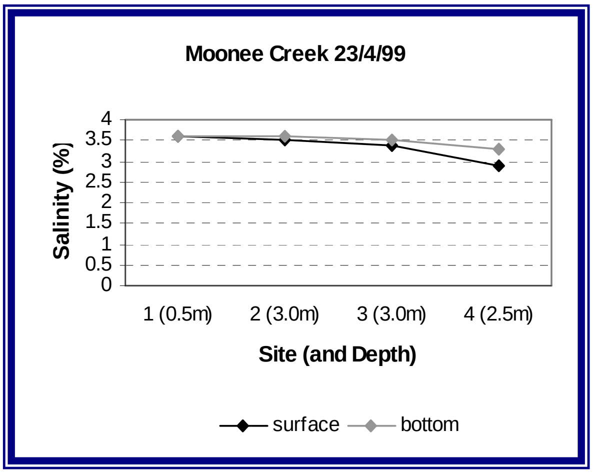


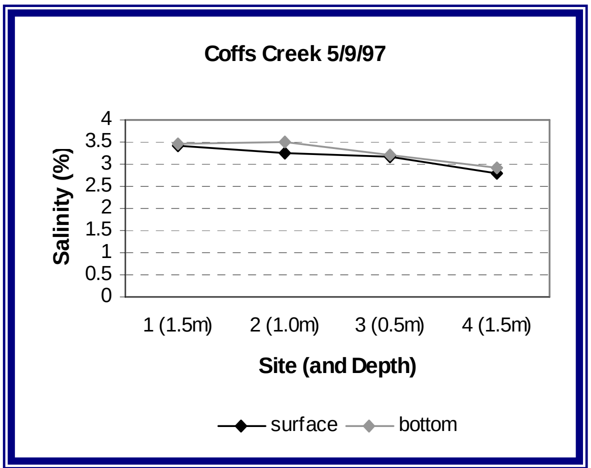


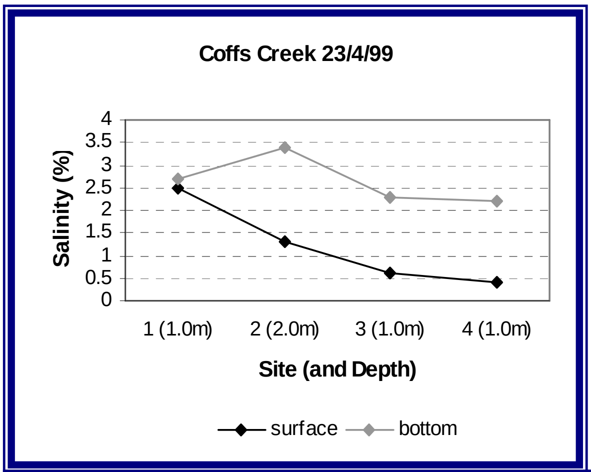


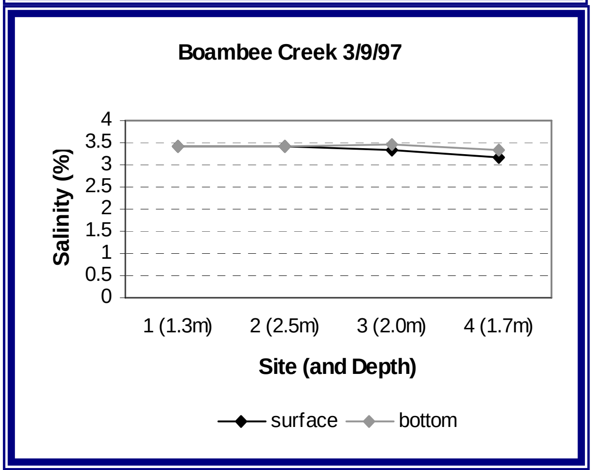
8.6 WATER QUALITY - IN SITU TESTING - SALINITY ALL CREEKS 1997 & 1999

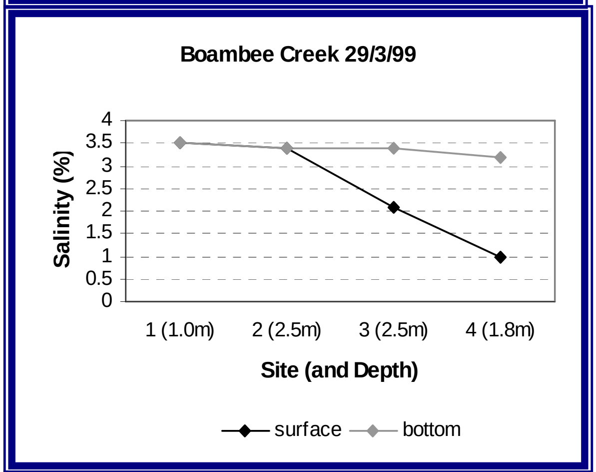


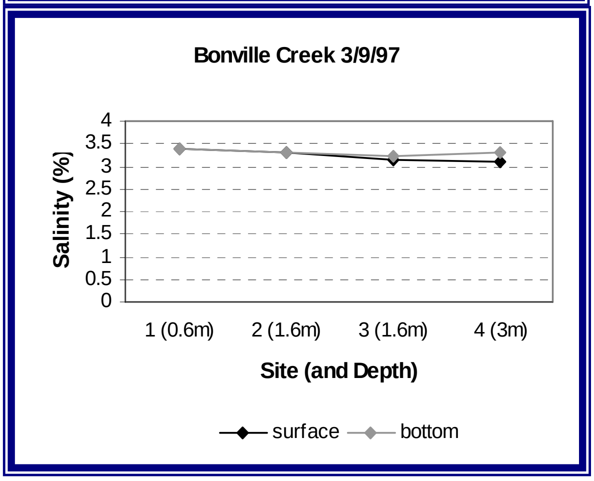


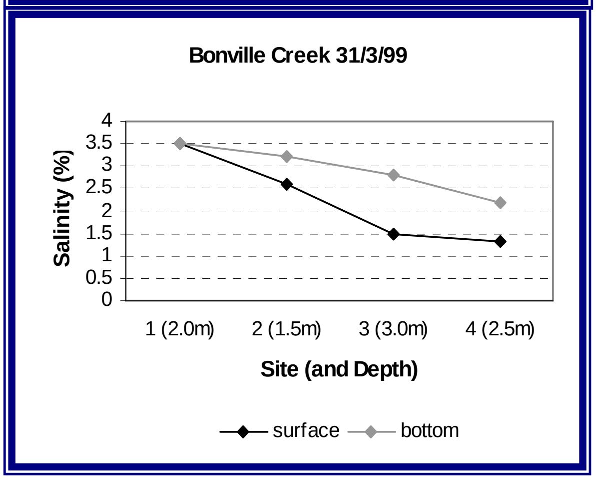












APPENDIX 9 FAECEAL COLIFORMS AND TOTAL COLIFORMS

9.1 BONVILLE CREEK

Table 9-1 - Geometric means - coliform - Bonville Creek

YEAR	FAECAL COLIFORM/100ml	TOTAL COLIFORM/100ml
1997	49.15	80.37
1999	75.04	255.16

9.2 BOAMBEE CREEK

Table 9-2 - Geometric mean coliform

YEAR	FAECAL COLIFORM /100 ml	TOTAL COLIFORM /100 ml
1997	36.74	50.20
1999	139.11	335.55

9.3 COFFS CREEK

Table 9-3 - Geometric mean - coliform

YEAR	FAECAL COLIFORM /100m	TOTAL COLIFORM /100m
1997	113.85	161.1
1999	186.59	931.21

9.4 MOONEE CREEK

Table 9-4 - Geometric means - coliforms

YEAR	FAECAL COLIFORM /100m	TOTAL COLIFORM /100m
1997	140.22	185.47
1999	64.87	131.65

APPENDIX 10 GRAIN SIZE

10.1 BONVILLE CREEK

Table 10-1 - Weighted means - granulometry - Bonville Creek

BONVILLE Average Grain Size (microns Um)	
Site 1	144.42
Site 2	149.2
Site 3	127.9
Site 4	130.8

10.2 BOAMBEE CREEK

Table 10-2 - Weighted mean granulometry

BOAMBEE Average Grain Size (microns Um)	
Site 1	129.57
Site 2	144.79
Site 3	95.77
Site 4	83.74

10.3 COFFS CREEK

Table 10-3 - Geometric mean - granulometry

COFFS CREEK Average Grain Size (Microns Um)	
Site 1	164.4
Site 2	113.4
Site 3	126.5
Site 4	100.35

10.4 MOONEE CREEK

Table 10-4 - Geometric means - granulometry

MOONEE Average Grain Size (Microns Um)	
Site 1	140.92
Site 2	146.71
Site 3	126.08
Site 4	122.1