Age, growth and natural mortality of coney (*Cephalopholis fulva*) from the southeastern United States

Michael L Burton, Jennifer C. Potts, Daniel R. Carr

Coney (Cephalopholis fulva) sampled from recreational and commercial vessels along the southeastern coast of the United States in 1998–2013 (n = 353) were aged by counting opaque bands on sectioned sagittal otoliths. Analysis of otolith edge type (opaque or translucent) revealed that annuli formed in January–June with a peak in April. Coney were aged up to 19 years, and the largest fish measured 430 mm in total length (TL). The weight-length relationship was $\ln(W) = 3.03 \times \ln(TL) - 18.05$ (n = 487; coefficient of determination [r^2]=0.91), where W = whole weight in kilograms and and TL = total length in millimeters. Mean observed sizes at ages 1, 3, 5, 10, and 19 years were 225, 273, 307, 338, and 400 mm TL, respectively. The von Bertalanffy growth equation for coney was $Lt = 377 (1 - e^{(-0.20 (t + 3.53))})$. Natural mortality ($M$) estimated by Hewitt and Hoenig's longevity-based method which integrates all ages was 0.22. Age-specific M values, estimated with the method of Charnov and others, were 0.40, 0.30, 0.26, 0.22, and 0.20 for ages 1, 3, 5, 10, and 19, respectively.

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3 **States**

5 **Michael L. Burton***

6 **Jennifer C. Potts**

7 **Daniel R. Carr**

10 Beaufort Laboratory

11 Southeast Fisheries Science Center

12 National Marine Fisheries Service, NOAA

13 101 Pivers Island Road

14 Beaufort, North Carolina 28516-9722

19 *Mr. Burton: michael.burton@noaa.gov   252-728-8756; fax: 252-728-8784

20   **Abstract**

21   Coney (*Cephalopholis fulva*) sampled from recreational and commercial vessels along the southeastern

22   coast of the United States in 1998–2013 ($n = 353$) were aged by counting opaque bands on sectioned

23   sagittal otoliths. Analysis of otolith edge type (opaque or translucent) revealed that annuli formed in

24   January–June with a peak in April. Coney were aged up to 19 years, and the largest fish measured 430

25   mm in total length (TL). The weight-length relationship was $\ln(W) = 3.03 \times \ln(TL) - 18.05$ ($n = 487$;

26   coefficient of determination [r^2]=0.91), where W = whole weight in kilograms and and TL = total

27   length in millimeters. Mean observed sizes at ages 1, 3, 5, 10, and 19 years were 225, 273, 307, 338,

28   and 400 mm TL, respectively. The von Bertalanffy growth equation for coney was $L_t = 377\,(1 - e^{(-0.20}$

29    $^{(t + 3.53))})$. Natural mortality (M) estimated by Hewitt and Hoenig's longevity-based method which

30   integrates all ages was 0.22. Age-specific M values, estimated with the method of Charnov and others,

31   were 0.40, 0.30, 0.26, 0.22, and 0.20 for ages 1, 3, 5, 10, and 19, respectively.

Introduction

The coney (*Cephalopholis fulva* Linnaeus 1758) is a small to medium-sized member of the grouper family (Serranidae) widely distributed throughout the tropical and subtropical waters of the western Atlantic from North Carolina and Bermuda through southern Brazil, including the Gulf of Mexico and Caribbean Sea (Heemstra & Randall, 1993). Coney inhabit shallow to moderately deep coral reefs (Nagelkerken, 1981) and associated rocky ledge habitats.

Coney are of minor importance to the commercial and recreational fishing sectors in southeastern United States (SEUS) Atlantic Ocean waters. Within the recreational sector, annual landings of coney are minimal compared to other serranids. Estimated landings of coney from headboats (vessels engaged in recreational fishing, usually carrying from 16-100 anglers) sampled by the Southeast Region Headboat Survey (SRHS), which is administered by the Beaufort Laboratory of the Southeast Fisheries Science Center (SEFSC), National Marine Fisheries Service (NMFS), averaged 205 fish totaling 114 kg annually from 1981-2012 for SEUS waters (K. Brennan, unpublished data). Estimated landings from private recreational boats and charter boats, the other component of the recreational sector, averaged 1473 fish annually during 1982–2011 in the SEUS. However, landings by this sector in Puerto Rico were substantially more important, averaging 32,768 fish annually from 2000-2012 (T. Sminkey, unpublished data). Commercial sampling programs in the SEUS accumulate small groupers such as coney in an unclassified grouper category, and thus commercial landings statistics of coney are unavailable (D.Gloeckner, SEFSC Miami, FL., pers. comm.). The majority of SEUS recreational landings of coney occur in Florida with the Carolinas contributing an average of only 58 fish annually from the headboat and private recreational sectors combined.

Coney are currently managed by the South Atlantic Fishery Management Council (SAFMC) through inclusion in a shallow water grouper category with a closed season from January - April and inclusion in a daily aggregate bag limit of three groupers per person for recreational fishermen (SAFMC, 2014).

57   Published studies on the aspects of life history of coney from the western Atlantic are limited. Potts

58   & Manooch (1999) reported on the age and growth of the species from headboat samples in SEUS

59   waters. Trott (2006) and Trott & Luckhurst (2007) examined aspects of the biology and population

60   status of the species in Bermuda waters. Araujo &Martins (2006, 2009) studied the age and growth

61   and population dynamics of coney from the central coast of Brazil.

62   We revisited coney from the SEUS because it is one of the 60 species managed by the SAFMC and

63   little new biological information on the species has been published in recent years. This study provides

64   information on life history parameters for coney collected from the commercial and recreational

65   fisheries of the SEUS and compares these new parameter estimates to previous life history studies.

66

67   **Materials and methods**

68   **Age determination**

69   Coney were sampled from fisheries landings along the SEUS coast (North Carolina through the

70   Florida Keys) from 1998 to 2013 by port agents employed by the SRHS, which samples headboats, and

71   the SEFSC Trip Interview Program (TIP), which samples commercial fisheries landings. Both surveys

72   operate using a random sample design methodology. All specimens used in this study were killed as

73   part of legal fishing operations and were already dead when sampled by the port agents, thus all

74   research was conducted in accordance with the Animal Welfare Act (AWA) and with the U.S.

75   Government Principles for the Utilization and Care of Vertebrate Animals Used in Testing, Research,

76   and Training (USGP) OSTP CFR May 20, 1985, Vol. 50, No. 97. The majority of specimens from

77   both fisheries were captured by conventional, vertical hook-and-line gear. Total length (TL) of

78   specimens was recorded in millimeters. Whole weight ($W,$ kg) was recorded for fish landed in the

79   headboat fishery. Whole weights were unavailable for fish landed commercially because they were

80   eviscerated at sea. Because of predetermined sampling protocols and time constraints imposed by their

81   workload, as well as the protogynous nature of coney and their small size, samplers were not required

82   to determine the sex of sampled coney due to uncertainty in macroscopic staging.

83   Sagittal otoliths were removed from 367 coney and stored dry in coin envelopes. Otoliths were

84   sectioned in the transverse dorso-ventral plane on a low-speed saw, following the methods of Potts &

85   Manooch (1995). The sections were mounted on microscope slides with thermal cement and covered

86   with mounting medium before analysis. The sections were viewed under a dissecting microscope at

87   12.5 × with transmitted light. Readings were taken from the dorsal lobe of the otolith. Initial ring

88   counts were made along the sulcal groove (vertically from the core) and then confirmed by following

89   the rings out to the lateral plane (horizontal from the core). Each sample was assigned a ring count

90   equal to the number of opaque zones. Two readers interpreted otolith sections. To ensure consistency

91   between readers in the interpretation of growth structures, each individual read all 367 slides, then we

92   calculated between-reader indices of average percent error (APE) following the methodology of

93   Campana (2001).

94   Edge analysis was used to validate the annual deposition of the opaque zone in coney otoliths. The

95   edge type of the otolith section was noted: 1=opaque zone forming on the edge of the otolith section;

96   2=narrow translucent zone on the edge, generally <30% of the width of the previous translucent zone;

97   3=moderate translucent zone on the edge, generally 30–60% of the width of the previous translucent

98   zone; 4=wide translucent zone on the edge, generally >60% of the width of the previous translucent

99   zone (Harris et al. 2007). Frequency of all edge types by month was then plotted to determine the

100   period of opaque zone deposition. Edge analysis is based on the assumption that there is a yearly

101   sinusoidal cycle in the plot of relative frequency of edge types over time (Campana 2001).   On the

102   basis of this frequency analysis of edge type, all samples were assigned a chronological, or calendar,

103   age obtained by increasing the opaque zone count by one if the fish was caught before that increment

104   was formed and had an edge with an translucent zone that was moderate to wide (type 3 or 4). All fish

105   caught after opaque zone formation would have had a chronological age equivalent to the opaque zone

106   count.

Growth

108   Von Bertalanffy (1938) growth parameters were estimated from the observed length-at-age data,

109   using the chronological age. Parameters were derived using PROC NLIN, a non-linear regression

110   procedure using least squares estimation and the Marquardt iterative algorithm option, in SAS

111   statistical software (vers. 9.3; SAS Institute, 1987). Appropriate statistical tests were employed to

112   examine differences in mean size and age by fishery sector (Student's *t*-test [$P<0.05$] for normally

113   distributed data; non-parametric Kolmogorov-Smirnov test [$P<0.05$] for skewed distributions).   We

114   also examined mean length-at-age data by sector (recreational versus commercial) to determine if

115   pooling of data was appropriate (i.e., there were no significant differences in length- at-age by sector).

Body–size relationships

117   We regressed fish whole weight (kg) on fish TL (mm) using data for all coney measured by the

118   SRHS from 1976 – 2014 (n=487). We evaluated a nonlinear fit, using PROC NLIN in SAS (SAS

119   Institute, 1987), and a linearized fit of the log-transformed data, examining the residuals to determine

120   which regression was appropriate.

121

Natural mortality

123   We estimated the instantaneous rate of natural mortality (*M*) using 2 methods.

124   (1) Hewitt & Hoenig's (2005) longevity mortality relationship:

125    $M \approx 4.22/t_{\max}$,

126   where $t_{\max}$ is the maximum age of the fish in the sample.

127   (2) Charnov, Gislason and Pope (2013) method, which uses the von Bertalanffy growth parameters:

128    $M = (L/L_\infty)^{-1.5} \times K$,

129   where L_∞ and K are the von Bertalanffy growth equation parameters (asymptotic length and growth

130   coefficient) and L is fish length at age. The Hewitt & Hoenig (2005) method uses life span or longevity

131   to generate a single point estimate, and it is an improvement to the original equation of Hoenig (1983).

132   The newer Charnov method, which incorporates growth parameters, is an improvement to the

133   empirical equation of Gislason et al. (2010) and is based on evidence that M decreases as a power

134   function of body size. The Charnov method generates age-specific rates of M and is currently in use in

135   Southeast Data Assessment and Review (SEDAR) stock assessments (E. Williams, pers. comm.).

136

137   **Results**

138   **Age determination**

139   A total of 367 sagittal otoliths of coney were sectioned. The distribution of samples by state and

140   fishery sector is shown in Table 1. The majority of samples (75%) came from the commercial sector in

141   the Carolinas. Only 9% of aging samples were from Florida, with the majority of those samples from

142   headboats. Opaque zones were counted on 353 (96.2%) of the 367 sectioned otoliths. Sections from

143   the other 14 otoliths (3.8%) were judged illegible and were excluded from this study.

144   For our analysis of increment periodicity, we assigned an edge type to all 353 samples. Opaque

145   zones on the otolith marginal edge occurred in samples collected from January to June (Fig. 1);

146   occurrence of opaque zones was highest from March to June with peak formation in April (Fig. 1). We

147   concluded that opaque zones on coney otoliths were annuli. Chronological ages resulting from edge

148   analysis were assigned as follows: for fish that were caught from January to June and had an edge type

149   of 3 or 4, the chronological age was the annuli count plus one; for fish that were caught during the

150   same period and had an edge type of 1 or 2 and for fish that were caught from July to December, the

151   chronological age was equivalent to the annuli count.

152   Growth increments of coney were moderately easy to interpret. Based on Campana's (2001)

153   acceptable value of APE (5%), agreement was good between the two readers (MLB–JCP APE=6.4%,

154   *n*=353). Percent agreement values between the two readers were moderate (49%) but increased for

155   estimates within (±) 1 year (87%) and (±) 2 years (92%). These results indicate acceptable between-

156   reader agreement.

157   **Growth**

158   Coney in this study (*n*=353) ranged from 217 to 430 mm TL and from age 1 to 19. There were only

159   11 (3%) fish older than age 12 (Table 2). Length and age distributions by sector are shown in Fig. 2.

160   Visual examination of these size and age frequency distributions identified apparent differences by

161   sector. Modal lengths were 325 mm TL for the commercial sector and 275 mm TL for the recreational

162   sector (Fig. 2A). Mean lengths by sector were significantly different: 325 mm TL (± standard error

163   [SE] 2.1) for the commercial sector versus 280 mm TL (SE 3.6) for the recreational fishery (Student's t

164   test: *t*=11.00; *P*=0.0001) (Fig. 2A).   The modal age frequencies were age-5 years and age-3 years for

165   the commercial and recreational sectors, respectively (Fig. 2B). Due to the visually skewed appearance

166   of age frequency distributions, we tested for normality using PROC UNIVARIATE (SAS, 1987) and

167   found age frequency data to be non-normally distributed (Wilcoxon signed rank test, P<0.0001). Mean

168   ages were significantly different between fisheries: 6.6 years (SE 0.17) versus 4.4 years (SE 0.32) for

169   commercial and recreational sectors, respectively (non-parametric Kolmogorov-Smirnov test; *D*=0.51,

170   *P*<0.0001). Visual examination of mean size-at-age of coney by fishery sector (Fig. 3) revealed no

171   significant difference in growth by sector for ages 2-11, as indicated by overlapping error bars.

172   Additionally, we performed an analysis of covariance (ANCOVA) of length-at-age by sector, using age

173   as the covariate, and found no significant differences in size at age between sectors for six out of nine

174   ages for which we had adequate sample size for comparison.   On the basis of these results, we pooled

175   data across sectors. The resulting von Bertalanffy growth equation was:

176        $L_t = 377(1 - e^{-0.20(t + 3.53)})$

177   for all fishery sectors combined (n=353) (Table 3 and Fig. 4).

178   **Body–size relationships**

179   Statistical analyses revealed a multiplicative error term (variance increasing with size) in the

180   residuals of the W–TL relationship, indicating that a direct nonlinear fit was not appropriate. We used a

181   linearized ln-transform fit of the data, resulting in the following regression to describe the relationship:

182    $\ln(W) = 3.03 \times \ln(TL) - 11.15$ (n = 487, r^2 = 0.91)

183   where r^2 is the coefficient of determination. This equation was transformed back to the form

184        $W = a \times TL^b$

185   after adjustment of the intercept for log-transformation bias with the addition of one-half of the mean

186   square error (MSE) (Beauchamp & Olson 1973), resulting in this relationship:

187        $W = 1.457 \times 10^{-8} \, TL^{3.03}$ (n=487; MSE=0.022) (Fig. 5).

188

189   **Natural mortality**

190   The method of Hewitt & Hoenig (2005), which uses maximum age or life span (age-19 years in this

191   study), estimated that M was 0.22. The method of Charnov, Gislason and Pope (2013), which produces

192   age-specific estimates of M using von Bertalanffy growth parameters, estimated M of 0.49 for age-1,

193   0.28 for age-5, 0.22 for age-10, and 0.20 for age-19 (Table 2).

194

195   **Discussion**

196   Coney were relatively easy to age and we found consistent agreement between readers with low

197   APE values. Because our study included samples from the commercial and recreational sectors of the

198   SEUS fishery, we believe that the results are likely to be more robust and representative of the SEUS

199   coney population than those presented by Potts & Manooch (1999), due to our larger sample size and

200   wider fishery sector coverage. The results of this study represent the best contemporary information on

201   the longevity, growth and natural mortality of coney from SEUS waters.

202   The otolith edge analysis that we conducted strongly indicated that coney deposit one annulus per

203   year from January to June with peak annulus formation in April. This result compares favorably to

204   findings in other studies showing that peak annulus formation occurred in March in coney caught by

205   the headboat fishery of the SEUS (Potts & Manooch, 1999) and in April through June for fish from the

206   central coast of Brazil (Aruajo & Martins, 2006) (Table 3).

207   Body–size relationships were nearly identical for coney from this study (W = 1.46 $\times$ 10^{-8} TL$^{3.03}$), the

208   previous SEUS study by Potts & Manooch (1999) (W = 2.59 $\times$ 10^{-8} TL$^{2.94)}$, and the study by Araujo &

209   Martins (2006) from Brazil (W = 2.0 $\times$ 10^{-8} TL$^{2.97}$).

210   The growth rate for coney was relatively slow compared to other groupers, with coney attaining an

211   average observed size of 294 mm TL by age 4 (Table 2). Similarly, Potts & Manooch (1999) observed

212   a mean size of 278 mm TL by age 4. Growth of fish in our study slowed after age 4; coney reached

213   342 mm TL by age 8, then averaged annually only increments of 5 mm through age 19.

214   Our theoretical growth curve fit the observed data well (Fig. 4). Growth parameters estimated in our

215   study compare most closely with the previous SEUS study (Potts & Manooch 1999; Fig. 6) for fish age

216   6 and older. The lack of small coney in our samples [smallest fish was 218 mm TL versus 150 mm TL

217   in Potts and Manooch (1999)] explains differences in the early years of growth among studies (Fig. 6).

218   Greater numbers of smaller fish no doubt help define the growth curve for the younger ages. Also,

219   Potts & Manooch (1999) used back-calculated lengths to model growth; this approach allowed the

220   model to more adequately capture initial growth of coney. Though the size range of the coney in our

221   study overlapped with the mean lengths at age of those samples available in the Potts & Manooch

222   (1999) study, the fish in our sample were larger at age for ages 2 – 5. The theoretical maximum length

223   of coney in our study (L_∞=377 mm TL) was similar to that reported by Potts & Manooch (1999; 372

224   mm TL) but much larger than the L_∞ estimated for Bermuda (Trott, 2006, 281 mm TL) and Brazil

225   (Araujo & Martins, 2006, 316 mm TL). On the other hand, the studies from Bermuda (Trott, 2006,

226   maximum age 27) and Brazil (Araujo & Martins, 2006, maximum age 25) included fish that were

227   much older than our eldest fish (age 19). Perhaps fishing pressure in the SEUS is greater than in these

228   other areas, contributing to a truncated age structure in the SEUS. The lack of older fish in the previous

229   SEUS study (Potts & Manooch, 1999) is likely attributable to the lack of any commercially landed

230   samples in the study.

231   Natural mortality of wild populations of fishes is difficult to measure. A single estimate of M for the

232   entire life span of a fish is unreasonable, except for fish that have attained a size that renders them

233   invulnerable to high predation rates. The Hewitt & Hoenig (2005) estimate of M is based on the

234   maximum age attainable in an unfished population. In this sense, the point estimate of M, derived using

235   the method of Hewitt & Hoenig (2005), can serve as a lower boundary on the estimate of M derived for

236   older ages by an age-varying method. The maximum observed age for coney in our study was age 19,

237   in the middle of the range of maximum ages estimated by others (Table 3). Our estimates seem

238   reasonable given that our age-specific estimate of M (0.20) for the older ages that was derived using

239   Charnov, Gislason and Pope (2013) compares closely with the point estimate of M (0.22) found using

240   the method of Hewitt & Hoenig (2005) (Table 2).

241   This study of coney in the SEUS has confirmed the findings of previous studies that otolith sections

242   of coney are reliable structures for aging. Moreover, growth rings on coney sagittae are laid down once

243   a year in spring and growth is generally slow throughout life, as evidenced by the low value of K, the

244   von Bertalanffy growth coefficient. Our estimates of M are reasonable for a fish with a moderate life

245   span and longevity of age 19. We believe the results of this study accurately describe the fished

246   population of coney in the offshore waters of the SEUS. While the overall landings of this species in

247   the commercial and recreational fisheries of the SEUS make it an unlikely candidate for a stock

248 assessment by NMFS, our assembled data would be valuable inputs into multispecies- or ecosystem-

249 based modeling efforts, either as stand-alone species data or in defining more inclusive functional

250 groups of species (Christensen et al., 2009). A more likely use of these data would be applying it to

251 studies of the population dynamics of U. S. Caribbean stocks (U. S. Virgin Islands and Puerto Rico).

252 The U. S. Caribbean is typically a data poor region and studies from the SEUS could be used as proxies

253 in analyses for the region. However, precautionary management should dictate that for the purposes of

254 managing local stocks, local studies of growth, reproduction, etc., are used. The difference in growth

255 parameters between various regions found in this study highlights the problems inherent with drawing

256 scientific conclusions using data from outside the region.

257

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262

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Number of samples of sagittal otoliths that were used for age and growth study of coney (*Cephalopholis fulva*) collected from 1998–2013 primarily from fisheries landings along the coast of the southeastern United States. Samples were collected in the

2   Table 1. Number of samples of sagittal otoliths that were used for age and growth study of coney

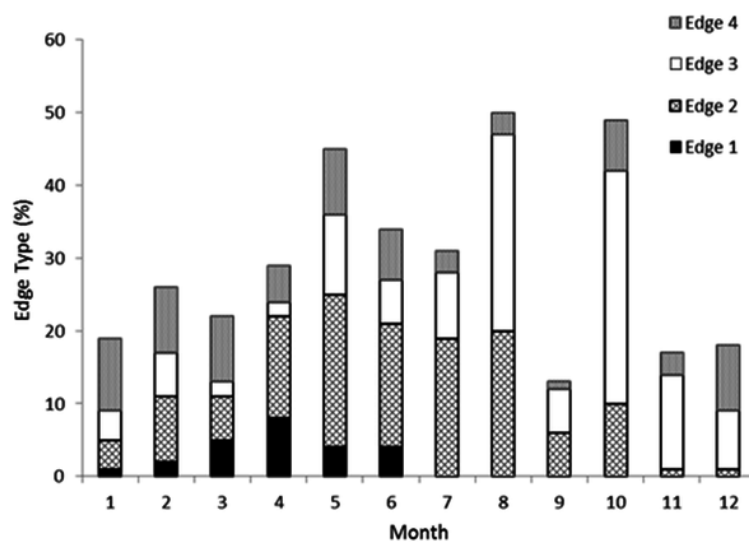
3   (*Cephalopholis fulva*) collected from 1998–2013 primarily from fisheries landings along the coast of

4   the southeastern United States. Samples were collected in the following states: North Carolina (NC),

5   South Carolina (SC), and Florida (FL).

State	Commercial	Recreational
NC	242	0
SC	32	2
FL	7	74

1

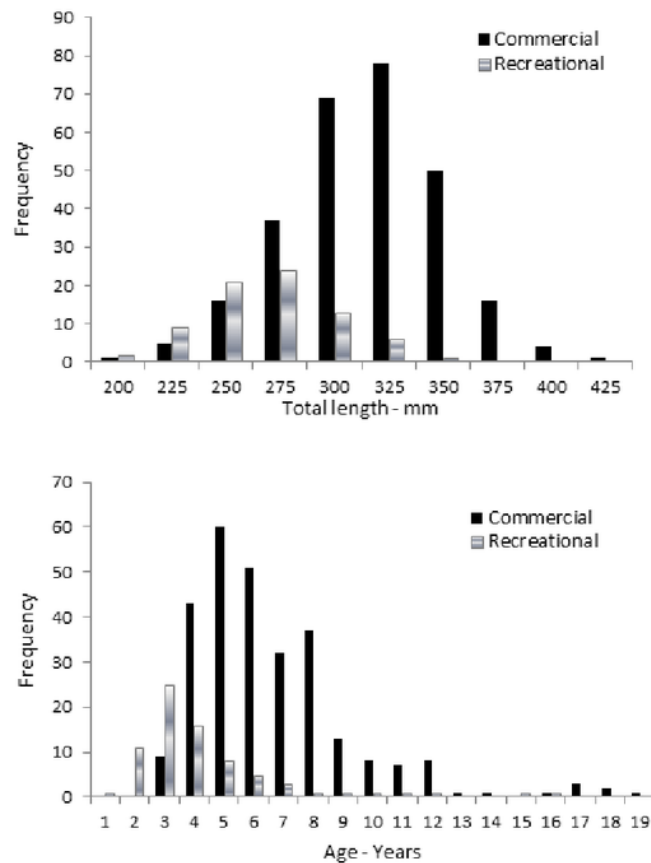
Monthly percentages of all edge types for coney (*Cephalopholis fulva*) collected from the southeastern United States in 1990–2012. Edge codes: 1=opaque zone on edge, indicating annulus formation; 2=small translucent zone, <30% of previous i

Observed and predicted mean total length (TL), measured in millimeters, and natural mortality at age (*M*) data for coney (*Cephalopholis fulva*) collected in 1996–2013 along the coast of the southeastern United States. Standard errors of the mean

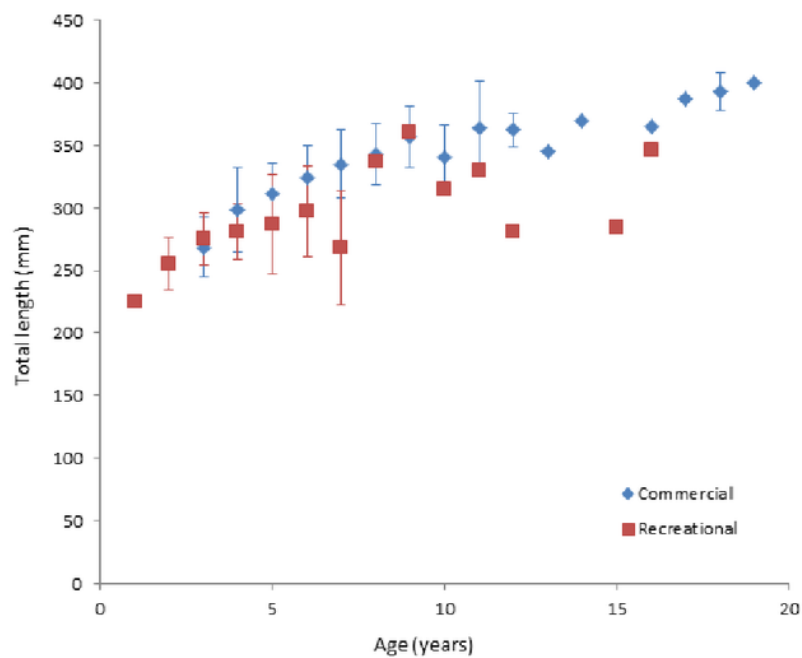
2   Table 2. Observed and predicted mean total length (TL), measured in millimeters, and natural

3   mortality at age (*M*) data for coney (*Cephalopholis fulva*) collected in 1996–2013 along the coast of the

4   southeastern United States. Standard errors of the means (SE) are provided in parentheses.

Age	*n*	Mean TL (± SE)	TL range	Predicted TL	*M*
1	1	225	–	225	0.49
2	11	255 (6)	218-287	252	0.40
3	34	273 (4)	237-325	275	0.34
4	59	294 (4)	220-362	293	0.31
5	66	308 (3)	227-377	308	0.28
6	56	321 (4)	250-392	321	0.26
7	35	329 (6)	217-380	331	0.25
8	37	342 (4)	287-395	339	0.24
9	14	357 (6)	310-402	346	0.23
10	9	338 (9)	310-390	352	0.22
11	8	360 (13)	330-430	356	0.22
12	9	353 (10)	281-380	360	0.21
13	1	345	–	363	0.21
14	1	370	–	366	0.21
15	1	285	–	368	0.21
16	2	356	347-365	369	0.21
17	3	388 (1)	385-390	371	0.21
18	2	393 (11)	382-404	372	0.20
19	1	400	–	373	0.20

Distributions of (A) length frequency and (B) age frequency, by fishing sector, for aging samples of coney (*Cephalopholis fulva*) collected from the southeastern United States in 1990–2013. <!--�oRF��3-->

3

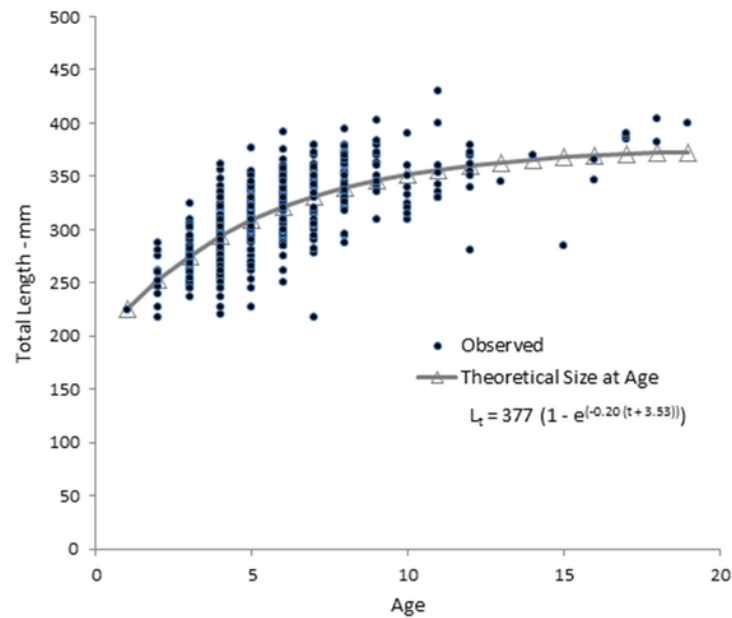
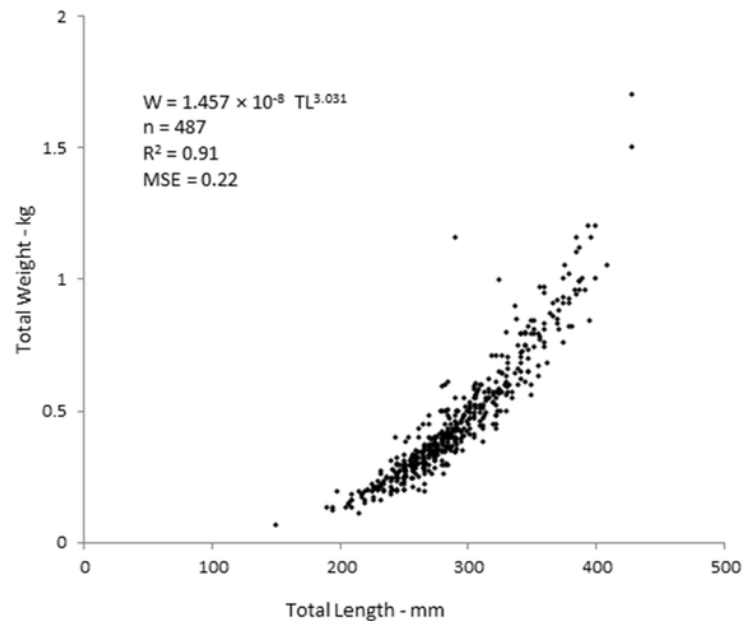
Comparison of mean size at age, measured in total lengths (TLs), for coney (*Cephalopholis fulva*), by fishery sector, sampled from the southeastern United States in 1998–2013.

Comparison of life history parameters of coney (*Cephalopholis fulva*) from various studies. L_∞=asymptotic length; K=growth coefficient; t_0=theoretical age at length of zero; n = sample size; SEUS=southeaste

2 Table 3. Comparison of life history parameters of coney (*Cephalopholis fulva*) from various studies.

3 L_∞=asymptotic length; K=growth coefficient; t_0=theoretical age at length of zero; n = sample size;

4 SEUS=southeastern United States; and TL=total length.

Study	Parameter					
	L_∞	K	t_0	Peak opaque edge	n	Maximum age
Potts and Manooch (1999)—SEUS	372	0.32	-0.20	March	55	11
Trott (2006) - Bermuda	281	0.20	-1.21	–	997	28
Aruajo and Martins (2006) - Brazil	316	0.14	-5.74	April-June	705	25
Burton et al. (current study)	377	0.20	-3.53	April–May	353	19

Observed and predicted lengths at age, measured in fork lengths (FLs), for coney
(*Cephalopholis fulva*) sampled from the southeastern United States in 1998–2013.
L_t=length at age t; t_0=time when length is zero.

Scatter plot of weight–length relationship for coney (*Cepohalophilis fulva*) sampled from the southeastern USA (W = weight; MSE = mean square error).

Comparison of von Bertalanffy growth curves for coney (*Cephalopholis fulva*) from various studies in western Atlantic waters.