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Models for length back-calculation in Caspian Kutum, *Rutilus kutum* (Pisces: Cyprinidae) from the Caspian Sea

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ABSTRACT

The Caspian Kutum, *Rutilus Kutum (*Kamensky 1901) specimens were sampled by purse seine in the northern Iranian coast of the Caspian Sea at four locations: Feridoonkenar Shahed, Mahmoudabad Khoram, Lariim Azadi fishing coop, and the Shiroud River in Ramsar city. "Back-calculation" is a retrospective method of estimating the characteristics of growth of fish in terms of length and rate of growth in the years preceding capture. Back-calculation of fish lengths at previous ages from scales or otoliths is a widely used approach to estimate both individual and population growth history. The back-calculated lengths of the Caspian kutum, *Rutilus kutum* (Kamensky 1901) were obtained using six different models, namely scale proportional hypothesis, body proportional hypothesis, Fraser Lee, nonlinear scale proportional hypothesis, nonlinear body proportional hypothesis, and the newest method, Morita Matsuishi model. The results showed that the preferred back-calculation models is Fraser Lee model for both males and females, while the nonlinear body proportional hypothesis is only for the females.

Key words: Northern Iran, Back-calculation; *Rutilus Kutum.*

INTRODUCTION

Back-calculation of lengths from scales is a widely used approach for estimating the growth history of individual fish and characterizing the growth of fish populations (Jearld 1983; Carlander 1987; Busacker *et al.* 1990). Back-calculation of lengths from scales relies on recognition of annual growth markings (annuli) on scales to calculate an estimated body length associated with each annulus. Body lengths estimated in this way make up a growth history technique (Francis 1990). Back-calculated lengths have been used for a variety of purposes. Often, the technique is simply a method of increasing the number of length-at-age data to be used in fitting some growth curves. For some species, back-calculation allows the estimation of lengths at ages that are rarely observed. Growth curves derived from back-calculated lengths have been used to compare growth rates between sexes, cohorts and populations of the same species, and to relate growth rates to various exogenous factors. Back-calculation has also been used to test the ageing of fish with annual, with an emphasis on the hypotheses that have been advanced to support the technique, and the extent to which these have been validated. Some problems that are of importance in the application of back-calculation are not relevant to these hypotheses, hence, they will not be considered here. In this category are physiological problems, e.g. resorption of scale tissue or occlusion of annual marks, which are sometimes a problem when fin spines are used, and ageing errors that cause back-calculated lengths to be associated with wrong ages. Another matter of great practical, but little theoretical, importance is the selection of hard parts of a given type, e.g. more precise results may be obtained in back-calculation from scales when the scales are chosen from a specific area of the body (the term 'key scales' is used) and measured in a particular way. Nor will enter into the debate on whether different back-calculation equations should be used for separating populations of a given species or an attempt is made to produce a single standard equation for the species (Francis 1990). Back-calculations can be used to trace the effects of winter oxygen levels (Casselman & Harvey 1975), fishing pressures (Nicholls 1958), and food consumption (Weatherly 1959) on growth rate. The number of circuli in the first ocean zone of Pacific salmon (*Oncorhynchus* spp.) scales is often used to identify racial differences (Martinson 2000).

"Back-calculation" is a retrospective method of estimating fish growth characteristics in terms of length and rate of growth in the years preceding capture. Back-calculation of fish lengths at previous ages from scales or otoliths is a widely used approach to estimate both individual and population growth history (Francis 1990). Identification of variations in growth seen in different populations provides tools for identifying environmental pressures or factors that challenge the populations of species under study. Back-calculation, in conjunction with other bio-environmental study tools, is a useful method for tracking environmental challenges encountered by fish populations.

Back-calculation of fish lengths has widely been used to increase the number of observations in length-at-age data or to estimate lengths at ages not included in the dataset. This procedure is based on the assumption that the growth of fish is proportional to the growth of its bony structures. A number of procedures are available for the length back-calculation (Horppila & Nyberg 1999). As a result of several possibilities at each step, back-calculation methodology has been diverse with no consistency achieved even within the same species (Horppila & Nyberg 1999). Many back-calculation formulae have been proposed (Francis 1990) and several studies evaluated which formulae are more accurate (Smedstad & Holm 1996; Horppila & Nyberg, 1999). Traditionally, back-calculation models were based on a proposal that fish grows in length as a linear relationship with the growth of fish otolith or scales (Bagenal & Tesch 1978). The relationship between a chosen structure and body length of fish may be described with various linear or non-linear equations (Francis 1990; Secor & Dean 1992). In the past decade, introduction of two variables into this seemingly linear relationship has added a certain complexity to these equations. These two factors are "growth effect" and "age effect" (Morita & Matsuishi 2001). The growth effect refers to the finding that otolith or scales in slow-growing fish are larger than those of fast-growing fish with the same size (Reznick *et al.* 1989) and that the age effect refers to the continuing increase in the otolith or scale size in the case when somatic growth has stopped (Mugiya 1990; Secor & Dean 1992).

MATERIALS AND METHODS

Rutilus kutum (Kamensky 1901) specimens were sampled by purse seine in the Iranian coast of the Caspian Sea at four locations: Feridoonkenar Shahed, Mahmoudabad Khoram, Lariim Azadi fishing coop, and the Shiroud River in Ramsar city (Fig. 1). The samples were taken on March 15, 16, 17, 25, and 26 in order to compare different models based on a single sampling attempt to verify the best adaptable model. On each occasion, 30 - 45 fish were randomly selected. Each fish was measured for total, standard, and fork lengths using a ruler with the precision of 0.1 cm. Fish weight was measured using a scale with the precision of 1.0 g. Some scales (n = 8 - 10) were taken from the upper side of the lateral line and also from the anterior base of posterior dorsal fin of each fish. Fish gender was determined based on the secondary sexual characteristics for each fish in spawning season. The scales (n = 3 - 4) from each fish were rinsed in water and kept in KOH solution for 1 to 2 min in the laboratory, then rinsed again in water and kept in glycerin.

The radii of scales were measured using a stereomicroscope monitor using Nikon’s Act-1 software. Each scale was magnified 24.6 times, the true size on the monitor. The scales were measured using the reference in the Atc-1 software, so that the length of the radii were determined in pixels and then converted into millimeters with a ratio of (228 pixels/1 mm). In the process of age determination based on the scales, identification of the first ring was relatively difficult due to the presence of false rings.

Therefore, in order to obtain a proper estimation of the first year ring on the scales, a number of (n = 30) two-month-old kutums (1.0 g) were selected from the Shahid Rajaee fish farm (Mazandaran, Iran) and the scales were analyzed for this purpose. Statistical analyses including regression analysis to achieve the formulas 12, 13, and 14, t-test, paired t-test, and One-Way ANOVA were employed, respectively, to compare mean scale radii between males and females, calculated lengths, and the measured and back-calculated lengths.

Back-calculation models used

The majority of back-calculation models assume that fish growth and otolith (or scale) growth are proportional. Several linear and nonlinear back-calculation models have been proposed. The most common back-calculation models are based on the following regression formulas (Morita & Matsuishi 2001):

1) O = a + bL
2) L = c + dO
3) O = uLv or lnO = lnu + vlnL
4) L = wOk or lnL = lnw + klnO

Where O is the radius of otolith or scale, L is fish body length, and a, b, c, d, u, v, w, and k are constants obtained from regression analyses. The most commonly used back-calculation models are as the following.

Scale proportional hypothesis [SPH (5)]

5) Lt = - ab-1+ (Lt + ab-1) Ot OT-1

Which assumes that deviation of the scale radius (or that of some other hard structures) of a fish from the average value for a given size of fish is relatively the same throughout the life of a fish (Whitney & Carlander 1956).

Body proportional hypothesis [BPH (6)]

6) Lt = [(C + dOt) (C + doT)-1] LT

Which hypothesizes that deviation of the length of a fish from the average for fish with the same size of a scale is relatively similar throughout the life of a fish (Whitney & Carlander 1956).

Fraser Lee model (7)

7) Lt = C + (LT – C) (Ot OT-1)

The linear equation of Fraser and Lee (reviewed by Fraser 1916; Lee 1920; Bagenal & Tesch 1978) is popular and widely used but has been criticized because it follows no clear hypothesis on the body scale relationship (Whitney & Carlander 1956; Francis 1990).

Nonlinear scale proportional hypothesis [nonlinear SPH (8)]

8) Lt = (Ot OT-1)1/v LT

Nonlinear body proportional hypothesis [nonlinear BPH (9)]

9) Lt = (Ot OT-1) k LT

In the above models, L is back-calculated fish body length at age t, L is fish body length at the time of capture T, O is otolith or scale length at annulus t, O is otolith or scale length at the time of capture T, a and b are constants as in eq. 1, c and d are constants as in eq. 2, v is a constant as in eq. 3, and k is a constant as in eq. 4.

As the growth of scale is a conservative process with scales increasing continuously during starvation or negative somatic growth (Secor & Dean 1992; Holmgren 1996; Barber & Jenkins

2001), it is assumed that the scale number increases with increasing in both fish body length and its age (Morita & Matsuishi 2001):

10) $O = \alpha+\beta L+ \gamma t$

Where O is scale's radius, L is fish body length, t is fish age, and α, β, and γ are constants obtained from multiple regression analyses. If it is assumed that the deviation of the radius of a fish scale from the average for both fish length and age is relatively similar throughout the life span of a fish (i.e., SPH), then:

11) $Lt = - \alpha\, \beta\text{-}1 + (LT + \alpha\, \beta\text{-}1 + \gamma\, \beta\text{-}1\, T)\, Ot\, OT\text{-}1 - \gamma\, \beta\text{-}1\, t$

Where L is the back-calculated fish body length at age t, L is the fish body length at the time of capture T, O is the scale radius at annulus (age) t, O is the scale radius at the time of capture T, and α, β, and γ are constants as in eq. 10 (Morita & Matsuishi 2001).The aim of this study was to employ the models above for the estimation of back-calculated total length based on scale radius in the Caspian kutum. The following formulas were used for the back-calculation of fish length (BCLT): Scale proportional hypothesis [SPH (5)], body proportional hypothesis [BPH (6)], Fraser Lee (7), nonlinear scale proportional hypothesis [Nonlinear SPH (8)], nonlinear body proportional hypothesis [Nonlinear BPH (9)], and Morita Matsuishi model (11).

The length back-calculations from the first to the third years of life in the captured four-year-old fish have been abbreviated as: BCLT. 1 age 4, BCLT. 2 age 4, and BCLT. 3 age 4, BCLT. This fish year class was selected because there were far greater numbers of the fish caught in this year class than other age classes.

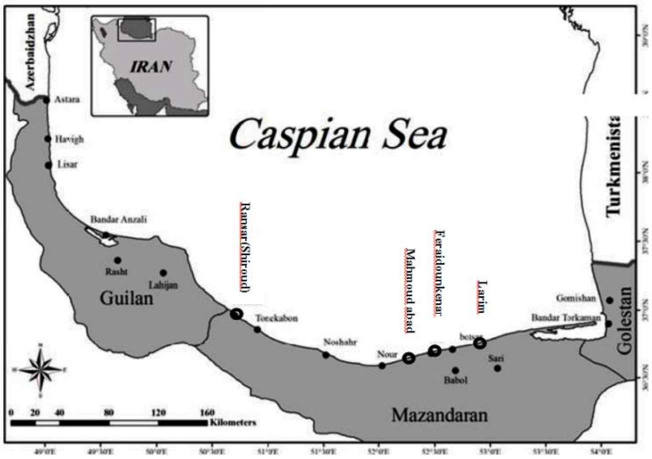


Fig. 1. Map of stations in northern Iran for sampling *R. kutum.*

RESULTS

The ages of 581 fish were determined. Weight, total length, and scale radii characteristics are shown in Table 1.

Irrespective of the gender, the correlation coefficient was significant for the relationship between the total length and scale radius ($p \leq 0.01$, $r = 0.61$).

To relate the fork and standard lengths, the following formula was used: The relationships between the total length and age are as in formulas for males and 13 for females:

13) $O = (-1.7) + 0.008\, LT + 0.266\, T$

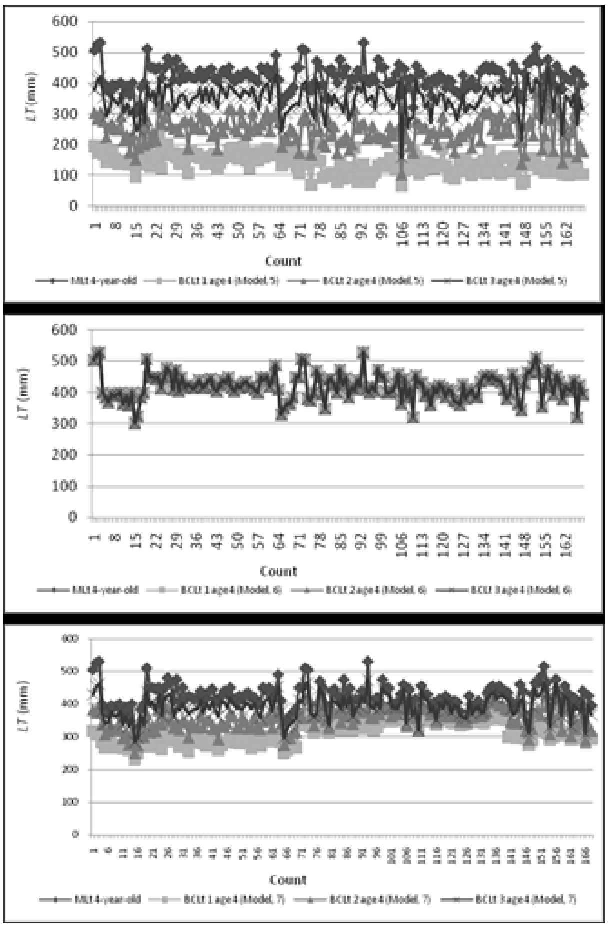
14) $O = (0.716) + 0.005\, LT + (-0.036)\, T$

The mean scale radii at all stages of growth were statistically larger in the females than in the males (t-test, $n = 579$; $p \leq 0.05$).

By using Fraser-Lee (7), no significant differences were obtained in three-year-old and four-year-old as well as nonlinear BPH (9), in four-year-old females only (One-Way ANOVA; females: $n = 112$, males: $n = 263$; $p \leq 0.05$) between the measured mean total length of the three-year-old fish and the back-calculated mean fish length in the third year of life among the captured four-year-old males and females. Back-calculations of the mean total length in the females at one year prior to capture using Fraser Lee and nonlinear BPH yielded different results (paired t test; females: n = 112, males: n = 263; p ≤ 0.05). The length estimates from the first through the third years of life in the captured four-year-old males and females are shown in Figs. 2 and 3, respectively.

Table 1. Weight, total length and scale radii characteristics for *R. kutum*.

Descriptive Statistics	N		Minimum		Maximum		Mean (mm)		Std. Deviation	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Total Length	348	233	303	300	535	590	419.4	460.9	44.3	58.1
Scale Total Radii (mm)	346	233	1.47	2.05	6.61	7.96	3.45	4.36	1.21	1.36
Mass (g)	302	156	220	200	2061	2000	701.6	1087.9	271.7	382.2



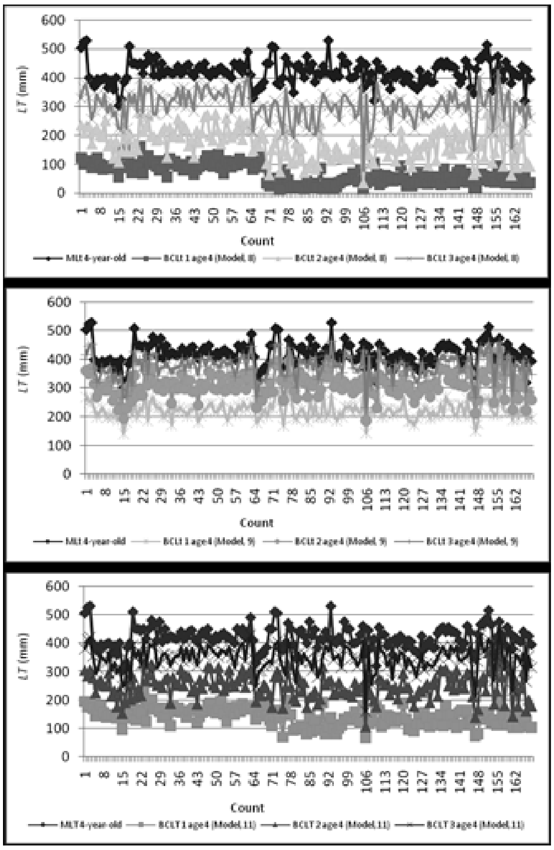
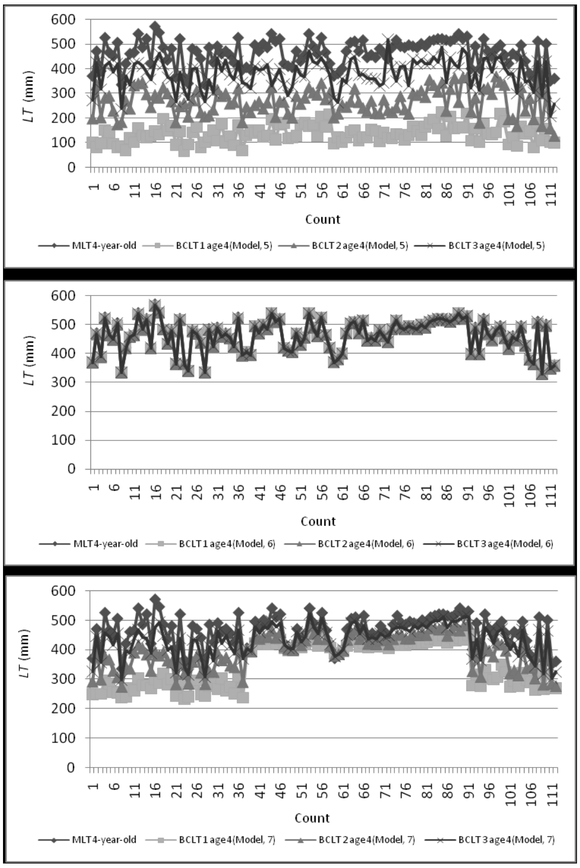


Fig. 2. Comparisons between measured (MLT) and back-calculated total lengths (BCLT; age: 1-3 year olds) using different models for the male *R. kutum*.



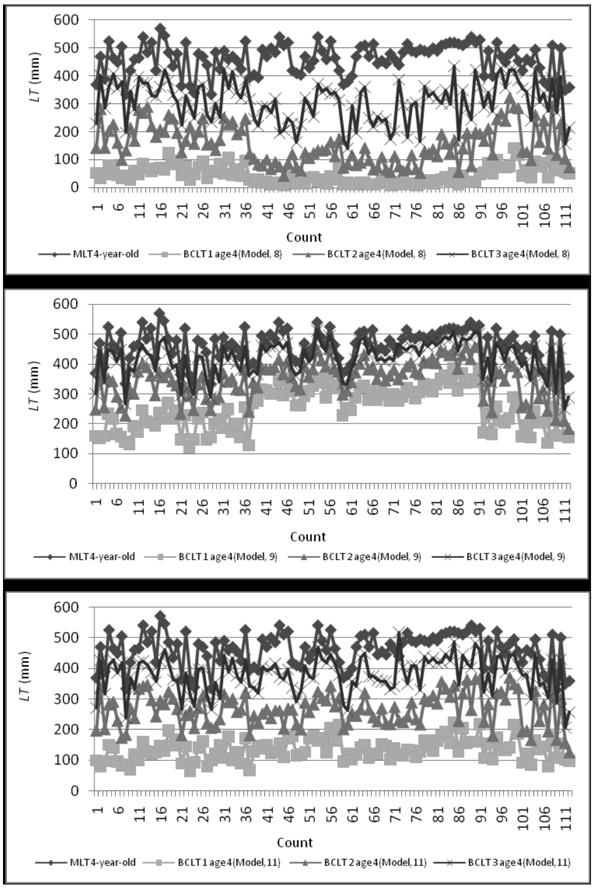


Fig. 3. Comparisons between measured (MLT) and back-calculated total lengths (BCLT; age: 1-3 year olds) using different models for the female *R. kutum*.

DISCUSSION

From the six models employed to achieve a model or models suitable for length back-calculation of Caspian kutum, only models 7 and 9 were found to be appropriate for the males and females, respectively. These two models, however, are applicable for the estimation of total length at the age of 3 for the 4-year-old fish, and not at the ages of 1 and 2. In addition, the averages of calculated total length obtained through models 7 and 9 showed that they were significantly different. Table 2 shows the mean total length of *R. kutum* from the first to forth years of life, in which the mean measured total length at the ages of 1 and 2 were studied by Razavi (1989). The present significant differences between Fraser Lee (7) and nonlinear BPH (9) models for the four year-old fish disagree with findings in silver carp, *Hypophthalmichthys molitrix* (Richardson 1845), in which the difference between estimates from Fraser Lee (7) and BPH (6) models at all ages were not significant (Johal *et al.,* 2001). Klumb *et al*. (1999) recommended that Fraser Lee model (7) to be used instead of Weisberg model because Fraser Lee back-calculated lengths for the small mouth bass, *Micropterus dolomieu* (Lacépède 1802) and walleye, *Stizostedion vitreum* (Mitchill 1818) had lower overall ranges of error, and also the use of Weisberg model for *S. vitreum* excessively overestimated lengths in one-year-old fish. Back-calculation models appropriate for various fish species may be species–specific. It is also possible, based on various bony structures used for length back-calculation of a species, that a variety of models are constructed. Moreover, suitable length back-calculation models are likely to be different at the initial and final ages of a fish species as well as between males and females.

Previous studies demonstrated that in e roach, *Rutilus rutilus* (L.) back-calculation using model six yielded valid results; models five and seven received relative acceptance with model seven being preferred over model five (Horppila & Nyberg 1999). Most recently, Li *et al*. (2010) have found that application of Dahl Lea method for the scales of *R. rutilus* (a close relative of *R. kutum*) provided the most unreliable estimates of fish lengths at previous ages, with the largest differences from the observed length (−26.0%). It was also significantly different from the other three models (regression, Fraser Lee, and BPH). They also reported that the differences among the back-calculated lengths using the regression, Fraser Lee (seven), and BPH (six) models and the observed lengths were small, namely, −6.7%, −7.0%, and −7.0%, respectively. Accordingly, Li *et al*. (2010) concluded that these three models were equally useful for the length back-calculations of *R. rutilus*. The use of Fraser-Lee (seven), biological intercept and Weisberg back-calculation models for the hybrid species *Lepomis macrochirus,* (Rafinesque, 1819) × *L. cyanellus,* (Rafinesque 1819) presented no significant difference between Fraser Lee (seven) and biological intercept models (Klumb *et al*. 2001). A comparison of SPH (five), BPH (six), [nonlinear SPH (eighth)], and [nonlinear BPH (nine)] back-calculation models in *Gadus morhua* (L.) showed that BPH (six) was more accurate than SPH (five), and that nonlinear back-calculation models seemed to provide the best results for otoliths of *G. morhua* (Smedstad & Holm 1996). In the present study, nonlinear BPH (nine) showed no difference between the back-calculated and measured length.

It is well-known that the bony structures used must be taken into account in the interpretation of results obtained from various back-calculations models.

Table 2. Comparisons between measured (MLT) and back-calculated total lengths (BCLT) for the 1- 4 year - olds *R. kutum*. Darkly shaded numbers indicate 3 and 4- year- old males in model 7 and the brightly shaded numbers represent the females in models 7 and 9.

			Back calculated total lengths (BCLT)											
Age	**Measured LT Mean (mm)**		**Model 5**		**Model 6**		**Model 7**		**Model 8**		**Model 9**		**Model 11**	
1	93		Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
2	190		148	142	392	413	334	331	68	62	233	235	150	142
3	Male	Female	346	390	411	441	393	423	336	348	383	414	364	390
	397	418												
4	419	462	410	448	426	468	418	458	400	436	407	455	410	448
5	443	479												

Nevertheless, the use of dorsal fin spines of *S. vitreum* for length back-calculation by Fraser Lee proportional method gave rise to lengths that closely approximated the back-calculated lengths obtained from the scales (Borkholder & Edwards 2001). In the European barbell, *Barbus sclateri* (Gunther 1868), the biological intercept method provided the most reliable estimates of fish lengths at previous ages when otoliths were used (Escot & Lorencio 1999). They noted that back-calculated lengths from earlier annuli of older fish were different from those observed at each age and also from back-calculated lengths from recent annuli. They also concluded that the accuracy of Dahl Lea back-calculation model was acceptable. Similarly, Heidarsson *et al*. (2006) reported that Dahl Lea model was less biased than Fraser Lee model for the back-calculation of smolt length in the wild Atlantic salmon, *Salmo salar* (L.). On the other hand, for the juvenile bluefish, *Pomatomus saltatrix* (L.) Dahl Lea equation estimations were not significantly different from the measured lengths, whereas the other three equations (Fraser Lee, BPH, and SPH) were significantly different (Roemer & Oliveira 2007). Back-calculation models are usually suggested by researches based on relationships between fish length and the radii of bony structures (formulas 1 - 4). It may be necessary to append other correction factors to these relationships in order to extend the models to different species, genders, and year classes. Addition of growth rate to the equation of fish length and the radii of bony structures (formulas 1 - 4) will probably result in the ability of back-calculation models in length assessment at different year classes.

From other point of view, growth of different fish species, in addition to an increase in fish length, is associated with elevated body height and diameter with variable ratios (fatness coefficient). Accordingly, fatness coefficient as a correction factor can also be added to formulas 1 - 4, likely leading to identical application of back-calculation models for a variety of fish species. Because fatness coefficient may also be different during a year for males and females, its inclusion as a correction factor (formulas 1 - 4) would result in the use of back-calculation models in males and females.

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مدل‌هایی برای پیشینه پردازی طول در ماهی سفید دریای خزر *Rutilus kutum*

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چکیده

ماهی سفید دریای خزر (*Rutilus kutum*, Kamensky 1901) توسط صید پره در شمال ایران در ساحل دریای خزر از چهار منطقه جمع‌آوری شد: تعاونی‌های صیادی شاهد فریدون‌کنار، خرم محمودآباد، آزادی لاریم و رودخانه شیرود در شهر رامسر. پیشینه پردازی (Back-calculation) یک روشی مبتنی بر گذشته برای برآورد ویژگی‌های رشد ماهی با استفاده از طول و نرخ رشد در سال‌های قبل از صید است. پیشینه پردازی طول ماهی در سنین قبل (از صید) با استفاده از فلس یا اتولیت برای تخمین تاریخچه رشد افراد و جمعیت رویکرد گسترده‌ای دارد. طول‌های پیشینه‌پردازی شده ماهی سفید دریای خزر با استفاده از شش مدل مختلف محاسبه شد که شامل فرضیه نسبی فلس، فرضیه نسبی بدن، فریزر لی، فرضیه نسبی فلس غیر خطی، فرضیه نسبی بدن غیر خطی و روش جدید موریتا ماتسوایشی است. نتایج نشان داد که مدل‌های پیشینه پردازی مناسب برای نرها و ماده‌ها مدل فریزر لی است در صورتی که مدل فرضیه نسبی بدن غیر خطی برای ماده‌ها فقط مناسب بود.

*مؤلف مسئول