Journal of Fish Biology (2006) **68,** 385–400
doi:10.1111/j.1095-8649.2005.00899.x, available online at http://www.blackwell-synergy.com

A field and experimental evaluation of the effect of data storage tags on the growth of cod

D. RIGHTON*†, O. S. KJESBU‡ AND J. METCALFE*

**The Centre for Environment, Fisheries and Aquaculture Science, Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, U.K. and ‡Institute of Marine Research, P. O. Box 1870, Nordnes, 5817 Bergen, Norway*

(Received 7 October 2004, Accepted 28 June 2005)

The effect of electronic data storage tags (DSTs) on the growth of cod *Gadus morhua* was evaluated in laboratory and field experiments. In the first laboratory experiment, large DSTs (60 × 18 mm, 3 g in water) attached externally for 3 months did not have any effect (ANOVA, $P > 0{\cdot}05$) on the growth of adult cod (mean ± S.D. 65 ± 4·5 cm total length) relative to untagged adult cod. In a second experiment, small DSTs (34 × 11 mm, 1·5 g in water) implanted into young cod (48·1 ± 4·4 cm) for an 8 month period did not have any effect upon the growth relative to untagged controls (ANOVA, $P > 0{\cdot}05$). Length data returned from tagging experiments conducted on adult cod (57·3 ± 7·5 cm) in the North Sea showed that the growth of fish tagged either externally or internally with large DSTs was not different (*t*-test, $P > 0{\cdot}05$). Attachment wounds, however, provided evidence that external attachment of DSTs should be avoided unless sensor configuration requires access to the external environment, and that internal implantation should be preferred whenever possible.

Key words: DST; electronic tags; growth; tagging.

INTRODUCTION

Tagging fishes with electronic tags is a method that has significantly advanced the understanding of fish behaviour in recent years (Arnold & Dewar, 2001). Electronic tags vary considerably in size and shape depending on the number and type of sensors, the number and type of batteries and the ingenuity of tag developers in packaging electronic components. Commonly, however, tags are made in streamlined cylindrical housings that are easy to manufacture. Although advances in tag technology have resulted in substantial reductions in tag size in recent years, such devices are still sufficiently large that attaching them may, in many cases, affect the behaviour and welfare of the fishes (Mellas & Haynes, 1985; Bégout Anras *et al.*, 2003).

Increasing awareness of the welfare and ethical issues of fish tagging has focussed attention on the effect of tags on fishes, and lead to a number of laboratory studies aimed at quantifying their effect and improving tagging

†Author to whom correspondence should be addressed. Tel.: +44 (0) 1502 524359; fax: +44 (0) 1502 526359; email: d.righton@cefas.co.uk

methods and advice (Bégout Anras *et al.*, 2003; Bridger & Booth, 2003). These studies have increased confidence in the utility of electronic tags, but there will always be a requirement to develop and test methods of tag attachment to ensure that they are as efficient and humane as possible (Bridger & Booth, 2003). The response of some fish species to tagging, especially large marine species that can be difficult to keep in captivity for extended periods, however, can be difficult to predict in advance. Evidence of the effect of electronic tags on such species relies on, often limited, information returned after the recapture of a limited number of fishes.

Although cod *Gadus morhua* L. have been tagged with acoustic or data storage tags (DSTs) for field studies of migratory behaviour (Pedersen & Andersen, 1985; Arnold & Greer-Walker, 1992; Godø & Michalsen, 2000; Righton & Metcalfe, 2002; V. Thorsteinsson, pers. comm.), no long-term evaluations of the effect on cod of external and internal attachment techniques have been undertaken. Experiments on cod were undertaken in which an assessment was made of the effect of tags on growth performance. Growth was measured as a proxy of the impact of the tag on the energy budget of the fish because tag attachment may increase drag and increase energy expenditure during swimming (Begout-Anras *et al.*, 2003) and reduce energy available for somatic growth. Length or mass data are easily collected with a minimum of handling stress during experiments, and are the variables most likely to be returned from tagged fish released in the field. In one laboratory experiment, the growth of adult cod (*c.* 65 cm total length, L_T) tagged externally with DSTs was compared with the growth of untagged cod over a 3 month period. In a second laboratory experiment, the growth and condition of young cod (*c.* 48 cm) tagged internally with DSTs were compared to the growth of untagged cod over a year-long period. Finally, a field experiment in the North Sea compared the growth (over periods of liberty between 30 and 500 days) of adult cod tagged either internally or externally with DSTs.

MATERIALS AND METHODS

TANK EXPERIMENTS

External tagging

In spring 1999, 35 cod were caught by rod and line within 20 miles of Lowestoft, transported to the CEFAS laboratory and placed indoors in an large annular holding tank. The tank was an extended annulus 1·2 m wide and 1 m deep, with an internal 'diameter' of 4·8 m and external 'diameter' of 7·2 m. The water in the tank was 0·83 m and refreshed constantly with fresh sea water. The sea water was continuously circulated in a clockwise direction at a speed of 0·35 m s^{-1}. Each day, the fish were fed *ad libitum* with sprat *Sprattus Sprattus* (L.). On 25 August, 14 cod were randomly assigned to each of two treatments: pit-tagged controls and external tagging with DSTs (Lotek LTD_1200, cylindrical 60 × 18 mm, 3 g in water, LOTEK Marine Technologies, St Johns, Newfoundland, Canada). The remaining cod were moved to another holding facility. Immediately before tagging, individuals were anaesthetized in a shallow (20 cm) bath containing 0·05% phenoxyethanol. Once loss of equilibrium had been achieved, fish were removed from the anaesthetic tank and placed into a 'V'-shaped channel (12 cm wide × 70 cm long × 10 cm deep) cut into a large block of (wetted) sponge and a wet towel placed over their head and operculae. A pit-tag was then inserted into the dorsal musculature and the fish weighed (g) and measured (L_T, cm). If an individual was assigned to the control group it was then

returned to the annular tank. If an individual had been assigned to the tagged group, it was then externally tagged with a DST on the opposite flank to the pit-tag. This was achieved by pushing a curved tagging needle through the muscles between the pterigiophores of the first dorsal fin and threading a piece of inert (but flexible) polyethylene plastic tubing (diameter 3 mm) through the hole created. A second plastic tube was inserted at a distance of *c*. 4 cm [Fig. 1(a)]. Double stranded monofilament line attached at the head of the DST was passed through the anterior plastic tubing and a standard Petersen disk on the opposite side, then fastened securely with metal crimps. This process was repeated with the rear attachment points on the DST and fish. A 4 mm thick neoprene disk was placed between the tag and each attachment point to cushion the tag against the skin of the fish. The fish was then returned to the annular tank. Overall, the external tagging procedure took *c*. 120 s. Tagging was conducted under U.K. Home Office Licence 80/1022, concerning the Animals (Scientific Procedures) Act. The L_T, mass (M) and condition $\left(K, K = 100ML_T^{-3}\right)$ of tagged individuals ($n = 8$) was greater than those in the control treatment ($n = 6$) at the start of

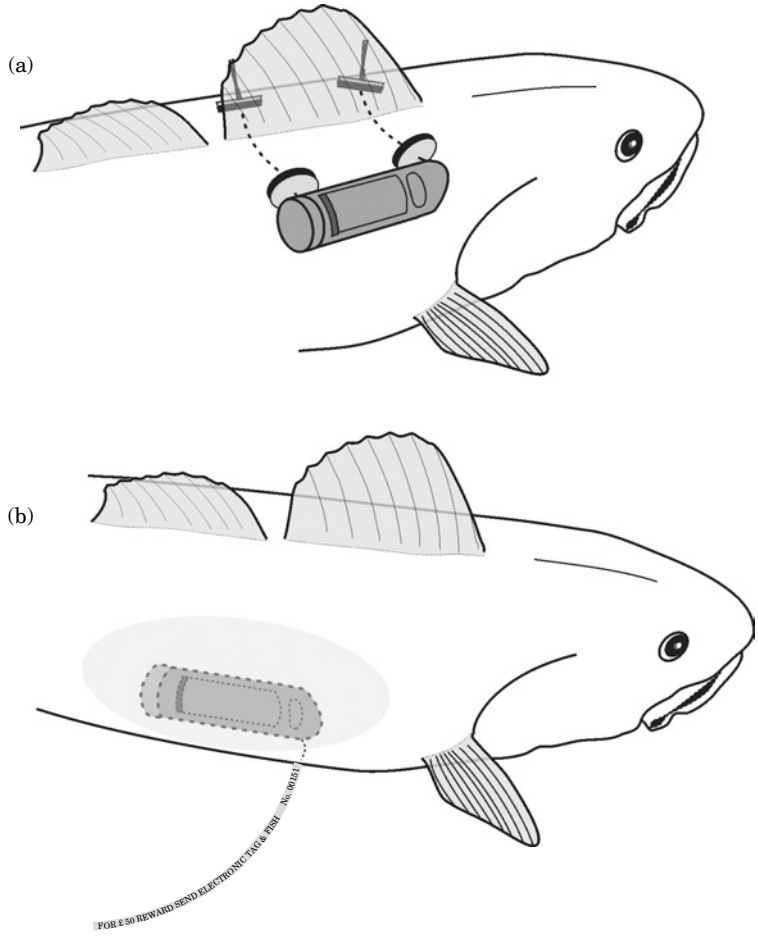

FIG. 1. Drawings showing the position and tag attachment methods used in the experiments: (a) externally attached Lotek 1200 tag (---, the path of the attachment cords through the dorsal musculature) and (b) internally implanted Lotek 1200 tag. The external 'spaghetti' tag was used to identify the presence of the internal tag to fishers.

the experiment (Table I), but not significantly so (*t*-test, d.f. = 12, $P > 0{\cdot}05$ for all variables).

After an initial post-tagging starvation period of 2 days, fish were fed *ad libitum* as before for the duration of the experiment. At the end of the experiment on 17 November 1999, all fish remaining were deeply anaesthetized, humanely killed, then measured and weighed.

Internal tagging

In May 2002, 424 1 year old cod originating from the Institute of Marine Research (Bergen) experimental facility at Parisvannet (Blom *et al*., 1991) were transplanted to two covered outdoor concrete tanks at IMR's laboratory in Bergen: 222 fish were placed into one tank, and 202 were placed into the other. The tanks were *c*. 30 m^3 in volume ($6 \times 3 \times 1{\cdot}65$ m) and were continuously supplied with 80 l min^{-1} fresh sea water from 120 m depth in the fjord. From the outset, fish were fed by hand using specially designed dry feed for cod (Dana Feed A/S: DAN-EX 1758, www.danafeed.dk) providing a moderate ration of between 0·25 and 0·40% feed per g fresh whole body mass per day (Kjesbu *et al*., 1991), depending upon appetite. Temperature of the holding tanks was measured once a week with an electronic thermometer (calibrated with an oceanographic thermometer) dipped into a 10 l bucket filled with water from just below the tank surface. The vertical temperature gradient in the tank was low ($\leq 0{\cdot}2^{\circ}$ C).

In June 2002 all fish in the holding tanks were pit-tagged, weighed (g) and measured (nearest 0·5 cm). For the next 6 months, all fish were weighed and measured at *c*. 8 week intervals as this was considered to properly reflect growth rate during the experimental period (Kjesbu *et al*., 1991; Karlsen *et al*., 1995). During all handling the fish were anaesthetized in benzocaine in oxygenated sea water (Kjesbu *et al*., 1991).

In January 2003, during the prespawning period, a total of 50 cod (36 females and 14 males) were chosen at random to be used in the tagging experiment. Of these, 27 female fish were put into a control group and the remaining individuals were tagged internally with a DST. Control and tagged fish were then randomly assigned to each holding tank: one tank contained 11 tagged and three control fish, and the other held 13 tagged fish and 24 control fish (due to the lack of a male control group in the experiment, L_T and mass measurements from sacrificed male fish were used as substitute, 'control males'). The mean L_T and mass of individuals in tagging and control treatments, regardless of sex or holding tank, was not significantly different (ANOVA, treatment: $F_{1,3}$, $P > 0{\cdot}05$; tank × animal: $F_{3,49}$, $P > 0{\cdot}05$) at

TABLE I. Results of the external tagging tank experiment. (a) Mean ± S.D. total length (L_T), mass (M) and condition (K) for individuals at the start and end of each treatment; and (b) the proportional increase in M and specific growth rate (G) at the end of the experiment

(a)

		n	L_T (cm)	*M* (g)	*K*
Control group	Start	6	63·5 ± 5·6	2586 ± 858	0·97 ± 0·19
	End	6	66·7 ± 4·1	2975 ± 753	0·99 ± 0·17
Tagged group	Start	8	66·1 ± 3·3	2624 ± 770	0·90 ± 0·21
	End	8	68·3 ± 3·5	3353 ± 661	1·04 ± 0·08
Treatment *P*			0·19	0·48	0·88

(b)

	n	*G*	Per cent increase
Control group	6	0·21 ± 0·27	1·22 ± 0·31
Tagged group	8	0·32 ± 0·29	1·34 ± 0·40
Treatment *P*		0·3	0·3

the time of tag implantation (Table II). It was consequently assumed that any effects of the operation *per se* would be reduced to a minimum during the main growth period in the following summer and autumn (Hansen *et al.*, 2001), and would be negligible in the context of monitoring growth over a full growth cycle between successive spawning seasons.

Immediately before tagging, individuals were placed in a shallow (20 cm) bath containing 0·5% benzocaine as anaesthetic. Once loss of equilibrium was observed, fish were placed into a V-shaped wooden tagging saddle lined with sponge and kept wet by a continous flow of fresh sea water. A small (1·5 cm) incision was made in the abdomen, just behind the ventral fins and the DST (Lotek LTD_1100, cylindrical 34 × 11 mm, 1·5 g in water) inserted. The wound was then closed with monofilament sutures (considered to be more robust in a tank situation than absorbable sutures) and sealed with glue (Histocryl; Andersen *et al.*, 2000). The sutures were removed after 1 month. It did not prove possible to tag two of the fish with DSTs in January; instead these were tagged at the next opportunity (mid-March) at the time of the next measurement. Overall, the internal tagging procedure took *c.* 180 s. Tagging was conducted under Norwegian licence: Laboratory Animal Science, FELASA category C researchers.

Over the following 12 months, all fish were weighed and measured at *c.* 8 week intervals. A total of 23 cod did not recover from anaesthesia (3816 procedures were undertaken) during the course of the experiment. Added to natural mortality (38 cod in total), and handling induced mortality, this reduced the stocking density in each tank over time. At the end of the experiment on 8 January 2004, all fish in both tanks were humanely killed and the masses of liver, viscera (excluding gills) and gonads (to the nearest 0·01 g) were taken, together with total mass and L_T.

FIELD EXPERIMENT

External tagging

Cod were caught by rod and line or on longline at several locations in the southern North Sea where the depth did not exceed 25 m. In all cases, fish were

TABLE II. Size [total length (L_T) and mass (M)] and condition (K) of cod in different internal tagging treatments at the time of tag implantation (day 226). (a) Results of ANOVA showing the probabilities associated with the F values computed in comparisons of starting values for L_T, M and K of fish in different treatments and tanks, and (b) values of mean ± S.D. for the different experimental treatments

(a)

	d.f.	L_T	M	K
Tank	1	0·72	0·42	0·01
Treatment	3	0·10	0·06	0·13
Tank × treatment	3	0·93	0·86	0·74
Error	49			
Total	56			

(b)

Treatment	n	L_T (cm)	M (g)	K
Control females	27	48·8 ± 3·9	1420·4 ± 318·4	1·215 ± 0·14
Control males	4	46·6 ± 4·6	1202·6 ± 298·2	1·175 ± 0·079
Tagged females	9	50·6 ± 4·2	1621·6 ± 273·6	1·26 ± 0·165
Tagged males	14	46·1 ± 4·5	1313·8 ± 362·7	1·31 ± 0·147

brought slowly to the surface to minimize the risk of rupture of the swimbladder. This would have been indicated at the water surface by postural problems or stomach eversion through the mouth (Arnold & Greer-Walker, 1992). Any such individuals were returned to the sea without tagging. As cod recently caught on lines are typically docile as a consequence of the fishing procedure it was judged to be less stressful to the fish to carry out the brief tagging procedure (*c.* 60–80 s) without anaesthetic (Thorsteinsson, 2002). Cod of $\geq$50 cm L_T (*i.e.* $\geq$age 2 years) and in good condition were considered suitable for tagging, and were immediately fitted with a Lotek 1200 DST as described earlier. Post-tagging, individuals were placed in a shallow tank (60 cm deep) for at least 15–30 min to detect any adverse effects of the tagging procedure before they were released back into the sea. Tagged fish that did not recover fully within this period were not released back into the sea. Otherwise, tagged fish were released in the immediate vicinity of their capture location within 2 h of capture. A total of 165 fish in the southern North Sea were tagged externally, with a mean L_T of 59·8 cm. Tagging was conducted under U.K. Home Office Licence 80/1022 and 80/1620, concerning the Animals (Scientific Procedures) Act. Return of the tags was made through the commercial fishery, with a financial incentive for returning the tags.

Internal tagging

Cod to be tagged internally were caught by lines in the southern North Sea and by trawling in the northern North Sea. Trawled cod were caught at depths >80 m using a BT 158 Jackson Rock-hopper trawl modified to include a PVC liner in the codend that retained *c.* 1 m^3 of sea water upon hauling. This modification prevented fish from being excessively pressured by the mass of the trawl mesh and other fishes during hauling, and resulted in healthy and lively specimens. As before, individuals were brought slowly to the surface to avoid damaging the swimbladder, and any fish unsuitable for tagging were returned to the sea. Internal tagging required anaesthesia to be used, so immediately before tagging, individuals were anaesthetised in a shallow (20 cm) bath containing 0·05% phenoxyethanol then placed into a 'V'-shaped channel (12 cm wide $\times$ 70 cm long $\times$ 10 cm deep) cut into a large (wetted) sponge and a wet towel placed over their head and operculae. Once loss of equilibrium had been achieved, a small (1·5 cm) incision was made in the abdomen, just behind the ventral fins and a DST (Lotek LTD_1200) pushed into the peritoneal cavity. A spaghetti tag attached to the DST [to alert fishers to the presence of an internal tag; Fig. 1(b)] was pushed through the lateral body wall using a curved needle. The incision was then stitched twice with coated vicryl absorbable sutures, and the wound smeared with antibiotics (Cicatrin). As for external tagging, fish were then placed into a recovery tank before release. In total, 209 fish in were tagged internally, under U.K. Home Office Licence 80/1620. The mean L_T of internally tagged fish was 56·2 cm, slightly but significantly lower (*t*-test, d.f. = 372, $P < 0{\cdot}001$) than the externally tagged fish.

ESTIMATING THE GROWTH OF WILD COD

To assess whether growth of cod tagged and released back to the wild differed from the growth of wild cod, use was made of market sampling data collected by CEFAS as part of the routine biological sampling programme. Measured L_T of 3 year-old cod

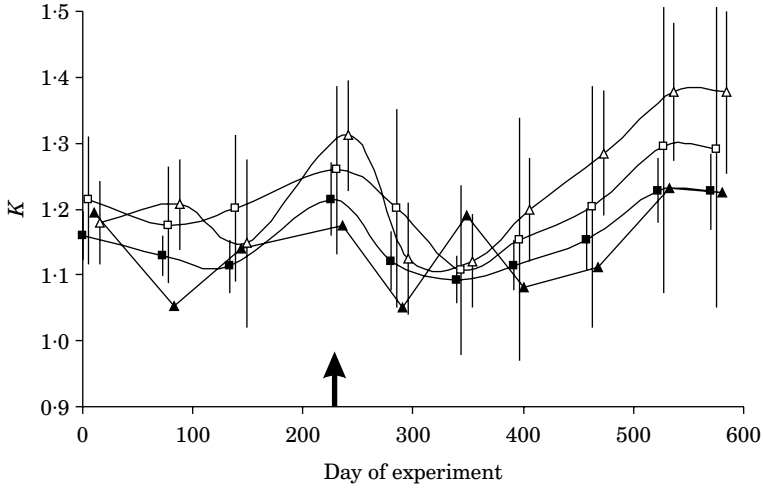

FIG. 2. Cod mean ± 95% CI condition in control (■, ▲) and tagged (□, △) groups. Measurements of control and tagged fish (■, □ females and ▲, △ males) were taken on the same day, but are offset for clarity. ↟, the time that DSTs were implanted. There were no significant differences between groups.

caught in the North Sea (ICES areas IVa-c) each month between 1999 and 2002 were retrieved from the biological sampling database ($n = 7510$). Mean L_T was then calculated for each month of the year and used to calculate an estimate of mean daily growth per month.

DATA ANALYSIS AND STATISTICS

Four measures of growth were used to compare L_T and mass changes between measurements and treatments: L_T, M, proportional increase in mass ($M_2 M_1^{-1}$, where M_2 is the mass at time t_2 and M_1 is the mass at the start of the experiment) and specific growth rate (G, $G = 100[(\ln(M_2) - \ln(M_1))(t_2 - t_1)^{-1}]$. In addition, K was calculated.

Statistical analysis was carried out using Statistica 7.0 (Statsoft Inc.). Measurements of L_T, M and K were compared using parametric ANOVA or t-tests after data had been tested for normality. Individual fish L_T or M were the test variables and the factors were: tank number (if applicable and which was never influential), fish sex and tagging treatment. Where significant differences were indicated, *post hoc* (Tukey's HSD) tests were conducted to determine the treatments that were significantly different. Measures of G and proportional growth rate were compared using Kruskal-Wallis ANOVA.

RESULTS

TANK EXPERIMENTS

Effect of external tagging

No mortality of cod was observed in either treatment in the 3 months of the experiment. All externally attached tags remained in place for the duration of the

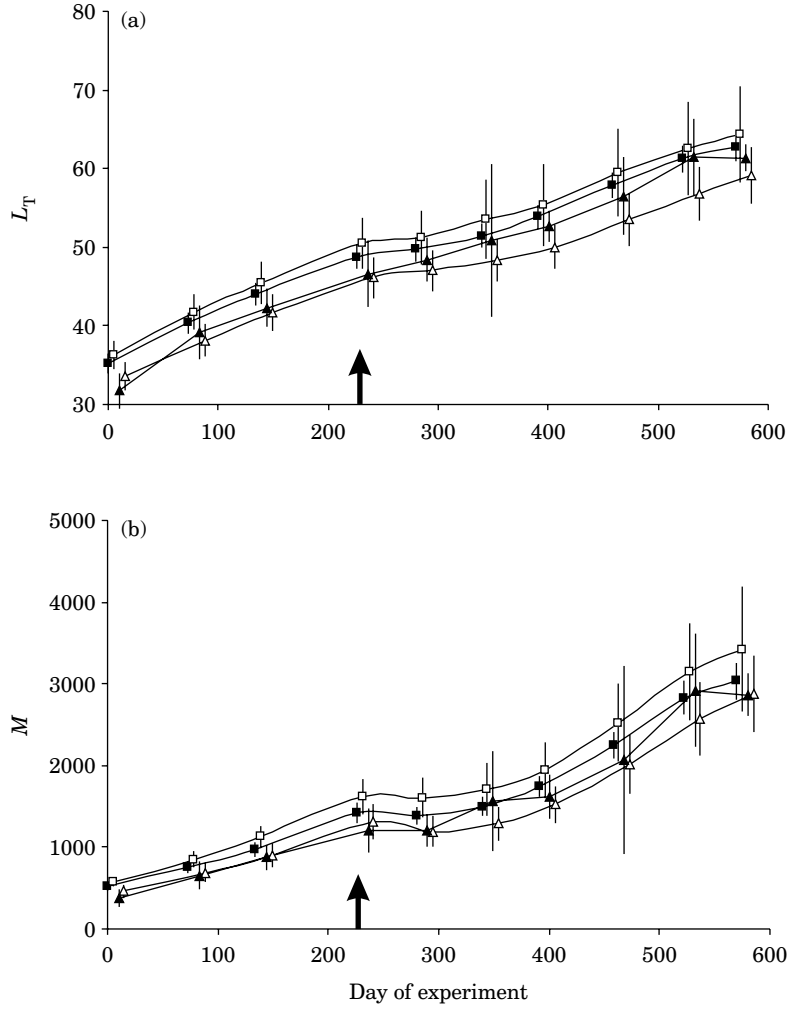

FIG. 3. Cod mean ± 95% CI (a) total length and (b) mass in control (■, ▲) and tagged (□, △) groups. Measurements of control and tagged fish (■, □ females and ▲, △ males) were taken on the same day, but are offset here for clarity. ↟, the time that DSTs were implanted. There were no significant differences between groups.

experiment. Minor friction wounds had developed at the electronic tag attachment sites by the end of the experiment, despite the addition of the neoprene disks to cushion the tag. Control fish grew by 3·16 cm and 390 g on average, compared to growth of 2·12 cm and 729 g of the tagged fish [Table I(a)]. The value of K also increased in both groups. The L_T, M and K were not significantly different between measurements, tagging treatment or the interaction between them (ANOVA, measurements: $F_{1,1}$, $P > 0{\cdot}05$; measurements × treatments: $F_{1,24}$ $P > 0{\cdot}05$). The proportional increase in M and the G did not differ significantly between tagged and control treatments [Kruskal Wallis ANOVA, $n = 14$, $P > 0{\cdot}05$; Table I(b)].

Effect of internal tagging

No mortality was observed among the tagged or untagged cod. As the operation was undertaken close to and during the spawning season subsequent swelling of gonads after the first month meant that extra sutures needed to be added to a few fish. In all other fish, wound healing was excellent and rapid: tagged fish could not be distinguished from untagged fish within 3 months of tag insertion. Two tags were shed during the course of the experiment, although this was only discovered when the holding tanks were drained. The value of K fluctuated throughout the course of the study, and was lower during the summer for both control and tagged fish (Fig. 2). K was high throughout winter, and peaked in late November 2003 at a mean value of 1·23 for the control fish, 1·30 for tagged females and at 1·37 for tagged males.

No significant difference in L_T or M was found between control and tagged groups of the same sex at the start, the time of tag implantation or the end of the experiment (ANOVA $F_{1,3}$ and $F_{3,46}$, $P > 0{\cdot}05$; Table II). In all cases, L_T [Fig. 3(a)] and M [Fig. 3(b)] increased significantly between the beginning and end of the experiment, and between tag implantation and the end of the experiment (ANOVA, $P < 0{\cdot}001$ for all treatments; Table III). No significant difference was found between treatments at the majority of measurements in between the start and end of the experiment (Table IV). Significant differences were found in M between tagged females and tagged males at day 280 and day 391, and between tagged females and control males at day 0 and day 280. These results were confirmed by ANCOVA, which demonstrated that females were longer and heavier than males overall (ANCOVA, measurement d.f. = 1, sex d.f. = 1, treatment d.f. = 1, sex × treatment d.f. = 1 number of animals d.f. = 57, $P < 0{\cdot}01$ in both cases). While K of tagged fish was, overall, higher than untagged fish ($P < 0{\cdot}01$), tagging had no significant effect upon L_T or M ($P > 0{\cdot}05$ in both cases).

Per cent increase in growth increased throughout the experiment [Fig. 4(a)] but G declined [Fig. 4(b)]. Both per cent increase in growth and G were significantly different at the end of the experiment than they were at the beginning, at the time of the tag implantation and the beginning of the experiment, and at the end of the experiment and tag implantation (Table III). At the end of the experiment, control females had a significantly lower G than the tagged fish (Kruskal Wallis test, $n = 45$, $P = 0{\cdot}01$), but there were no differences in G or proportional increase in growth at any other time (Table IV). The growth of control males could not be calculated because the L_T and M were measured from fish that were killed. Given that there were no significant differences in L_T or M between control males and tagged males, however, it is unlikely that any differences in growth between control males and any other treatment would have been significant.

Partitioning of resources

The mass of the viscera, liver and gonads of tagged fish at the end of the experiment were not significantly different from the masses of those of control fish of the same sex (ANOVA, $P > 0{\cdot}05$ in all cases; Table V). Females had significantly heavier viscera and livers than males (ANOVA, $F_{1,\ 75}$, $P < 0{\cdot}01$), and lighter gonads (although this was not significant; ANOVA, $F_{1,75}$, $P > 0{\cdot}05$).

TABLE III. Overall growth of cod used in the internal tagging tank experiment. Results of ANOVA and Kruskal-Wallis tests (probabilities associated with *F*-values) comparing individual total length, mass, condition, proportional increase in mass and specific growth rate between treatments at different times during the experiment. *n* refers to the sample size at the end of the later period and, because fish occasionally died between measurements, the value for d.f. is not always $2n - 1$

Overall	*n*	d.f.	L_T	*M*	*K*	Per cent increase	*G*
Control females							
Beginning to end	27	53	<0·001	<0·001	<0·05	<0·001	<0·001
Beginning to implantation	27	53	<0·001	<0·001	0·09	<0·001	<0·001
Implantation to end	27	53	<0·001	<0·001	0·77	<0·001	<0·001
Control males							
Beginning to end	30	29	<0·001	<0·001	0·55		
Beginning to implantation	11	10	<0·001	<0·001	0·83		
Implantation to end	33	32	<0·001	<0·001	0·2		
Tagged females							
Beginning to end	7	15	<0·001	<0·001	0·44	<0·001	<0·001
Beginning to implantation	9	17	<0·001	<0·001	0·52	<0·001	<0·001
Implantation to end	8	15	<0·001	<0·001	0·76	<0·001	<0·001
Tagged males							
Beginning to end	10	24	<0·001	<0·001	0·004	<0·001	<0·001
Beginning to implantation	14	27	<0·001	<0·001	0·011	<0·001	<0·001
Implantation to end	12	24	<0·001	<0·001	0·33	<0·001	<0·001

Control fish had heavier gonads than tagged fish (ANOVA, $F_{1,75}$, $P < 0{\cdot}01$), although this result may also have been influenced by an apparent effect of tank on liver and gonad masses. Liver and gonad masses were significantly lower in tank 2 (ANOVA, $F_{1,75}$, $P < 0{\cdot}01$ in both cases), where most tagged cod resided.

FIELD EXPERIMENT

Of 374 fish released, 108 had been returned by September 2004, a comparable return rate to conventionally tagged cod (G. Burt, pers. comm.). Of these, 61 fish had been tagged externally and 47 tagged internally. The condition of all recaptured fish was good, with no visible sign of wastage or disease. Externally tagged fish often had friction wounds at the site of tag attachment, and tissue at the wound site was occasionally necrotic and ulcered even in those fish recaptured a few weeks after release. The wounds of internally-tagged fish returned after only a few weeks at liberty showed progressively increased healing and after 1 month or more at liberty were fully healed with no evidence of tissue necrosis or infection. Tags were often covered in a film of tissue (Cote *et al.*, 1999). Dissection of internally tagged fish revealed that the gut epithelium occasionally adhered to the site of the wound.

Only 51 externally tagged fish and 41 internally tagged fish were returned with capture L_T information. These individuals had spent between 6 and 557 days at liberty. The 74 fish had grown between 0 and 22 cm betweeen release and recapture while 18 of the reported capture lengths indicated negative growth

TABLE IV. Growth of cod at different stages of the internal tagging tank experiment. Results of ANOVA and Kruskal-Wallis tests (values give probability associated with calculated values of F, *, a significant result), n gives sample size for control female (C F), control male (C M), tagged male (T M) and tagged female (T F) respectively, comparing total length, mass, condition, per cent increase in mass and specific growth rate (G) of individuals in different treatments at different times through the experiment. Per cent increase and G comparisons do not include the control male treatment. Comment refers to which treatment group differed significantly from another

	n	L_T	M	K	Per cent increase	G	Comment
Pre-implant							
Day 0	27,4,9,14	0·06	0·047*	0·57	n/a	n/a	C M < T F
Day 73	27,8,9,14	0·27	0·21	0·01*	0·51	0·32	C M < T
Day 134	27,9,9,14	0·13	0·13	0·59	0·34	0·42	
Day 226	27,7,9,14	0·1	0·06	0·13	0·38	0·12	
Post-implant							
Day 280	27,11,9,14	0·17	0·02*	0·12	0·12	0·92	T F > M
Day 339	27,6,7,14	0·7	0·25	0·88	0·26	0·7	
Day 391	27,16,7,14	0·06	0·04*	0·06	0·44	0·61	T F > T M
Day 458	27,4,7,12	0·06	0·15	0·05	0·58	0·15	
Day 522	27,9,7,12	0·07	0·24	0·06	0·58	0·05	
Day 570	27,26,7,11	0·13	0·11	0·02*	0·58	0·01	C F < T

between 1 and 9 cm (mean ± S.D. 2·6 ± 2·6 cm). Shrinkage of fish can occur after death or freezing, so negative growth was re-coded as zero for statistical analysis.

Externally tagged cod exhibited mean ± S.D. growth of 0·02 ± 0·04 cm day^{-1}, internally tagged cod of 0·02 ± 0·02 cm day^{-1}) and wild cod 0·03 ± 0·06 cm day^{-1}). The growth of tagged fish did not differ significantly between tagging treatments (t-test, d.f. = 91, $P > 0·05$).

DISCUSSION

Electronic tagging is a valuable technique that has considerably enhanced the understanding of fish behaviour in the last few years (Arnold & Dewar, 2001). Modern concerns about animal welfare, and the increasing preciousness of marine resources demand that tagging techniques are evaluated as fully as possible. The experiments described here have shown that, relative to untagged control groups, the growth of cod was not affected by attachment or implantation of DSTs in field or laboratory settings.

External tag attachment techniques are quicker and easier than internal implantation, and probably result in higher return rates than internal tagging (pers. obs.) because the tags are more obvious. External tagging did not appear to affect growth rate of cod, relative to untagged or internally tagged fish, in the field or laboratory experiments. The growth in length (0·02 cm day^{-1}) of externally tagged cod released to the wild was similar to laboratory-held externally tagged cod (*c.* 0·03 cm day^{-1}). While the condition of externally tagged fish returned through the commercial fishery was always good, the external

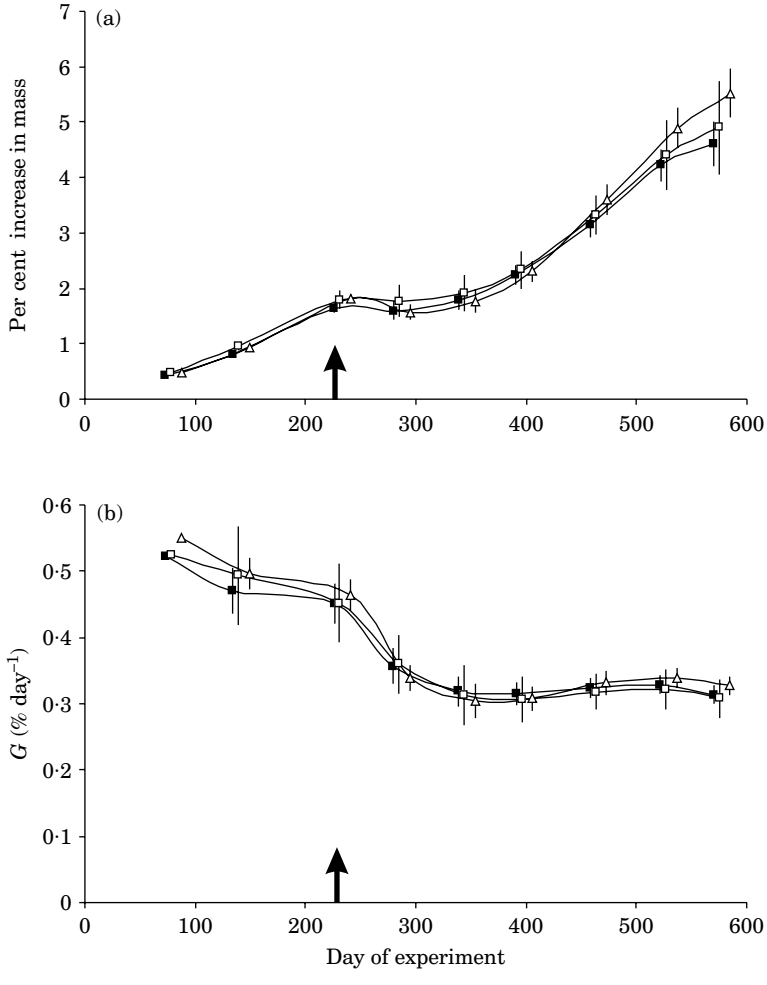

FIG. 4. Cod mean ± 95% CI (a) per cent increase in mass and (b) specific growth rate in control females (■) and tagged (□, △) groups. Measurements of control and tagged fish (■, □ females and △ males) were taken on the same day, but are offset for clarity. ↑, the time that DSTs were implanted. There were no significant differences between groups.

attachment of tags inevitably resulted in the development of wounds and tissue necrosis at the tag attachment sites, despite the measures taken to cushion the tags against the dorsal surface. Similar wounding has been reported elsewhere for salmonids (Roberts *et al.*, 1973), and is probably a combination of tag abrasion due to current induced drag (Arnold & Holford, 1978) and the effect of the fish's swimming movements. In addition, external tagging may have caused buoyancy problems (Lefrançois *et al.*, 2001). Combined, these factors may explain the slightly lower growth shown by externally tagged cod returned from the wild.

In contrast, internal implantation techniques were relatively lengthy and involved (Pedersen & Andersen, 1985; Thorsteinsson, 2002) but this initial

TABLE V. Comparison of viscera masses between treatments at the end of the internal tagging experiment. (a) Results of ANOVA tests (probabilities associated with *F*-values) (b) comparing the mass (g) of individual organs between tank and treatment and mean ± S.D. mass of viscera for each treatment

(a)

	d.f.	Viscera	Liver	Gonad
Tank number	1	0·98	0·00	0·00
Sex	1	0·00	0·05	0·11
Treatment	1	0·75	0·13	0·00
Tank number × sex	1	0·24	0·55	0·42
Tank number × treatment	1	0·89	0·14	0·37
Sex × treatment	1	0·75	0·33	0·42
Tank number × sex × treatment	1	0·78	0·98	0·27
Error	68			
Total	75			

(b)

	d.f.	Viscera (g)	Liver (g)	Gonad (g)
Control females	3,24	114·2 ± 27·9	266·3 ± 100·8	198·9 ± 111·1
Control males	10,16	87·3 ± 23·7	231·8 ± 80·7	295·4 ± 112·8
Tagged females	4,5	109·7 ± 39·7	251·6 ± 111·3	158·6 ± 102·2
Tagged males	6,8	82·9 ± 20·2	227·5 ± 85·7	232·0 ± 155·9

investment appeared to pay off in the long-term: internal implantation of tags did not appear to affect the growth or condition of cod, relative to untagged fish, in either the laboratory or field experiment. Internally tagged cod held in the laboratory exhibited similar growth to untagged cod and, in most cases, actually outgrew the untagged fish. In a similar experiment on juvenile (<40 cm) cod, Cote *et al.* (1999) reported growth of *c.* 0·03 cm day^{-1} for internal tagging. Comparison of the laboratory experiment with the field tagging experiment is compromised by the difference in mean fish L_T (48 *v.* 56 cm for laboratory and field experiments respectively). Further evidence that internal tagging had relatively little effect upon growth, however, was indicated by cod released back into the North Sea, which exhibited similar growth rates to wild cod caught in the same area (0·03 cm day^{-1}). These were comparable to the growth (8·2 cm year^{-1}) of shallow living (<100 m) Icelandic cod (Palsson & Thorsteinsson, 2003) tagged and released to the wild.

Two results of the experiments indicate that there may be potential for improvement in the implantation technique. First, internally implanted tags had a significant negative effect upon the mass of gonads. This may be because the tag took up the potential space for gonad growth. An alternative explanation is that, while the tag may not have had an impact upon somatic growth, the investment towards the growth of gonads may have been reduced or delayed by the presence of the tag. It is not possible to distinguish between these alternatives with the data collected, and further work is needed. Secondly, while the surgery wounds of cod returned through the commercial fishery were always in good

condition with fish having achieved good growth there might be slight concerns relating to the presence of the 'spaghetti tag' used to advertize the internal tag to fishers. This was likely to have held the internal DST in place close to the incision wound and also displaced the gut, causing occasional adherence of the gut epithelium to the tag and scar tissue at the incision wound site.

Overall, the experiments provide evidence that electronic tags can be implanted into cod in the expectation they will have little to no effect on somatic growth. Previous experimental studies of the effect of tagging on fishes report normal growth in the medium-term following internal tagging [rainbow trout *Oncorhynchus mykiss* (Walbaum), Mellas & Haynes, 1985; juvenile cod, Cote *et al*, 1999; European sea bass *Dicentrarchus labrax* (L.) and common sole *Solea solea* (L.), Bégout Anras *et al*., 2003]. This study broadens the range to include adult cod and, in addition, extends the period over which tagging has been evaluated to the long-term.

For ethical reasons, cost-effective field research and reliable statistical analysis, it is crucial that fishes survive the tagging procedure, and that the tag itself has as small an impact upon behaviour and well-being as possible. The present study suggests that although external markers are required to alert fishers to the presence of an internally implanted tag, the method of internal implantation appears to be a preferable tagging technique in most instances. While external tagging will provide good returns through the commercial fishery and is therefore an excellent data collection tool, the deleterious long-term effects of abrasion and chafing at attachment points makes it very much the second choice of attachment method. This will probably remain the case until the size of electronic tags is reduced considerably below the current state of the art, and subcutaneous tagging becomes a realistic possibility (J. Metcalfe, unpubl. data). Further experiments on the short-term stress of different components of internal tagging methods (*i.e*. handling *v*. tag implantation, Cote *et al*. 1999; Lower *et al*., 2005) will enable further refinements to be made to tagging techniques for cod.

We would like to express our gratitude to A. Buckley, the crew of RV Clupea and P. Wright for their help in catching, tagging and measuring fish in the U.K. M. Fon and V. Mangerud provided technical assistance in Bergen. P. Robinson helped enormously with the provision of U.K. market sampling data. N. Lower provided valuable comments on an earlier draft of the manuscript. The laboratory and experimental work was funded by the U.K. Department of Environment, Food and Rural Affairs under project codes MF0149 and MOU 'A', and by the EU under project codes QLRT-2001–00813 (CODYSSEY) and Q5RS-2002–01825 (RASER). We would like to thank the three anonymous referees for comments that helped us to improve the manuscript considerably.

References

Andersen, T. E., Witthames, P. R., Kjesbu, O. S., Bromley, P. & Tyler, C. R. (2000). Development of a surgery protocol for unilateral ovariectomy (ULO) on cod (*Gadus morhua*). In *Proceedings of the 6th International Symposium on the Reproductive Physiology of Fish* (Norberg, B., Kjesbu, O. S., Taranger, G. L., Andersson, E. & Stefansson, S., eds), pp. 304. Bergen: Department of Fisheries and Marine Biology, University of Bergen.

Arnold, G. P. & Dewar, H. (2001). Electronic tags in marine fisheries research: a 30-year perspective. In *Electronic Tagging and Tracking in Marine Fisheries* (Sibert, J. R. & Nielsen, J. L., eds), pp. 7–64. Dordrecht: Kluwer Academic Press.

Arnold, G. P. & Greer-Walker, M. (1992). Vertical movements of cod (*Gadus morhua* L.) in the open sea and the hydrostatic function of the swimbladder. *ICES Journal of Marine Science* **49,** 357–372.

Arnold, G. P. & Holford, B. H. (1978). The physical effects of an acoustic tag on the swimming performance of plaice and cod. *Journal du Conseil International pour l'Exploration de la Mer* **38,** 189–200.

Bégout Anras, M. L., Covés, D., Dutto, G., Laffargue, P. & Lagardère, F. (2003). Tagging juvenile seabass and sole with telemetry transmitters: medium-term effects on growth. *ICES Journal of Marine Science* **60,** 1328–1334.

Blom, G., Otterå, H., Svåsand, T., Kristiansen, T. S. & Serigstad, B. (1991). The relationship between feeding conditions and production of cod fry (*Gadus morhua* L.) in a semi-enclosed marine ecosystem in western Norway, illustrated by use of a consumption model. *ICES Marine Science Symposia* **192,** 176–189.

Bridger, C. J. & Booth, R. K. (2003). The effects of biotelemetry transmitter presence and attachment procedures on fish physiology and behavior. *Reviews in Fisheries Science* **11,** 13–34.

Cote, D., Scruton, D. A., Cole, L. and McKinley, R. S. (1999). Swimming performance and growth rates of juvenile Atlantic cod intraperitoneally implanted with dummy acoustic transmitters. *North American Journal of Fisheries Management* **19,** 1137–1141.

Godø, O. R. & Michalsen, K. (2000). Migratory behaviour of North-east Arctic cod, studied by use of data storage tags. *Fisheries Research* **48,** 127–140.

Hansen, T., Karlsen, Ø., Taranger, G. L., Hemre, G.-I., Holm, J. C. & Kjesbu, O. S. (2001). Growth, gonadal development and spawning time of Atlantic cod (*Gadus morhua*) reared under different photoperiods. *Aquaculture* **203,** 51–67.

Karlsen, Ø., Holm, J. C. & Kjesbu, O. S. (1995). Effects of periodic starvation on reproductive investment in first-time spawning Atlantic cod (*Gadus morhua* L.). *Aquaculture* **133,** 159–170.

Kjesbu, O. S., Klungsøyr, J., Kryvi, H., Witthames, P. R. & Greer-Walker, M. (1991). Fecundity, atresia, and egg size of captive Atlantic cod (*Gadus morhua*) in relation to proximate body composition. *Canadian Journal of Fisheries and Aquatic Sciences* **48,** 2333–2343.

Lefrançois, C., Odion, M. & Claireaux, G. (2001). An experimental and theoretical analysis of the effect of added weight on the energetics and hydrostatic function of the swimbladder of European sea bass (*Dicentrarchus labrax*). *Marine Biology* **139,** 13–17.

Lower, N., Moore, A., Scott, A. P., Ellis, T., James, J. D. & Russell, I. C. (2005). A non-invasive method to assess the impact of electronic tag insertion on stress levels in fish. *Journal of Fish Biology* **67,** 1202–1212.

Mellas, E. J. & Haynes, J. M. (1985). Swimming performance and behaviour of rainbow trout (*Salmo gairdneri*) and white perch (*Morone americana*): effects of attaching telemetry transmitters. *Canadian Journal of Fisheries and Aquatic Sciences* **42,** 488–493.

Palsson, O. K. & Thorsteinsson, V. (2003). Migration patterns, ambient temperature, and growth of Icelandic cod (*Gadus morhua*): evidence from storage tag data. *Canadian Journal of Fisheries and Aquatic Sciences* **60,** 1409–1423.

Pedersen, B. H. & Andersen, N. G. (1985). A surgical method for implanting transmitters with sensors into the body cavity of cod (*Gadus morhua* L.). *Dana* **5,** 55–62.

Righton, D. & Metcalfe, J. (2002). Multi-torsking: simultaneous measurements of cod behaviour show differences between North Sea and Irish Sea stocks. *Hydrobiologia* **483,** 193–200.

Roberts, R. J., McQueen, A., Shearer, W. M. & Young, H. (1973). The histopathology of salmon tagging. II. The chronic tagging lesion in returning adult fish. *Journal of Fish Biology* **5,** 615–619.

Electronic Reference

Thorsteinsson, V. (2002). Tagging methods for stock assessment and research in fisheries. *Report of Concerted Action FAIR CT.96.1394 (CATAG). Marine Research Institute Technical Report, No. 79. Reykjavik*. Available from: http://www.hafro.is/catag/