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Could the small size of sunbleak, *Leucaspius delineatus* (Pisces, Cyprinidae) be an ecological advantage in invading British waterbodies?

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A b s t r a c t . Since the introduction of sunbleak (*Leucaspius delineatus*) to southern England in 1986, its life history characteristics (such as reproductive behaviour, early sexual maturity and an unusually small adult size) have contributed to its rapid dispersal. This study examines the length-weight relationships and age of this non-indigenous cyprinid to highlight the potential threat to native 0+ cyprinids. Sunbleak populations demonstrated an unusual growth pattern for a cyprinid, with an average of 42 % of its maximum growth occurring in the first year, followed by extremely low annual growth until death. Very few significant differences were found between the mean length of several sunbleak age groups and the length of native 0+ bream *Abramis brama*, roach *Rutilus rutilus*, bleak *Alburnus alburnus* and rudd *Scardinius erythrophthalmus*. We have also found that young-of-the-year of these cyprinids share the same food and habitat with all sunbleak year class, which in some places has had a detrimental impact on the recruitment of native species.

Key words: bream *Abramis brama*, roach *Rutilus rutilus*, bleak *Alburnus alburnus*, rudd *Scardinius erythrophthalmus*, young-of-the-year, growth models, ageing, diet, invasive, ecological impact

Introduction

Sunbleak *Leucaspius delineatus* (Heckel, 1843) previously called the motherless minnow is of importance since it is a little known, invasive species that poses a potential ecological threat to many of the fish species native to Britain. The main feature of invasive species like the sunbleak is an ability to occupy an empty ecological niche within their new ecosystem (L é v ê q u e 2000a), or to compete successfully with the native species already occupying a particular niche (W i t t e et al. 1992). The reason they are able to compete successfully with native species could either be that the ecosystem is already fragile (pollution, reduction of habitat etc.) (C a r l t o n & G e l l e r 1993, M a l a k o f f 1999, L é v ê q u e 2000b) or that the new species competes during a particularly vulnerable aspect of native species life cycle (e.g. early life, reproduction, parasitism) (D a s z a k et al. 2000). Although sunbleak has been used as a biological model in experimental research (e.g. R a d a k o v & S i v e r t s e v 1972, S i e g m u n d & W o l f f 1972, D a r k o v 1975, G u l i d o v 1975, D o b l e r 1977, A n d ö r f e r 1980), very little is known about the sunbleak ecology, apart from its status in England (F a r r - C o x et al. 1996) as well as in Europe (L e l e k 1987) and some aspects of its reproductive biology (B i a ł o k o z et al. 1978, L e l e k 1987, C a s s o u & L e L o u a r n 1991).

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Sunbleak were deliberately introduced at Two Lakes Fisheries in southern England in 1986 with other fish species from Europe. Since, it has spread rapidly and is now present in large numbers in several locations in southern England (F a r r - C o x et al. 1996). This success could partly be the result of sunbleak life history characteristics, including reproductive behaviour (batch spawner, nest guarder), early sexual maturity and an unusually small adult size for a cyprinid, which may favour its further dispersal in the British Isles.

This study will examine length-weight and growth relationships in a population of sunbleak to identify potential overlaps in the use of habitat and food resources with native 0+ cyprinid species and to contribute to the knowledge of its life history.

We discuss the potential ecological impacts on the native coarse fish populations and attempt to predict the habitat characteristics of watercourses, which should favour the sunbleak's future dispersal in Britain.

Materials and Methods

More than 10 000 sunbleak were sampled on 23rd April 2001 from Stoneham Lakes, Hampshire (National Grid Reference SU436 173, Fig. 1) using a 10m long seine net (mesh diameter of 5 mm). The three lakes at Stoneham were so overcrowded with sunbleak chasing food on the surface that only one netting was required to obtain our fish collection. A sub-sample of approximately 3000 fish was brought back to the laboratory alive for further research and 596 fish were anaesthetised and killed on capture using 2-Phenyl Ethanol and preserved immediately in 4 % formalin.

Reading sunbleak scales proved to be particularly difficult due to their very small size (0.7 to 1 mm). Consequently, fish were aged using opercula, as their larger size facilitates annulus reading. At the laboratory, the fish fork length as well as wet weights were measured to the nearest mm and 0.01g (before removal of the opercula) respectively.

Ageing was determined according to the number of annuli on the opercula and back-calculations were carried out according to F r a s e r (1916) using radii of annual rings measured from the most anterior part of the operculum. Back-calculations were made individually and then averaged in order to study growth by year-class and to remove the inter-annual variations (i.e. average of annual back-calculated growth for different age groups). Mean fork lengths were then plotted according to F o r d (1933) and W a l f o r d (1946) and parameters in Bertalanffy's growth model (H o h e n d o r f 1966) were calculated in order to describe the asymptotic growth of sunbleak.

In order to compare the growth of sunbleak with the growth of native young-of-the-year cyprinid species which share overlapping habitat needs in British watercourses, we have used the fork length at the end of the first winter of 104 0+ bream *Abramis brama*, 95 0+ roach *Rutilus rutilus*, 82 0+ bleak *Alburnus alburnus* and 69 0+ rudd *Scardinius erythrophthalmus* (unpublished data from Centre for Ecology and Hydrology database). An analysis of variance (ANOVA) was performed on the individual back-calculated data to compare average lengths at age for the sunbleak, with average length at the end of the first year for the native cyprinid species.

The entire gut of 30 sunbleak was removed and the contents mounted on glass slides. Prey were identified to genus level only, due to the damage caused by pharyngeal teeth. Animal prey taxa were counted individually, but detrital material (mainly aufwuchs) was

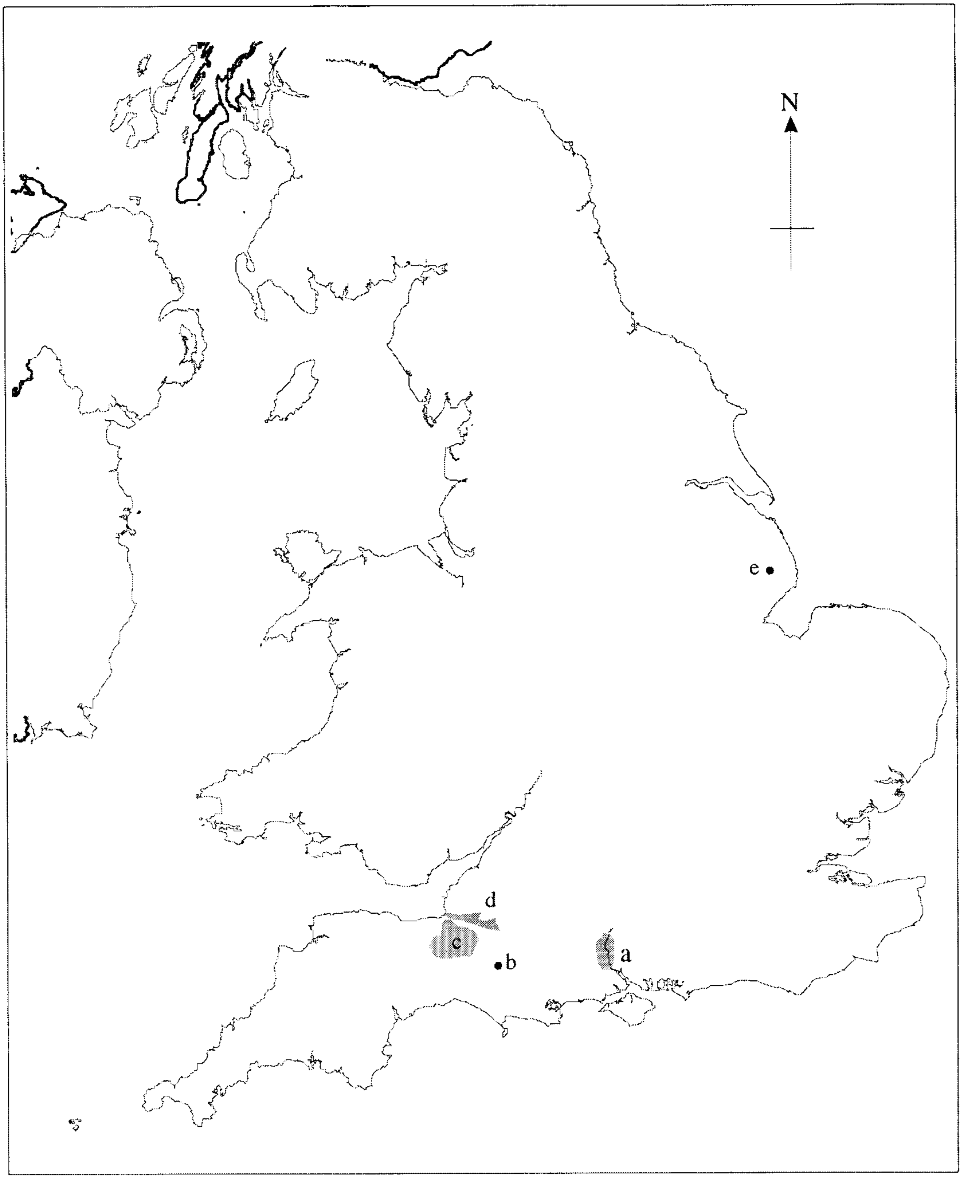

Fig. 1. Sunbleak distribution map, based on a CEH 2001 questionnaire, fisheries survey results and F a r r - C o x et al. (1996). a- R. Test, R. Itchen, Two lake Fishery, Broadlands lake, Stoneham Lakes. b- Revels Fisheries. c- Entire Bridgwater catchment including King's Sedgmoor. Drain, Bridgwater & Taunton Canal, R. Parrett, Wych Lodge Lake, Combe Lake. d- The Huntspill, South Drain, North Drain, R. Brue, R. Alham, R. Whitelake. e- Skegness, Lincolnshire.

assessed as a percentage of the gut fullness (see H y s l o p 1980). The relative importance of each animal prey taxon was indicated as a percentage of the total number of food items found in the guts. The Schoener Index was used as a diet overlap index (W a l l a c e 1981, W a l l a c e & R a m s a y 1982) between three different size classes of adult sunbleak (F_L<50mm; 50≤F_L≤55; F_L>55). It expresses the overlap between two compositional data sets as

$$\alpha=1-0,5(\sum_{i=1}^{n}(|p_{xi}-p_{xi}|)$$

where p_{xi} *(*p_{yi} respectively*)* is the proportion of food category *i* in the diet of size classes *x* (*y* respectively): the weakest values of α highlight little overlap.

Results

In Stoneham Lakes the majority of sunbleak (56%) ranged between 37 and 47 mm fork length following a plurimodal size distribution (Fig. 2). Sunbleak demonstrated an unusual

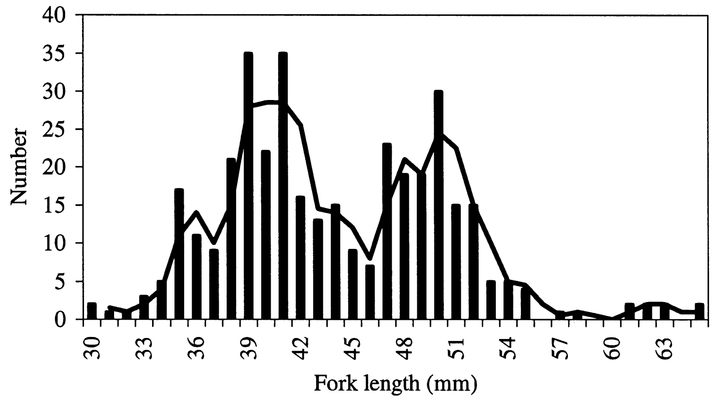

Fig. 2. Size distribution of sampled sunbleak populations (n = 368) from Stoneham Lakes (Hampshire). A moving average of period 2 has been calculated to highlight the various modes of the distribution (black line).

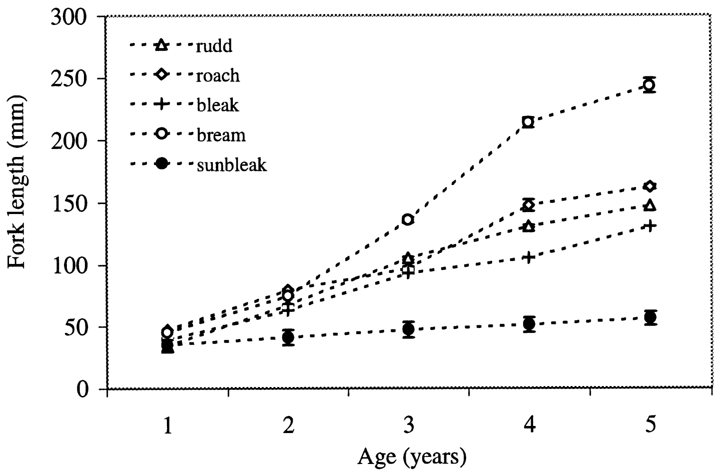

Fig. 3. Growth in fork length (mm) and standard deviation of sunbleak from Stoneham Lakes compared with UK of bream, roach, bleak and rudd.

growth pattern for a cyprinid, with very strong growth in the first year (average 42% of its maximum length) followed by extremely low annual growth thereafter (Fig. 3).

When compared with other cyprinid species (roach, rudd, bream, bleak) living in the same type of habitat, sunbleak growth was significantly lower from year 2 to year 5 (Fig. 3) and few significant differences in length between the four 0+ cyprinid species and different sunbleak age groups were observed (Table 1). Variations in annual growth are derived from individual back-calculated data to remove the 'years effects' (Table 1, Fig. 4).

After the first year, unlike the four other cyprinid species, the sunbleak growth rate was low and remained low until death. This is confirmed by the exponential weight-length relationship ($w = 0.0879e^{0.0576Fl}$, $R^2 = 0.95$). The Walford plot (Fig. 5) revealed that a slow growing population (higher theoretical maximum length, $L_\infty = 83$ mm) as well as a high k value ($k = 0.1536$, $t_0 = -0.404$) was characteristic of sunbleak. Comparison of back-calculated standard lengths in successive age groups of sunbleak by different methods

Table 1. Mean fork length (M_{FL}, in mm), standard error (SE), number of specimens (N) as well as range (Min-Max) of four one year old native cyprinids and of several sunbleak age groups (1 to 5 years old) is given. An analysis of variance (ANOVA, Scheffe F-Test) between mean fork length of the four native cyprinid and the different sunbleak age groups was performed (ns indicates variance was not significantly different).

Min-Max	N	SE	M_{FL}	Species	rudd	bleak	bream	roach
26-43	69	1.34	34	rudd	-			
29-52	82	3.51	39	bleak	ns	-		
31-64	104	3.08	45	bream	ns	ns	-	
33-60	95	2.49	47	roach	p<0.05	ns	ns	-
21-49	70	0.66	35	sunbleak 1	ns	ns	p<0.05	p<0.05
28-56	70	0.73	41	sunbleak 2	ns	ns	ns	ns
34-52	67	0.76	47	sunbleak 3	p<0.05	ns	ns	ns
38-61	57	0.78	51	sunbleak 4	p<0.05	p<0.05	ns	ns
44-65	20	1.23	56	sunbleak 5	p<0.05	p<0.05	ns	ns

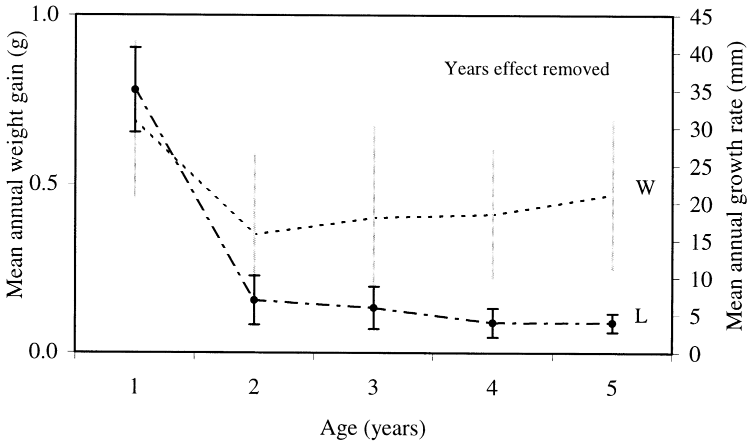

Fig. 4. Back-calculated mean annual length growth rate (L) as well as mean annual weight growth rate (W) for sunbleak.

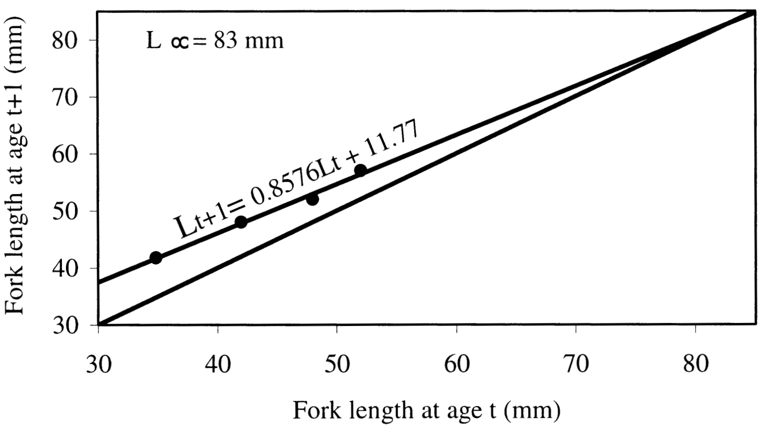

Fig. 5. Walford plots for sunbleak from Stoneham Lakes. Ultimate length l(∞) and the equation of Walford line are given.

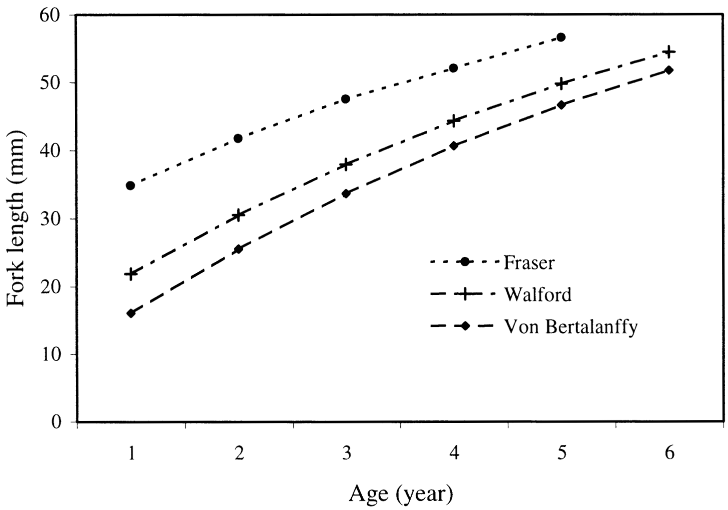

Fig. 6. Growth in fork length (mm) in successive age groups of sunbleak using different methods (Fraser, $R_t = 2.4506 + 1.7931\ Fl_t$; Walford, $Fl_{t+1} = 0.8576Fl_t + 11.77$ and Bertalanffy's model, $Fl_t = 83 * [1 - e^{-0.1536\,(t\,-\,0.404)}]$ where R_t is scale radius at age & Fl_t is fork length at age).

(Fraser, Walford, Von Bertalanffy) highlighted a strong underestimation of growth calculated with the last two models (Fig. 6).

The content of adult sunbleak guts highlight a large spectrum of prey types with a clear switch in the diet between April and May from chironomids (larvae and pupae) hydracarina and bryozoan toward zooplanktonic Cladocera (eg, *Bosmina* sp., Table 2). In May, different types of fish scales including those of sunbleak have also been found in large quantities in the guts of the three size-groups of sunbleak. The Shoenner Index highlights an increase in the diet overlap between the different size of adult sunbleak in May when compare to April (Fig. 7).

Table 2. Contents of the guts of three size-groups of sunbleak from Stoneham lakes caught during the spring 2001. Food items are expressed as percentage of the total number of items found in the guts and as percentage of gut fullness for the first four items (H y s l o p 1980).

Date		05/04/2001			29/05/2001		
Size of fish examined (mm)		<50	50-55	>55	<50	50-55	>55
Number of fish examined		n =8	n = 4	n = 3	n =5	n =6	n=4
Benthic diatoms		6.9	11.3	23.3	-	-	-
organic detritus		17.4	29.9	23.3	-	-	-
inorganic detritus		1.3	5.0	-	-	-	7.5
plant tissue		34.8	12.5	26.6	-	-	2.5
Rotifera		-	-	-	-	3.3	-
fish scales	-	-	-	9.8	8.5	28.4	
Bryozoan	Statoblast	1.6	20.6	-	0.1	-	-
Crustacean	*Bosmina*	0.0	0.7	-	88.7	80.5	61
	Daphnidae	3.2	-	13.4	1.4	7.7	0.2
	Copepoda	7.9	-	-	-	-	0.2
	Ostracoda	3.2	-	-	-	-	-
	Argulus	-	-	-	-	-	0.1
Oligochaeta	Naididae	1.6	-	-	-	-	-
Hydracarina	-	14.0	-	-	-	-	
Chironomidae	larvae	3.2	5.3	13.4	-	-	-
	pupae	6.3	0.7	-	-	-	-
	adult	1.6	-	-	-	-	-
Diptera	adult	11.0	-	-	-	-	-
Aphid		-	-	-	-	-	0.1

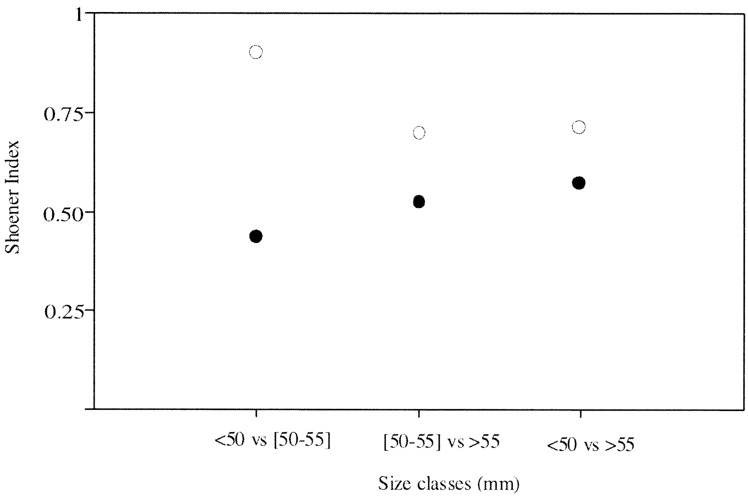

Fig. 7. Shoenner Index comparison between three classes of adult sunbleak size during April (black circle) and May (white circle).

Discussion

Sunbleak possess many important attributes to be an ideal invasive species. The short life span and early life reproduction aids the colonization process by increasing the turnover of the population (R o s e c c h i et al. 2001), the egg guarding behaviour of the males ensures high survival of eggs and the batch spawning tactic (Cassou & Le Louarn 1991) provides the larvae with a better survival rate, with regard to temporal environmental variations.

There is also a very important factor contributing to the rapid dispersal of sunbleak within a catchment, in that this species has the ability to spawn on any smooth objects such as branches, floating leaves, plastic debris, even the bottom of boats (Cassou & Le Louarn 1991, CEH unpublished data). This range of spawning substrate could aid dispersal of the eggs from upstream to downstream on floating objects but also on boats from downstream to upstream and even between different catchments via navigation canal connections.

Sunbleak has already proved to be very well adapted to different watercourses in southern England since its introduction in 1987 (Farr-Cox et al. 1996) and has since spread throughout the entire Bridgewater canal and River Brue catchment as well as mysteriously appearing in still waters such as Revels Fisheries (Dorset) and several unconnected lakes and ponds in the Somerset area. This unexplained dispersal highlights that sunbleak could spread even further if introduced to the neighbouring Bristol Avon catchment as this river provides access to the canal network of Britain.

The unusual growth pattern of sunbleak is of particular importance when compared with native species, as some differences in length between 0+ roach, bleak, bream and rudd and several sunbleak age groups are not significant. Early life in fishes has always been described as a period of high mortality (Balon 1990, Copp & Kováč 1996, Gozlan et al. 1998, 1999), but if food resources must be shared with juveniles and adults of sunbleak which are better adapted to competition (Masuda & Tsukamoto 1999), early life for these native cyprinids will be an even more vulnerable period (Gardner 1996, Bischoff & Freyhof 1999).

After the first year, sunbleak are already participating in reproduction, which could explain the reduction in length growth rate, which appeared during the second year, as it will be related to the redistribution of their energetic reserves to gonad production (Taborsky 1998, Essington et al. 2001). In terms of bioenergetics, resources allocated to one aspect of the life history will not be available for others (Partridge & Sibly 1991). According to the He & Stewart (2001) new predictive model based on von Bertalanffy coefficient (k, L_{∞}), age at first reproduction in sunbleak should be between two and three years old. This discrepancy in the prediction of age at first maturity in sunbleak corresponds to an underestimation of sunbleak growth observed when calculated from Von Bertalanffy or Walford models. This underestimation is mainly due to the individual variability in growth, which can strongly influence the accuracy of estimates of population parameters (Morita & Matsuishi 2001, Pilling et al. 2002). In the case of sunbleak estimates of growth, parameter variability among individuals is increased by the inevitable estimation errors of growth parameter for each individual associated with the sunbleak batch spawning strategy (see Pilling et al. 2002). Young-of-the-year sunbleak have an extended hatching period from early May until the end of June allowing great individual variability in growth at the end of the first year (Białokoz et al. 1978).

In the short term, spatial and temporal variations of food will increase in synergy with large populations of sunbleak, generating additional competition for food within native 0+ cyprinids in their feeding areas and accelerate following the development of several comparably sized sunbleak age groups. Although the life histories of roach, rudd, bream and bleak differ greatly from that of sunbleak, as juveniles they frequently share the same food spectrum (B i a ł o k o z et al. 1978, M a n n et al. 1997). The increase of dietary overlap in May could explain in part the reduced growth in older sunbleak year classes highlighting a possible recruitment bottleneck.

It is reasonable to speculate that, if sunbleak colonise new river catchments with suitable habitat (i.e. Great Ouse, Thames), it could potentially become locally dominant (i.e., as in the Bridgwater canal and River Brue catchments), with serious consequences for the native fish populations as other invasive species have demonstrated in Europe (i.e. topmouth gudgeon *Pseudorasbora parva*, nase *Chondrostoma nasus*) (R o s e c c h i et al. 2001).

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