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Long-term changes in nutrients, weed mats and shorebirds in an Estuarine System

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Abstract : Long-term data sets on agricultural practice, river nutrients, biomass of macro-algal mats and numbers of shorebirds are analysed for the Ythan estuary, Aberdeenshire, Scotland. The results suggest a 2-3 fold increase of nitrogen in river water over a 25-year period, associated with an increase in the proportion of land under cereal crop production. Biomass of the green seaweed *Enteromorpha* has also increased over this period which now forms dense mats in much of the estuary. The abundance of the amphipod *Corophium volutator* is reduced under weed mats but there are at present sufficient unweeded refuge areas between the mats to maintain an overall highly productive invertebrate community. A general increase in mudflat invertebrate productivity may account for increases in the numbers of several species of shorebirds on the Ythan over the study period. However, if weed mats become too extensive, these highly productive refuges may disappear altogether with dramatic consequent effects on the general ecology of the estuary.

Résumé : Un ensemble de données à long terme sur les pratiques agricoles, les éléments nutritifs des rivières, la biomasse des tapis de macro-algues et un certain nombre d'échassiers est analysé dans l'estuaire d'Ythan, Aberdeenshire, Ecosse. Les résultats suggèrent un accroissement de 2 à 3 fois du taux d'azote dans l'eau des rivières au-delà d'une période de 25 ans, associé à une augmentation de la proportion de terres produisant des céréales. La biomasse de l'algue *Enteromorpha* a aussi augmenté au-delà de cette période. L'étendue de cette couverture d'algues réduit l'abondance de l'amphipode *Corophium volutator*, mais il y a suffisamment d'endroits sans algue entre les tapis pour maintenir une communauté d'invertébrés très productive. Cet accroissement général de productivité peut justifier l'augmentation du nombre d'échassiers dans l'Ythan au-delà de la période d'étude. Cependant, si l'étendue des tapis d'algues devient trop importante, ces refuges hautement productifs peuvent disparaître et l'écologie s'en ressentir de manière dramatique.

INTRODUCTION

One of the most visible effects of nutrient enrichment in estuaries is an increase in the cover and density of opportunistic green macroalgae. Initially, enrichment may increase the overall productivity of the estuary, but under dense algal mats the sediment becomes anoxic, affecting the abundance of mudflat invertebrates (Soulsby *et al.*, 1982 ; Nichols *et al.*, 1981 ; Hull 1987), and, possibly, their shorebird predators (Tubbs 1977, Tubbs & Tubbs 1983). However, the nutrient enrichment process is insidious, and may not be recognized until major ecological effects, such as heavy weed cover, are already evident. It is then usually too late to quantify the course of changes in the physico-chemical and biological components of the system because the appropriate measures were not made at the time. Indeed, this is one of the major problems in interpreting ecological changes in terms of suspected eutrophication (Postma 1985). Over the past 25 years, there have been many surveys of nutrients, macroalgae and shorebirds on the Ythan estuary, Aberdeenshire, Scotland. Here we describe the temporal changes in these parameters and discuss their possible relationships.

The Data Sets

(a) *Nutrients*

Nitrogen and phosphorus enter the estuary from : drainage of the agricultural land in the catchment ; discharges of domestic sewage (primary treatment only) at Ellon and Newburgh (Fig. 1) ; the sea on the flood tide.

Data on nitrogen and phosphorus concentrations in river water were provided by the North East River Purification Board (NERPB) with estimates of water flow for the period 1975 to 1984. This enabled us to calculate amounts of nutrients (kg of total nitrogen (TON-N) and kg of phosphate (PO_4^3 -P) per day reaching the estuary during the spring (March-May), summer (June-August), autumn (September-November) and winter (December-January) for the two periods 1975-79 and 1980-84. Years were blocked because complete data sets were not available for every year. NERPB also provided a more extensive data series (1959-1986) for nitrogen concentrations, which, because of variability imposed mainly by fluctuations in water volume, have been analysed using a rolling mean. These data have been supplemented by those of Leach (1969) for the period 1966-67, who also estimated nutrient input from the open sea. It is assumed that marine inputs from the northern North Sea have not changed significantly since Leach's study. The nutrient data have been analysed separately for river water above and below Ellon discharge so that the relative contributions of agricultural run-off and sewage could be assessed.

(b) *Macroalgal mats*

Enteromorpha spp are the most abundant macroalgae over most of the estuary, but *Chaetomorpha linzii* and *Ulva* spp are locally common (Green 1977). Estimates of macroalgal biomass (grams fresh weight/m^2) were obtained from Green (1977) for the period 1973-74 and from our own unpublished data for the periods 1963-69 and 1985-86. Most of the records are from the South Quay area in the middle reaches of the estuary (Fig. 1), but weed cover is extensive over large areas of the Ythan (Fig. 2).

(c) *Shorebirds*

Regular winter counts of waders and wildfowl on the Ythan estuary have been made since the 1960's by the British Trust for Ornithology and Wildfowl Trust respectively. The wader data have been supplemented by independant counts by Goss-Custard (1966) and Hepplestone (1968). Six species were analysed : oystercatcher (*Haematopus ostralegus*), curlew (*Numenius arquata*), bar-tailed godwit (*Limosa lapponica*), redshank (*Tringa totanus*), dunlin (*Calidris alpina*) and knot (*Calidris canutus*). Numbers are expressed as the average of the counts for November, December, January and February. When there was more than one count in a month these were averaged to give the count for that month. Only when there were counts available for all four months were the data analysed for that year.

The Wildfowl Trust counts have been augmented by additional records provided by Dr. M. Bell for the period 1954-84. Three species were analysed : mute swan (*Cygnus olor*),

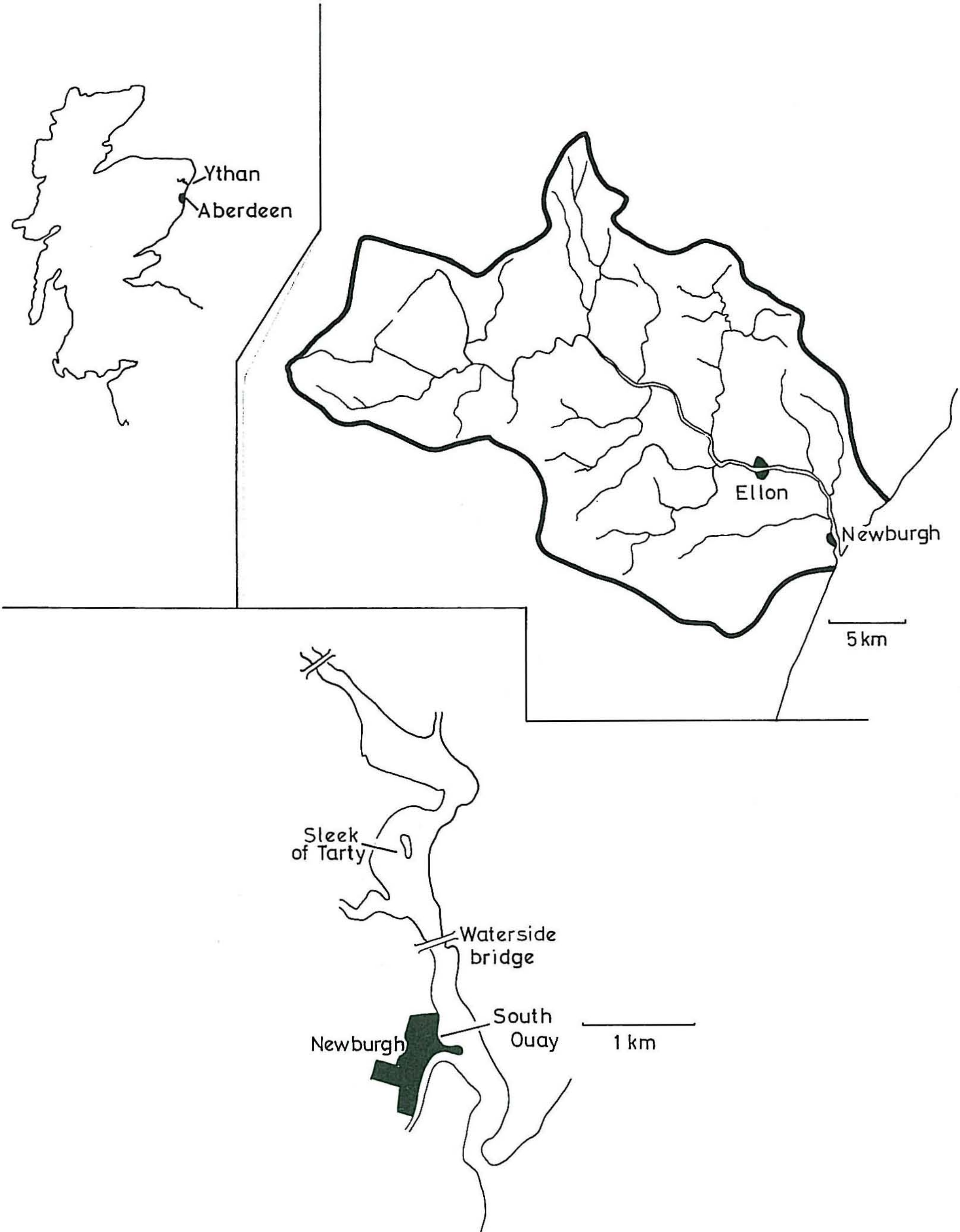

Fig. 1 - The Ythan estuary and the catchment of the Ythan river.

and wigeon (*Anas penelope*), which feed on macroalgal mats, and shelduck (*Tadorna tadorna*), the foraging behaviour of which may be disrupted by the presence of mats (Atkinson-Willes 1976). For mute swan and wigeon the counts are expressed as the average of the December to February monthly counts. Shelduck counts are expressed as the mean of the January to March counts, this species being virtually absent from the Ythan in December (Patterson 1982).

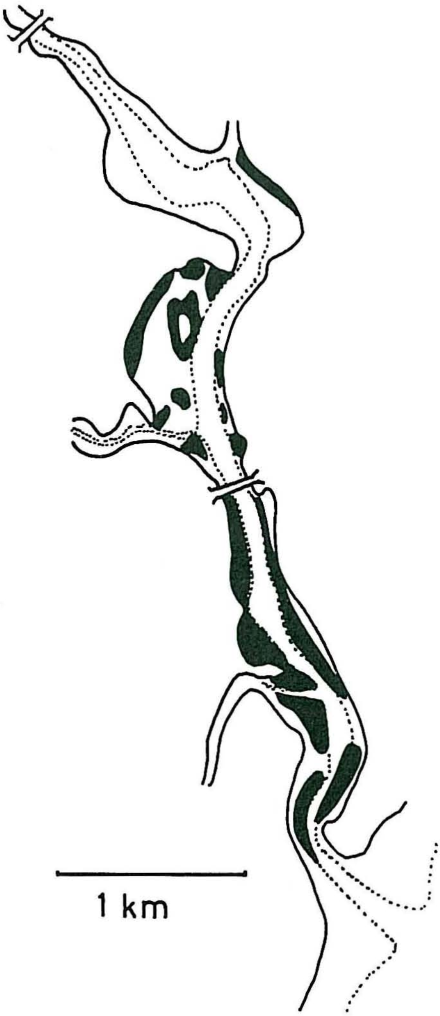

Fig. 2 - The distribution of weed mats (*Enteromorpha*) on the Ythan estuary, August 1986. Shaded areas have a weed cover greater than 1 kg wet weight/m^2.

RESULTS

Amounts of nitrogen and phosphorus in the Ythan river and estuary vary seasonally, being lowest in summer and highest in winter (Table I). This is probably due to a combination of higher run-off in winter, and increased release of nutrients from soil after harvest and ploughing (Royal Society 1983). Amounts of nitrogen in the river above Ellon increased at least two-fold between 1967 and 1975 for all seasons, with less of an increase between 1975 and 1984 for autumn and winter, and a suggestion of a slight decrease in spring and summer, although the 1984 values were always higher than those in 1966 (Table I). The longer term data set on nitrogen concentrations shows an increase from about 2.5 to 6 mg/L in the late 1960's/early 1970's (Fig. 3). Phosphorus loadings above Ellon vary seasonally in a similar way to nitrogen, but unlike the latter there is little evidence of any increase in phosphorus over the period 1967 to 1984 (Table I).

TABLE I

Nutrient loadings in the Ythan river above and below Ellon Sewage works. Data from Leach (1969) and NERPB. Nutrient additions at Ellon over the period 1966-67 were insignificant.

	Phosphorus kg PO_4^3-p per day			*Total Oxidised Nitrogen* kg TON-N per day	
	1966-67	1980-84	1966-67	1975-79	1980-84
(a) Above Ellon					
Spring	18.0	15.4	1665	4591	3729
Summer	14.1	11.0	488	1716	1167
Autumn	28.0	22.0	1251	2787	3084
Winter	33.2	38.1	2239	6480	8532
(b) Below Ellon					
Spring	18.0	30.9	1665	-	3617
Summer	14.1	26.6	488	-	1057
Autumn	28.0	34.3	1251	-	2174
Winter	33.2	38.2	2239	-	8915

Ellon sewage works discharges about 25kg/day of phosphorus and 75kg/day of nitrogen (TON-N) ; data from Grampian Regional Council and NERPB. This amount of nitrogen is insignificant compared that already in the river, but the phosphorus added at Ellon could contribute significantly to the river's phosphorus loading, although it is not reflected in an increase in the quantities of phosphorus measured below Ellon (Table I), possibly because of incomplete mixing in the water body. Inputs from Newburgh outfall are about 8kg/day nitrogen and 2.6 kg/day phosphorus, reflecting its lower population.

In the 1960's and 70's, weed cover on the Ythan was generally low although blooms did occur in some years (Milne, pers. obs.). This is reflected in the South Quay data where biomass ranged from about 170 to 1340 g/m^2 between 1963 and 1974 (Table II). In the 1980's there has been extensive growth of weed mats reflected in the high biomasses (> 2 kg/m^2) recorded in 1985 and 1986 (Table II).

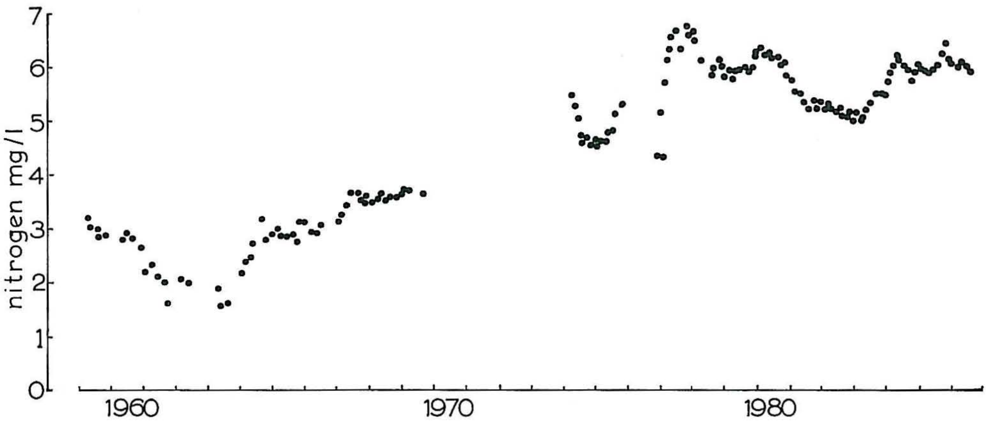

Fig. 3 - Long-term variation in the concentration of nitrogen in the Ythan river above Ellon sewage works, 1959-1986. There are no data for the period 1970-3.

TABLE II

Long-term changes in the peak summer biomass of *Enteromorpha* on Newburgh South Quay mudflat.

	mean wet weight g/m^2
1963	1240
1964	169
1965	477
1966	634
1967	904
1968	1058
1969	1337
1973	1255
1974	607
1985	2087
1986	2314

Numbers of oystercatcher, curlew, bar-tailed godwit, redshank and dunlin have increased significantly on the Ythan since 1969 (Fig. 4). The national trends for oystercatcher and bar-tailed godwit are similar to those on the Ythan, but redshank, dunlin and curlew have declined nationally over the same period (Salmon and Moser 1985).

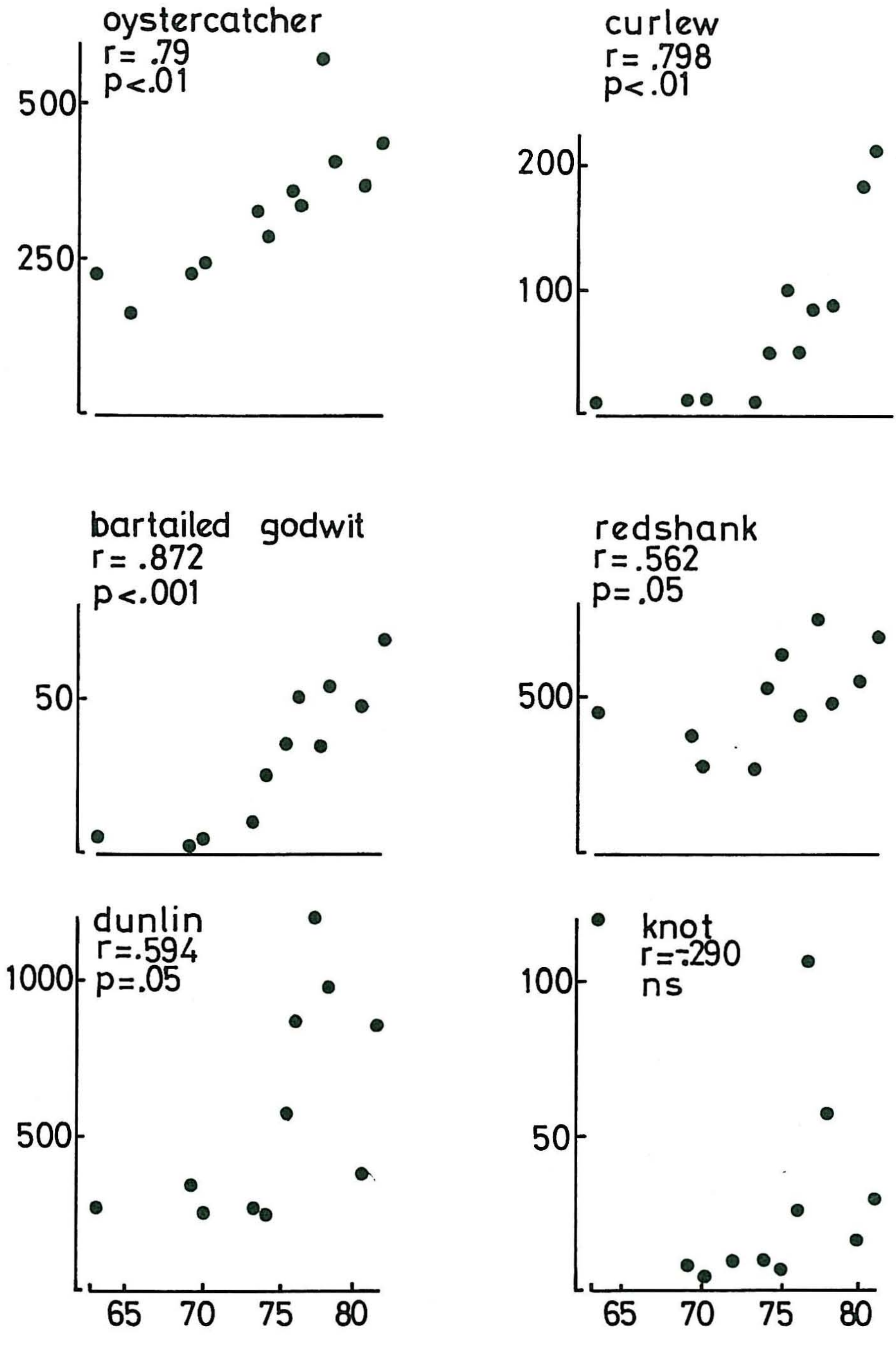

Fig. 4 - Winter counts of waders on the Ythan estuary 1963-1985.

From 1954 to 1986 wigeon have decreased in abundance in the Ythan whilst mute swan have increased over this period (Fig. 5). Shelduck numbers declined between 1954 and 1986, although the 1954 winter count was also low (Fig. 5). Nationally, the numbers of mute swan and wigeon show no trend in abundance over the same time period, but numbers of shelduck appear to be increasing (Owen *et al.* 1986).

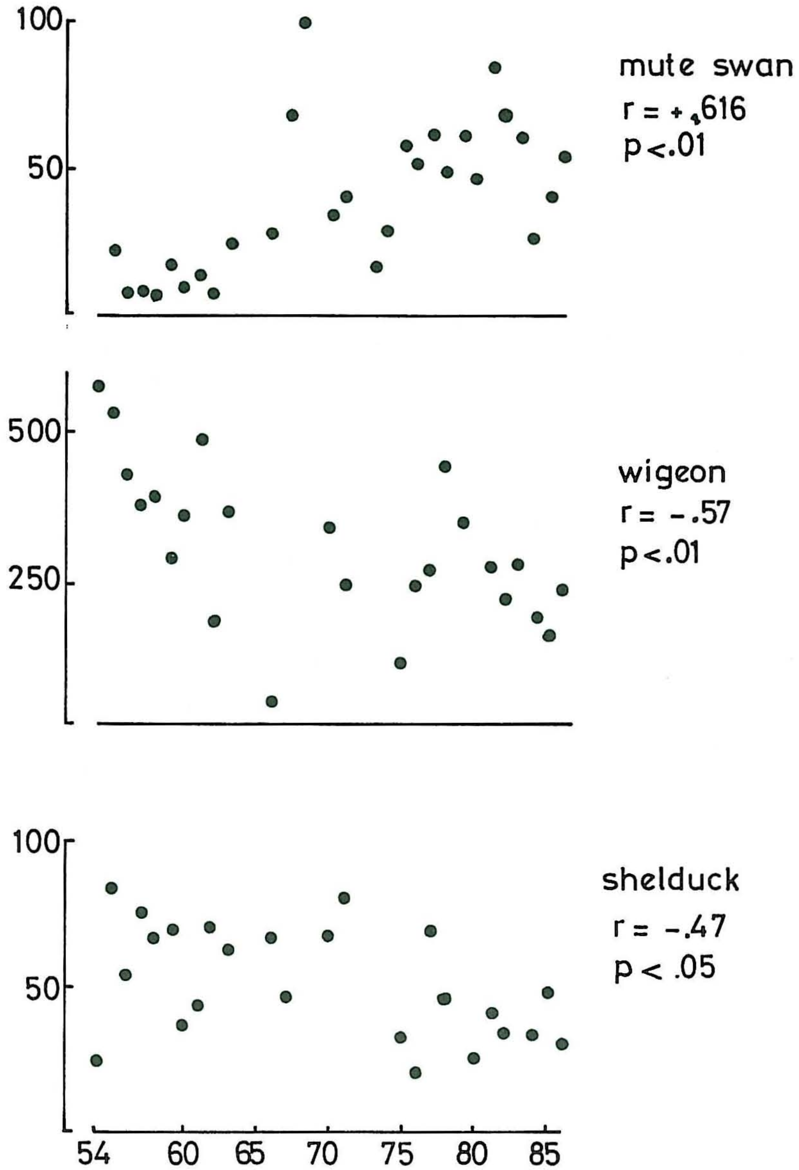

Fig. 5 - Winter counts of wildfowl on the Ythan estuary 1955-1986.

DISCUSSION

Levels of two nutrients known to be responsible for eutrophication have increased in the Ythan over the past 25 years. In terms of the estuary's overall budget, the majority of nitrogen enters the system in land run-off from agricultural land. In common with many other areas of Britain, there has been a significant increase in cereal production, principally barley and wheat, in the Ythan catchment (Fig. 6). The proportion of land under oats has declined over the last 25 years, but there has been an increase in the amount of barley grown, with a sharp increase in wheat production since 1980. The acreage of cereals grown in the catchment has increased from about 32 % to 42 % of the total agricultural area, mainly at the expense of grassland (Fig. 6). The increase in the proportion of land under cereals has been accompanied by a higher application rate of nitrogenous fertilisers to these crops (Church, 1981) and both these factors may account for the elevated levels of nitrogen in the Ythan above Ellon. Interestingly, phosphorus applications have not increased markedly over the past 25 years (Church, 1981) and this is reflected in the consistent phosphorus levels recorded above Ellon between 1966 and 1984.

The populations of Ellon and Newburgh have increased by a factor of 2-3 over the period 1960 to 1984, presumably resulting in 2-3 times the amount of sewage being discharged into the Ythan over the same period. The quantities of nitrogen and phosphorus from sewage are insignificant in the overall nutrient budget of the estuary, but these inputs could be locally important, especially for Newburgh sewer. A tracer survey by NERPB in 1980 showed that sewage is transported as far as Waterside bridge (Fig. 1) on the incoming tide and exported from the estuary on the next ebb tide. Some sewage may be retained on the tidal flats adjacent to the outfall and on the mussel beds in the lower reaches of the estuary and this may contribute in part to high densities of weed mats in the South Quay area adjacent to the outfall.

The relationship between nutrient levels and the growth of macroalgal mats on mudflats is contentious (Soulsby *et al.*, 1985, Nichols *et al.*, 1981, Lowthian *et al.*, 1985) and it will never be possible to demonstrate unequivocally a causal relationship between nutrients and weed growth. Nevertheless, our data do show that, over the past 25 years, nutrient levels have increased in the Ythan and that weed growth is now heavier than in the 1960's and 1970's. We suggest that these two changes are not unrelated. Weed mats can substantially affect the sediment invertebrate fauna ; some species such as the polychaete *Capitella capitata* become more abundant under mats whilst others may decline, e.g. the cockle *Cardium edule*. We have shown elsewhere that where weed biomasses exceed 1 kg/m^2 (wet weight) there is a significant decline in *Corophium volutator*, whilst at 3 kg/m^2 *Corophium* disappears (Hull 1987). When mats become dispersed or buried, *Corophium* can recolonize the now organically enriched patches, and the patchy distribution of mats is probably crucial to the maintenance of the *Corophium* population. If mats become contiguous over much of the summer, then there will be no weed-free refuges for *Corophium* and the species may disappear from large areas of the estuary. This is the situation now at South Quay

(Fig. 1), where *Corophium* is now absent for most of the year, but was widespread in the 1960's and 1970's (Noble 1962, Chambers 1966, Goss-Custard 1966, Joffe 1978, Milne & Woods, unpublished).

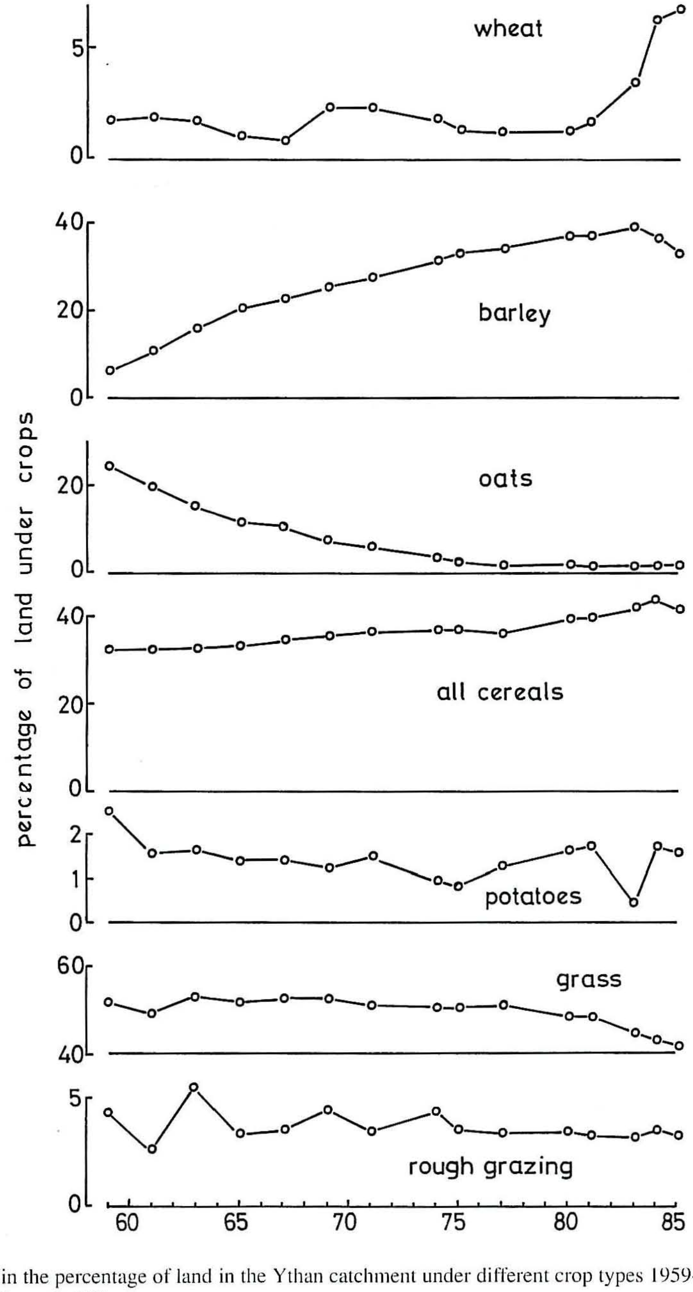

Fig. 6 - Changes in the percentage of land in the Ythan catchment under different crop types 1959-1985. Data from Scottish Records Office.

A decline in *Corophium* has important implications for the estuary because it is the main prey for most of the fish and shorebirds in the Ythan (Milne & Dunnet 1972, Baird and Milne 1981). Yet the numbers of many shorebirds have *increased* over the period of suspected eutrophication. In winter, the Ythan appears to be supporting fewer shelduck, but more oystercatcher, curlew, bar-tailed godwit, mute swan, redshank and dunlin, than in the 1960's. In the case of redshank, dunlin, curlew, mute swan and shelduck, this is contrary to national trends. We suggest that the higher number of shorebirds most probably reflects a general increase in the productivity of the Ythan through nutrient enrichment, as appears to have occurred in other estuaries (Pounder 1974, 1976; Campbell 1978; Van Impe 1985). The decline in shelduck may be due to physical interference by weed mats of the birds' foraging behaviour (Atkinson-Willes 1976).

Although eutrophication may have increased the estuary's carrying capacity for shorebirds, further nutrient enrichment might be disastrous. The present mosaic pattern of mats and unweeded areas provides refuges from which *Corophium* and other invertebrates can recolonize affected areas in autumn and winter. Should weed growth become so extensive that there are too few refuge areas to allow for recolonization the estuary could rapidly move to a different ecological state with low populations of *Corophium* and other invertebrates affected by algal mats and with detrimental effects on shorebirds and fish as claimed by Tubbs (1977) and Tubbs & Tubbs (1983) for Langstone Harbour, southern England. At present there is no way of predicting in advance when this stage will be reached by the Ythan. All we can demonstrate at present are associated changes in several parameters consistent with eutrophication. Nevertheless, the suspected eutrophication process in the Ythan, part of a National Nature Reserve, needs careful monitoring and a long-term programme of assessing weed cover is already under way. Sadly, this will not be the case for most other estuaries.

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