ECOLOGY OF THE FORTH ESTUARY

Donald S. McLusky

INTRODUCTION

The Firth of Forth below Queensferry widens out and the waters are predominantly marine, whilst above Stirling the rivers Forth, Teith and Allan are fresh-water. In between these limits the Forth Estuary stretches for 48km from Stirling to Queensferry and is subject to regular tidal fluctuations, with a gradation of salinity from fresh to salt water. Between Stirling and Alloa the Forth undergoes a series of narrow "windings" as it passes Cambuskenneth, Fallin and Cambus. East of Alloa the Forth gradually widens, and below Kincardine Bridge it is 5km wide at high tide, with the large mudflats of Skinflats, Kinneil, Torry Bay and others revealed at low water. The tidal inflow at Queensferry is over 350 x $10^6 m^3$, which is over 130 times the volume of land-water entering the estuary (Stout, 1976), hence the dominance of marine conditions in the east.

Attention has been given in recent years to the intertidal fauna of the Forth Estuary (see McLusky *et al* 1976, 1978), whilst the condition of the water has been studied for the past 20 years by the Forth River Purification Board (See Annual Reports and Collett 1961 and 1971). Inevitably recent studies have often pointed to the impact of pollution on this area, especially considering the effects of industry in the Alloa/Cambus and the Grangemouth areas. Before considering the present-day ecology of the Forth, it is worth looking at the Forth in retrospect.

HISTORICAL REVIEW

The New Statistical Account of Scotland of 1848 provides a fascinating and comprehensive account of the Forth Estuary at that time, although opinions often differed. The minister of St. Ninians regarded the Forth as "not attractive", whilst his neighbour in Stirling described it as an area of "extradordinary majesty and beauty". They both agree however that the Roman name for the Forth was Bodotria. The Forth in 1848 was a busy river with Stirling having 22 registered vessels of up to 350 tons, plus 4 or 5 regular steamers to Edinburgh. Alloa had a busy harbour trade, with 19,000

tons registered (boats up to 800 tons), and trading to every quarter of the globe. In 1838, 1250 vessels cleared Alloa harbour. The windings of the Forth were distinguished by navigational problems caused by several ancient fords, as well as the phenomenon of double or "leaky" tides.

The fish fauna of the Forth was comprehensively described by Parnell (1837), who listed 125 species for the Forth as a whole, with 35 of them present at Alloa. Throughout the New Statistical Account much attention was given to salmon fisheries, with a substantial fishery at Stirling for salmon and grilse *(Salmo salar)* yielding a rent of £766 per annum. Further down the Forth all reports of salmon fishing (by coble or long net at Alloa, and stake nets at Abercorn, Carriden and Dalmeny) emphasised that a decline had been taking place for some years. Stirling had a major fishery for smelt or sparling *(Osmerus eperlanus)* which appeared in the spring and provided an abundant food for the poorer classes. Herring *(Clupea harengus)* fishing was also reported on the decline. Bo'ness reported good herring fishing in 1794-5, but little since; whilst Queensferry stated that herring was the main industry there from November to March each year, having begun in 1792, but it had been in decline since 1831. Haddock *(Gadus aeglefinus)* Cod *(Gadus callarias),* Skate *(Raja batis)* and Flounder *(Platichthys flesus)* were also present, and caught locally from Alloa to Inverkeithing. Exotic fish and cetaceans (whales, dolphins and porpoises) were occasionally stranded in the Forth, most notably Opah *(Lampris luna)* at Alloa and Inverkeithing in 1835.

The common mussel *(Mytilus edulis)* was reported at several localities in the lower estuary. Most remarkable perhaps is the case of Bo'ness where the local mussel bed was cleared out by Newhaven fishermen in 1803, and attempts to revive it had been unsuccessful.

The Statistical Account of 1791-99 contains many reports of successful salmon and other fisheries in the Forth Estuary, but the theme running through the 1848 account is of decline in fisheries. The apparent reason for the decline in the fisheries, and perhaps the first major change in the ecology of the Forth Estuary is not hard to find. The Tulliallan (Kincardine) account of 1848 mentions "large quantities of moss floating down the river is supposed to have ruined the fishings". Whilst at Carriden they reported "considerable quantities of peat moss in large coherent masses or in a pulpy state are deposited on the shore, which has been floated down the river". At Carriden and Kinneil today can be seen extensive remains of

oyster *(Ostrea edulis)* beds which were apparently smothered by these moss deposits. At Inverkeithing and Rosyth in 1848 they reported that "no submarine moss is known to exist on the shores of the parish, though frequently these are covered to a considerable depth, with the moss thrown into the water at Blair Drummond. The clearing of Blair Drummond Moss had begun in 1766 (see Cadell, 1913), and over the years an expanse of peat moss and heather approx. 20km by 3km to a depth of up to 4m had been cleared to reveal a plain of good alluvial land – the Carseland. As the settlers on the Moss cleared the peat, it was carried away in drainage channels and discharged into the Forth. By 1787 the progress of clearing the moss was limited by the supply of sufficient water to carry the peat away, so in that year a Great Wheel was erected which lifted water 5m from the Teith and discharged it into a 5km canal. With the aid of this water, work proceeded apace and by 1817, 1130 acres had been cleared. Later clearings continued until 1865, during which time many of the estuary shores as far as Bo'ness were covered with lumps of peat. While this method of removal was an easy and expeditious way for riparian proprietors to get rid of their waste, writes Cadell, it was not so convenient for some of their neighbours and for other people who had fishing interests lower down the river. Salmon fishing, as we have already seen, was an important industry on the Forth and the mass of floating moss and peat pulp was so great that it grew into a public nuisance, and the fish traps and oyster beds became choked with moss litter. The floating away of the mosses had to be prohibited in 1865, to prevent further damage to the fisheries.

In 1866 the first attempt was made to get Scottish Fisheries statistics, and the Fishery Board reports of that year list Queensferry, Bo'ness, Grangemouth, Dunmore, Alloa, Kincardine and Limekilns as operating as fishing ports. From then on the Fishery Board reports continue to chart the decline that was already evident in 1848. By 1900 all ports west of Edinburgh were declining, and by 1907 fishing west of Edinburgh was considered unimportant. First complaints about "pollution" from dye works and bleach works appear in 1905, from tanneries in 1910 and from gas works in 1911, and by 1913 upper firth salmon netters were seeking remedial measures against polluters. Pot ale and Nitre were blamed in 1917 for continuing the damage to the salmon fisheries. By 1937 it was declared that the Forth is undoubtedly in a most serious predicament due to mixed domestic and industrial effluent. Herring catches in the Forth estuary fluctuated, being fair in 1921, but poor or complete failures in other years (R. Johnstone; pers. comm.)

Rintoul and Baxter in "A Vertebrate Fauna of Forth" (1935) list 143 species of fish as occurring in the Forth, of which 33 may be recognised as living in the estuary, mostly up as far as Alloa. These totals compare closely with Parnell (1837). Some of the discrepancy is due to taxonomic changes between the authors, but also it must be observed that Rintoul and Baxter base some of their records on Parnell so therefore it is difficult to use their records as an indication of the state of the estuary in 1935. Rintoul and Baxter also list 17 species of cetacean in the Forth, with 9 occurring in the estuary. The Lesser Rorqual Whale *(Balaenoptera acuto-rostrata)* and the Porpoise *(Phocaena phocaena)* seem to have been commonest. Most remarkable perhaps are the records of Beluga or White Whales *(Delphinapterus leucas)* stranded at Stirling in 1915 and again in 1932.

The state of the fishing in the Forth was again reviewed by the Third Statistical Account published in 1966. In the post-war period boom-nets for herring, sprats *(Clupea sprattus)*, eels *(Anguilla anguilla)* and flounders continued to operate, especially based at Kincardine. Most of the catch was for fish meal, although in 1961 an unsuccessful attempt was made to set up a whitebait (young herring) industry at Dunmore. By 1976 and 1977 only one boom-net boat was left at Kincardine. Dunmore continues as a centre for a sweep-net fishery for salmon, with most boats working the Alloa to Kincardine stretch. For many of the men this fishing is a casual occupation, but the high price of salmon appears to make the fishery worthwhile.

The Annual reports of the Forth River Purification Board provide a continuous record from 1959 onwards of the water quality of the Forth estuary. Their first survey in 1959 pointed out that the combination of crude sewage discharge plus industrial waste from textiles, brewing and distilling served to depress the oxygen concentration very severely, and at spring tides produced an impassable barrier to migratory fish. On average the position of the minimum dissolved oxygen concentration moved from about 4km above Alloa at high water, to about 4km below at low water. No improvement was recorded in 1961, and of 25 days devoted to tidal sampling, on 18 days the dissolved oxygen of some part of the estuary was found to be less than 50% of saturation, a figure which may be taken as critical for migratory fish. In several cases over 16 or more km of the estuary were below this level. In both 1962 and 1963 on 17 days out of 27 sampled, the dissolved oxygen level at some part of the estuary was below 50% of saturation. In 1964 a

spent-wash evaporation plant was commissioned at Cambus distillery which it was hoped would reduce the total polluting load to the upper estuary by half. However 1964, 1965 and 1966 saw little improvement in the water quality, which was attributed to a large amount of unstabilised organic matter in the mud, which when disturbed exerts an increased oxygen demand. A definite improvement was however noted in 1967, with the dissolved oxygen level being below 40% of saturation on 7 out of 25 surveys, and approximating to zero on 3 surveys. The 1969 report draws attention to the need for sewage purification plants for the Stirling area, as polluting matter from Stirling caused a marked dip in oxygen in the estuary. Conditions were much the same in 1970, but it was hoped that the commissioning of a recovery plant at Carsebridge distillery would reduce the future organic effluent load to the estuary. The 1971 report also looked to benefits from sewage treatment in the Stirling and Alloa areas. For the first time in 1973 it was reported that on no occasions did the dissolved oxygen level fall below 5% of saturation, however it must be commented that 8 out of 21 surveys did fall below 40% of saturation. By 1973 the improvement in water quality was manifest in an increased diversity of fauna and flora above Kincardine. In 1974, 1975 and 1976 only 3 out of 21 surveys each year showed oxygen levels below 40%. These lower oxygen conditions occurred at spring tides in June-August each year, when river flow might be lowest. At other times the water quality was generally above 80% dissolved oxygen, a notable improvement when compared to the situation before 1964 when the majority of surveys indicated less than 50% dissolved oxygen.

Apart from studying the oxygen content of the tidal waters, the Forth River Purification Board reports trace the planning and inception of Longannet Power Station, the heated effluent from which seems to have had little effect on water quality, and complaints of oil pollution in the estuary which have been generally attributed to shipping.

In parellel with the reductions in effluent discharge to the upper Forth estuary, there has been a steady increase in effluent discharge in the lower Forth estuary in the Grangemouth area. However Stout (1976) has calculated that due to the much greater volume of estuary water available for dilution there, these effluents should not produce a severe reduction in oxygen in the water, provided always that it is continuously and effectively dispersed in the water body.

ECOLOGY OF THE INTERTIDAL AREAS

The intertidal areas of the Forth comprise 22.6km^2, most of which is mudflat. Towards Queensferry patches of shingle or rock occur, but these are relatively small in area compared with Skinflats, Kinneil and Torry Bay mudflats which between them comprise 13km^2 (57% of total). Over the past few years a study has been made of the distribution and abundance of the intertidal fauna of the Forth estuary. Some of this work has been for research projects (Torry Bay – M. Elliott; Skinflats – J. Warnes, J. Leng and G. Moffat; Carriden – M. Teare), others under contract for the Nature Conservancy Council, and some by the author in conjunction with L. Brown. An attempt to summarise the results of these various studies has been made in Table 1. In this table each area has been listed, commencing at Rosyth, and moving westwards towards Stirling on the northern shore, then progressing eastwards to Port Edgar on the Southern Shore (Figure 1). For each area, the area in km^2 is given; this being the area between the tidal limits as indicated on the latest Ordnance Survey maps. The number of stations sampled is also shown. The sampling procedure generally involved a transect of the intertidal area along one or more lines from high to low water. At regular intervals (usually 100m) a 10 x 10 x 30cm deep sample and two 5 x 5 x 5cm deep samples were collected. These were sieved in the laboratory in a 1mm and a 0.25mm sieve respectively. The large sample material was examined for bivalve molluscs in particular, and the small sample material was examined for gastropods, amphipods and annelid worms. The results are expressed as mean number of each species per m^2 for each area, and for the entire intertidal area of the Forth estuary.

Molluscs

The baltic tellin *(Macoma balthica)* is the main bivalve inhabiting the intertidal areas. It is a deposit feeder, as well as a suspension feeder, and has been found most abundantly at Torry Bay and Skinflats each of which has almost 500m^{-2} and between them they have 65.1% of the total Forth population. Those at Skinflats are generally rather small, whilst those at Torry Bay grow larger. The *Macoma* in the Forth have a slow growth rate in comparison with other North European populations (McLusky and Allan, 1976), but no clear reason has yet been found for this situation. The common cockle, *(Cardium (Cerastoderma) edule)* is generally less abundant than *Macoma* in the Forth, and until 3 years ago was confined to the

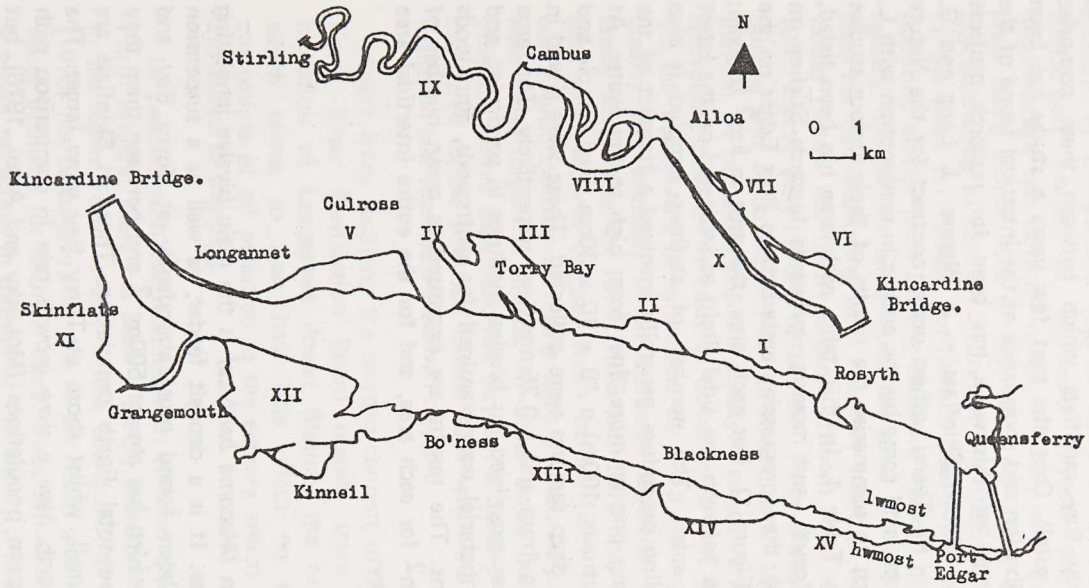

Figure 1 Map of the upper and lower Forth estuary, showing place names, and study areas (I — XV).

				MEAN N. M^{-2}									
	Area	km^2	N. stns.	*Macoma*	*Cardium*	*Hydrobia*	*Nereis*	*Nephthys*	Oligoch.	*Corophium*	Spionid	*Mya*	*Mytilus*
I	Charlestown-Rosyth	0.77	6	350	33	2733	16	8	0	633	2933	33	166
II	Ironmill Bay	0.86	4	175	0	1450	87	0	0	3150	6750	0	575
III	Torry Bay	3.50	14	480	62	15300	36	123	24000	480	1680	79	181
IV	Valleyfield	0.20	6	383	0	3100	966	66	8033	21866	16	33	175
V	Culross	1.73	28	207	3.5	400	75	114	4864	28	0	0	320
VI	Kennetpans	0.14	5	80	0	840	760	0	14240	5720	14240	20	0
VII	Black Devon	0.22	5	0	0	480	1000	0	11440	260	0	0	0
VIII	Alloa-Devon	1.03	13	0	0	0	30	0	7107	15	0	0	0
IX	Devon-Stirling	0.20	4	0	0	0	0	0	23274	0	0	0	0
X	Kincardine Br.—Airth	0.36	3	133	0	66	733	0	7066	533	0	0	0
XI	Skinflats	3.82	10	496	174	11080	307	33	10400	1200	1040	0	0
XII	Kinneil	5.62	88	55	176	7984	232	114	10806	70	631	5	3
XIII	Carriden	1.40	28	78	43	1282	141	N.R.	1050	44	N.R.	N.R.	N.R.
XIV	Blackness Bay	1.39	15	220	33	1373	120	200	0	300	2013	7	13
XV	Hopetoun	1.38	13	200	15	1846	138	107	0	0	1476	8	84
	TOTAL	22.6	242										
	Mean for Area	m^{-2}		242	89	6721	185	89	9512	700	1252	15	78
	TOTAL tonnes flesh dry wt.			17.4	10.6	54.9	10.4	4.0	21.5	7.9	3.1	1.3	14.3

Table 1. Intertidal fauna of the Forth estuary. Number of each species expressed as number m^{-2} for each study area, and for the entire estuarine area. Total weight of each species is also given.

areas to the east of Torry Bay and Carriden. However recently young cockles have appeared in significant numbers at Skinflats and Kinneil. The settlement of young cockles can be rather erratic, and there is some evidence to suggest that the salinity in the Skinflats/Kinneil area has been higher than in the past, and thus has permitted successful spatfall.

The bivalve *Mya arenaria* is widely, if sparsely, distributed in the lower Forth estuary. The common Mussel *(Mytilus edulis)* occurs in large beds in the lower Forth, notably Ironmill Bay, Torry Bay, Culross and Hopetoun. Locally it may be very abundant, but when expressed for the whole area the abundance is only $78m^{-2}$ compared to 242 and $89m^{-2}$ for *Macoma* and *Cardium.* However because of their larger size mussels contribute 9.3% of the total biomass, as compared to 11.4 and 6.9% for *Macoma* and *Cardium* respectively. Rocky intertidal areas support large numbers of the winkles *(Littorina littorea* and *L. saxatilis)* as far up as Kincardine Bridge.

The laver spire shell *(Hydrobia ulvae)* is a small gastropod snail which occurs in immense numbers throughout the intertidal Forth, with a mean for the entire area of $6721m^{-2}$ and peaks of population abundance at Torry Bay, Skinflats and Kinneil. On a flesh dry weight basis (i.e. excluding water and shells) there are 55 metric tonnes of *Hydrobia* in the complete area, which is 35.9% of the total intertidal biomass. *Hydrobia* is preyed upon by a small but significant population of *Retusa obtusata.*

Annelids

The common rag worm *(Nereis diversicolor)* is a common inhabitant of brackish waters, and in the Forth reaches its maximum abundance ($700 - 1000m^{-2}$) in the Kincardine Bridge – Alloa area. This is an area with salinity generally below 20%, and it is clear that *Nereis* is thriving here. Above Alloa the salinity is further reduced, and oxygen conditions deteriorate, and apparently *Nereis* does not live there. As conditions improve in the future it might be expected that *Nereis* will be found up at least to Cambus. Below Kincardine Bridge *Nereis* becomes less abundant and when present is usually associated with a local freshwater discharge. The catworm *Nephthys hombergii* is never found above Kincardine Bridge, and this study confirms that it is a more marine species than *Nereis.* The lugworm *(Arenicola marina)* is locally abundant, especially in Torry Bay.

Oligochaete worms (including *Tubifex, Limnodrilus* and *Peloscolex* spp.) are some of the least conspicuous inhabitants of mudflats, however numerically they are the most numerous animal in the Forth, with a mean abundance of $9512m^{-2}$, and peaks of over $24{,}000m^{-2}$. They are the dominant inhabitant of the upper Forth Estuary, where their wide salinity tolerance, coupled with their ability to withstand organic pollution, places them at an advantage. Below Kincardine Bridge, the distribution and abundance of oligochaetes is a valuable criterion for the community classification of mudflats as an indication of pollution (McLusky *et al* 1978). Oligochaetes are second only to *Hydrobia* in terms of total biomass, with 14% of the total for the intertidal Forth.

Others

The amphipod *Corophium volutator* is patchily distributed within the study area. Locally it can be very abundant, for example at Valleyfield or Kennetpans. Like *Nereis, Corophium* can successfully withstand low salinities, and occurs up the estuary as far as Alloa, and like *Nereis* should be able to live as far as Cambus, as water quality improves. The shore crab *(Carcinus maenas)* is found up as far as South Alloa. The small Spionid worms are widely distributed in the area, but do not appear to penetrate beyond Kennetpans. Nematode worms occur especially between Cambus and Kincardine.

Biomass

Utilising the data on number m^{-2}, the biomass may be calculated by use of appropriate conversion factors. In table 2 the mean flesh dry weight m^{-2} for each area is given. A maximum of $18.81gm^{-2}$ can be seen for the small area at Valleyfield, whilst the neighbouring Torry Bay has been calculated as $14.5gm^{-2}$. The importance of the three main mudflat areas can be readily seen, for although Skinflats, Kinneil and Torry Bay contribute only 57% of the total area, they contribute 75% of the total biomass, due to their large populations of *Hydrobia* and bivalves. Elsewhere values of $2 - 3gm^{-2}$ are common. The lowest biomass is recorded in the Alloa – Devon Mouth (Cambus) area, where it falls to $0.88\ gm^{-2}$. As has been commented on for *Nereis* and *Corophium* above this area has been adversely affected by organic pollution, and abatement of the effluent discharges should lead to an increase in biomass. The overall estimate

Area	g. flesh dry wt/m^{-2}	Total $gx10^6$ biomass
I	4.07	3.13
II	8.60	7.39
III	14.50	50.73
IV	18.81	3.76
V	2.92	5.05
VI	8.57	1.20
VII	6.22	1.37
VIII	0.88	0.91
IX	2.32	0.46
X	3.20	1.15
XI	8.39	32.04
XII	5.74	32.28
XIII	4.97	6.96
XIV	2.28	3.16
XV	2.63	3.63
TOTAL		$153.23 \times 10^6 g$ = 153.23 tonnes flesh dry wt.
Mean	$6.78m^{-2}$	
		data Jan. 76 except XII – Jan. 77
Aug 77:		
Mean	$8.64m^{-2}$	195 tonnes

TABLE 2

Mean biomass for each study area, expressed as g flesh dry wt m^{-2}, and total biomass at each area. The mean biomass for the entire Forth area, and the total for the entire area are also given.

for the winter biomass of the intertidal Forth estuary is 6.78g flesh dry wt. m^{-2}, which may be expressed as 153 tonnes for the total area of 22.6km^2. Estimates of the summer biomass suggest 8.64gm^{-2}, or 195 tonnes for the entire area.

CONCLUSION

The important bird populations of the Forth have not been dealt with in this review. For information on these the reader should consult Bryant and McLusky (1975-77). From the historical record, it would appear that until the end of the 18th century the Forth estuary was largely unaffected by man. In the first half of the 19th century, the estuary was adversely affected by the clearing of Blair Drummond and other Mosses. Although this ceased in 1865, the estuary failed to improve because, throughout the latter half of the 19th century and the first half of the 20th century, increasing effluent loads have been discharged to the estuary from enlarging centres of population, and industrial expansion such as whisky distilling in the Cambus area. By the 1950's the upper part of the estuary was suffering from marked deoxygenation of the water for lengthy periods. Improvements in the 60's and 70's have resulted in a marked increase in water quality, especially oxygen content. Measures which have been taken, especially in the Cambus area, should facilitate the passage of migratory fish such as salmon, however vigilance is still essential if other domestic and industrial discharges are not to undo the work which has been done.

The latter part of the 20th century is witnessing a major expansion of industry in the area between Kincardine and Bo'ness, especially petro-chemicals and electricity generation. Grangemouth docks have become the busiest in Scotland, and projected expansion in this area will make it even more important. For the ecologist too, the focus of attention has moved from the windings of the upper Forth, down to the mudflats of the lower Forth estuary, which support large numbers of invertebrates, and internationally important shore bird populations (Bryant and McLusky 1975, 76, 77).

Overall despite its history of utilisation by man for effluent disposal, the Forth estuary today continues to function as a highly productive ecosystem. The intertidal fauna, on which many species of birds such as waders and Shelduck, as well as fish such as flounders, depend has been found to be highly productive, especially in the Skinflats, Kinneil and Torry Bay areas. The biomass of food available

is however reduced in polluted areas, and the continuing availability of this food source for birds and fish alike depends on the installation and maintenance of appropriate effluent treatments from present and future industries in the Grangemouth area. Obliteration of the mudflats by reclamation schemes also represents a major threat to the wildlife of the Forth. It is already possible for industry, man and wildlife to co-exist in the Forth estuary, and provided always that care is taken in the design and control of effluent treatment and reclamation schemes it will be possible for them to co-exist in the future.

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BIRD-RINGING IN THE STIRLING AREA REPORT FOR 1977

Martin Davies

This report is the first of its kind specifically concerning bird-ringing in the Stirling area. It is hoped that it will serve to stimulate local interest and encourage people to look out for ringed birds and particularly to examine for rings any corpses of birds that they might find. The list of recoveries shown below serves to illustrate how rewarding this can sometimes be.

The report has been compiled from information supplied by four active qualified ringers working in the Stirling area during 1977:– D. M. Bryant, M. Davies, S. Mitchell and H. Robb. Table 1 shows the total numbers of birds ringed of each species during the year by these four ringers. (Totals are given for all species ringed except Pied Flycatcher, details of which have been withheld by the ringer for confidential reasons). Table 2 gives a list of all recoveries reported to date for 1977, and a selection of some of the more interesting recoveries from previous years.