Selected fishery and population parameters of eight shore-angling species in the Tsitsikamma National Park no-take marine reserve

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Selected fishery and population parameters of eight shore-angling species in the Tsitsikamma National Park no-take marine reserve

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An eight-year research angling dataset collected between February 1998 and December 2005 in the Tsitsikamma National Park marine protected area (MPA), along the south-eastern Cape coast of South Africa, was examined to provide estimates of important fishery and population parameters for eight important shore-angling species. Five different estimates of natural mortality (*M*), and the coefficients of variation (CVs) of catch per unit effort (CPUE) and size measurements were calculated. There was no consistency in estimates of *M* between methods, highlighting the difficulty in obtaining reliable estimates of this parameter for per-recruit assessments. The CVs of CPUE measurements were generally higher than those for size measurements. Estimates obtained for the most abundant species (blacktail *Diplodus capensis*), with a mean CPUE of 0.252 fish h^{-1}, yielded the lowest CVs for CPUE (0.806) and size (0.130) measurements. Therefore, blacktail is considered the preferred indicator species for making comparisons with estimates obtained for shore-angling fish in exploited areas and other MPAs along the South African coastline. The large interannual variations in mean CPUE and size for all species indicated that a minimum assessment period of four years is required to obtain reliable estimates.

Keywords: catch per unit effort, fisheries management, marine protected area, natural mortality, shore-angling fishery

Introduction

Excessive fishing pressure at a global level has reduced, and continues to threaten, endemic marine fish populations. In many parts of the world, exploitation spanning several generations of top predators has shifted ecological equilibria to an unknown extent (Jackson *et al.* 2001, Carr *et al.* 2003). In an attempt to resolve this situation in South African waters a new management protocol for the linefishery, defined as the capture of fish with a hook and line (excluding the use of longlines), was drafted (Griffiths 2000) and in 2000 the Minister of Environmental Affairs and Tourism, in terms of a provision in the Marine Living Resources Act (1998), placed this fishery under a conservation emergency. The declared emergency precipitated a number of catch-and-effort restrictions aimed at recovering fish density and the ecological balance. The effectiveness of these management actions, however, requires reliable information to compare population parameters under unexploited conditions with those from exploited populations. Unfortunately, pre-exploitation fish population parameters such as natural mortality (*M*) and catch per unit effort (CPUE), important abundance indices in measuring fishing-induced changes, are lacking. This lack of baseline information has frustrated attempts to assess exploited fish populations using conventional catch rate or per-recruit (PR) methods. In particular, PR methods can be biased, mainly on account of the difficulty in obtaining reliable estimates of *M* (Hilborn and Walters 1992, Bohnsack 1993, Ludwig *et al.* 1993, Hutchings 2000, Pinnegar *et al.* 2000).

In South Africa, there are several large, well-established 'no-take' marine protected areas (MPAs) which offer opportunities to measure population parameters that are close to pristine levels (i.e. indexed parameters). Because of natural interannual variability of reef fish abundance, Thompson and Mapstone (2002) suggested that absolute values of indexed parameters should be calculated from datasets spanning several years. Soto (2002) recommended that datasets used to assess the level of pristine natural variability of these absolute values relative to those obtained from exploited areas should be shorter than a decade.

The Tsitsikamma National Park (TNP) is the oldest and one of the largest no-take MPAs in Africa. After 40 years of protection, biotic communities are likely to be stable and thus provide a good example of a pre-exploitation inshore marine ecosystem. One of the primary functions of the TNP is to protect reef fish (Attwood *et al*. 1997), which are the most critically depleted component of the South African linefishery (Griffiths 2000).

This paper uses data from an ongoing research angling survey conducted in the TNP in order to estimate population parameters such as *M*, age structure, size structure and CPUE of eight important shore-angling species, which are presumed to be exempt of fishing pressure. The species under consideration include seven sparids (blacktail *Diplodus capensis*, black musselcracker *Cymatoceps nasutus,* bronze bream *Pachymetopon grande*, fransmadam *Boopsoides inorata*, roman *Chrysoblephus laticeps*, white musselcracker *Sparodon durbanensis* and zebra *Diplodus hottentotus*) and one dichistid (galjoen *Dichistius capensis*). The aim is to provide information that can be used to compare population and fishery parameters of populations of these species at other protected and/or exploited areas along the South African coastline. Furthermore, we compare the results from five commonly used methods to estimate *M*, and assess natural variability of CPUE and mean sizes of fish over time. Such information is important for the design of future per-recruit and CPUE assessments.

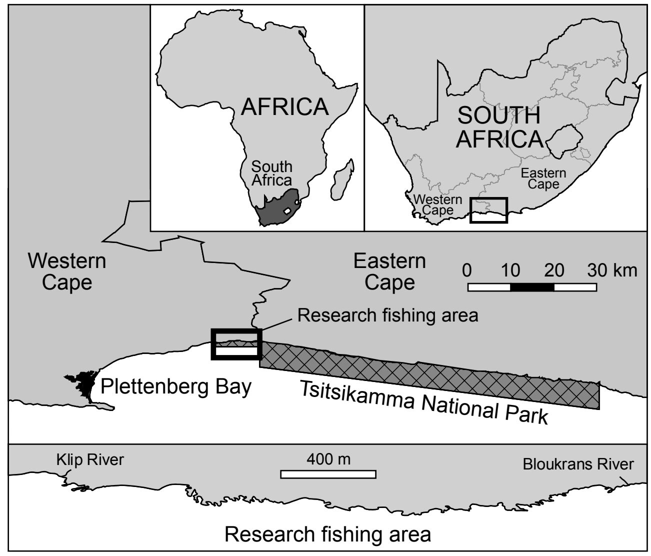

Figure 1: The South African coastline showing the location of the research fishing area within the Tsitsikamma National Park

Material and Methods

Study area

The study is based on data collected from a designated research fishing area (approximately 5 km long) between the mouths of the Bloukrans and Klip rivers in the western section of the 320 km^2 TNP marine reserve (Figure 1). The shoreline topography within the research fishing area is rugged with high rocky cliffs. The shoreline consists of steep, rocky ridges with interlaying gullies filled with boulders or sand (Hanekom *et al.* 1997). With the exception of a few small bays, the coastline is exposed to strong wave action.

Field methods

Over the eight-year study period (February 1998–December 2005), research fishing effort was stratified evenly over all years, seasons, tidal cycles and existing habitat types in accordance with recommended sampling strategies for long-term monitoring programmes (Vos *et al.* 2000). Furthermore, randomly stratified re-sampling of different sites within the research fishing area improved the statistical power of the analyses by reducing potential noise associated with re-sampling fixed sites with lower spatial variability (Green 1989). This allowed for conclusions to be generalised for the entire research fishing area.

Research fishing, using conventional tackle, was conducted bimonthly over a 4–5 day period. During each field trip, a group of 4–8 anglers fished from the shore during daylight hours (normally between 07:00 and 17:00) using a variety of bait types and hook sizes. All fish captured were measured to the nearest millimetre (fork length for teleosts and total length for elasmobranchs), whereas those above a minimum stipulated size were also tagged prior to release, following the methods detailed in Attwood (1998).

Data analysis

Natural mortality rate

In theory, it is not difficult to obtain estimates of total mortality (*Z*) for fishery species; however, it is not easy to differentiate between mortality caused by fishing (*F*) and that attributed to natural causes (*M*). Because of the high degree of residency displayed by most reef-associated fish species (Cowley *et al.* 2002, Griffiths and Wilke 2002), fishing mortality in TNP populations is considered to be negligible. Therefore, *Z* is equivalent to *M*, assuming that losses imposed by sampling or by poaching in the research area, as well as the effect of 'recruitment overfishing', are insignificant. Five approaches were adopted to estimate *M*:

(i) Using the equation derived by Pauly (1980), which incorporates information on maximum length (L_∞), growth (*K*) and temperature (*T*):

$$\mathrm{Log}(M) = -0.0066 - 0.279\log(L_\infty) + 0.6543\log(K) + 0.4634\log(T) \quad (1)$$

where *T* is the mean annual water temperature (°C) of the species' environment (estimated at 16.8 °C for the study area [Marine and Coastal Management, unpublished data]) and L_∞ (cm) and *K* are parameters of the von Bertalanffy growth function (*VBGF*).

(ii) Using the crude assumption that *Z* is proportional to the inverse of the mean age of the resident population (after Butterworth *et al.* 1989):

$$1/Z = \text{average lifespan of the population } (A) \quad (2)$$

An estimate of A was obtained by assigning an age to the length of each fish captured during the study, using the inverse of the *VBGF* and respective parameters presented by Mann (2000).

(iii) Using the equation provided by Hoenig (1983):

$$\text{Ln}(M) = 0.941 - 0.873\ln(t_{max}) \quad (3)$$

for which values of t_{max} were obtained from Mann (2000).

(iv) The first direct estimate of $M = Z$ was estimated from length-converted catch curve analysis originally proposed by (Ricker 1975):

$$\text{Ln}(N_i) = a + bt_i \quad (4)$$

where $\ln(N_i)$ is the ln-converted numbers in length class i, and t_i is the age corresponding to length class i obtained from the inverse of the *VBGF*. M was estimated from the slope b of the right descending limb.

(v) Applying an improved length-converted catch curve by Pauly (1984). This approach takes into account the fact that fish growth slows down as length and age increase. This has the effect that older size classes contain more age classes than younger ones, referred to by Van Sickle (1977) as 'stack up' effect. The correction for this effect is computed by multiplying the number of fish in each length class by the growth rate of that class, so that:

$$\text{Ln}(N_i(\text{d}L_i/\text{d}t_i)) = a + bt_i \quad (5)$$

where $\text{d}L_i/\text{d}t_i$ is the growth rate at age t_i, which can be expressed as:

$$\text{d}L_i/\text{d}t_i = K(L_\infty - L_i) \quad (6)$$

M was then obtained from slope b, analogous to Ricker (1975).

Whenever possible, growth and age data (after Mann 2000) from studies encompassing or inside the TNP were used. For three species (blacktail, zebra and roman), the largest fish caught in this study (L_{max}) was larger than the L_∞ values given by Mann (2000). To incorporate fish larger than L_∞ in the catch curve analysis, L_{max} was set as L_∞, and K and t_0 were iteratively solved. This was achieved using a non-linear minimisation of a normal log-likelihood function based on the published mean length at age data for the respective species (Mann and Buxton 1997, Buxton 1993).

Coefficient of variation

Estimates of temporal variability generally include the standard deviation of the logarithm of a population estimate and the CV of successive population estimates (Stewart-Oaten *et al.* 1995). Estimates of variability using the standard deviation of the logarithm of a population over-estimate true temporal population variability. CVs provide slightly lower variability estimates and allow for comparison of the variation of populations that have significantly different means and standard deviation values, and were calculated by dividing the standard deviation of CPUEs (fish angler^{-1} h^{-1}) and sizes by the arithmetic mean. CPUE was calculated by dividing the total catch of a species on a particular day by the total effort (h) of all anglers on that day.

Results

Sample size

In all, 43 field trips totalling 184 days were conducted between 1998 and 2005. A total effort of 8 141 angler h^{-1} yielded 8 236 fish comprising 55 species (Table 1).

Natural mortality

The five methods used to estimate M yielded different results (Figure 2). Length-converted catch curve estimates were highest, particularly for blacktail and galjoen, and Pauly's catch curve analysis gave consistently higher estimates of M compared to Ricker's catch curve, by an average of 0.1 (SE = 0.03). The methods of Butterworth and Hoenig gave M values around and below 0.2, whereas Pauly's empirical M was slightly lower than estimates from catch curve analyses (mean = 0.27).

The errors of M estimates, expressed as CVs of means, were between 30% and 90%. There was no consistency in M estimates between methods for the same species or between species for the same method. Paucity of age and growth data precluded estimation of M for fransmadam.

CPUE and size

Variation was higher for CPUE than for size, with CVs ranging between 0.8 and 1.8 and 0.1 and 0.4 respectively for the eight species under study (Figure 3). High variability (CV) was found in the sizes of white musselcracker and black musselcracker because both species showed a bimodal length frequency distribution (App.Figures 4d and 6d). Particularly high CVs were calculated for fransmadam and zebra CPUE (Figure 3), in contrast to the markedly lower CV for blacktail CPUE, the most abundant species in the catches (Table 1).

Discussion

Ichthyofaunal assemblage

This study used conventional hook-and-line fishing methods and focused on the capture of important shore-angling species. Consequently, the diversity of species (n = 55) was lower than that reported by Wood *et al.* (2000) (n = 102) for the TNP, who used additional sampling methods including rotenone and scuba surveys. However, a single specimen of one additional species, white kingfish *Pseudocaranx dentex* (361 mm FL), was recorded during this study.

Natural mortality

In exploited systems, catch curve analysis is probably the most frequently applied method to estimate Z, whereas estimates of M are usually obtained from empirical equations. In unexploited systems such as the TNP, M should be similar to Z and thus can be directly obtained

Table 1: Quantities of the 55 fish species and taxa caught during the eight-year study period in the Tsitsikamma National Park (*n* = 8 236)

Species	*n*	Species	*n*
Blacktail (*Diplodus capensis)*	1 975	Spotted gullyshark (*Triakis megalopterus*)	26
Galjoen (*Dichistius capensis*)	905	Evileye blaasop (*Amblyrhynchotes honckenii*)	22
Fransmadam (*Boopsoidea inornata*)	635	Yellowbelly rockcod (*Epinephelus marginatus*)	21
Clinidae (two species)	550	Brown shyshark (*Haploblepharus fucus*)	17
Black musselcracker (*Cymatoceps nasutus*)	461	Smooth-hound (*Mustelus mustelus*)	17
Roman (*Chrysoblephus laticeps*)	437	Eagleray (*Myliobatis aquila*)	13
White musselcracker (*Sparodon durbanensis*)	433	Redfingers (*Cheilodactylus fasciatus*)	11
Zebra (*Diplodus hottentotus*)	345	Blue hottentot (*Pachymetopon aeneum*)	7
Bronze bream (*Pachymetopon grande*)	318	Barred fingerfin (*Cheilodactylus pixi*)	6
Puffadder shyshark (*Haploblepharus edwardsii*)	275	Dark shyshark (*Haploblepharus pictus*)	6
Janbruin (*Gymnocrotaphus curvidens*)	248	Yellowspotted catshark (*Scyliorhinus capensis*)	6
Santer (*Cheimerius nufar*)	212	Copper shark (*Carcharhinus brachyurus*)	5
Cape stumpnose (*Rhabdosargus holubi*)	173	Piggy (*Pomadasys olivaceus*)	5
White steenbras (*Lithognathus lithognathus*)	161	Banded galjoen (*Dichistius multifasciatus*)	4
Strepie (*Sarpa salpa*)	142	Mugilidae (one species)	4
Striped catshark (*Poroderma africanum*)	118	Spotted grunter (*Pomadasys commersonnii*)	3
White seacatfish (*Galeichthys feliceps*)	111	Stonebream (*Neoscorpis lithophilus*)	3
Steentjie (*Spondyliosoma emarginatum*)	98	Hottentot (*Pachymetopon blochii*)	2
Koester (*Acanthistius sebastoides*)	74	Red steenbras (*Petrus rupestris*)	2
Leopard catshark (*Poroderma pantherinum*)	71	Blenniidae (one species)	1
Elf (*Pomatomus saltatrix*)	66	Cape moony (*Monodactylus falciformis*)	1
Twotone fingerfin (*Chirodactylus brachydactylus*)	56	Dusky shark (*Carcharhinus obscurus*)	1
Black seacatfish (*Galeichthys ater*)	40	Bullray (*Pteromylaeus bovinus*)	1
Dusky kob (*Argyrosomus japonicus*)	40	Red tjor-tjor (*Pagellus bellottii natalensis*)	1
Lesser guitarfish (*Rhinobatos annulatus*)	37	Rocksucker (*Chorisochismus dentex*)	1
Geelbek (*Atractoscion aequidens*)	36	Soupfin shark (*Galeorhinus galeus*)	1
Sand steenbras (*Lithognathus mormyrus*)	31	White kingfish (*Pseudocaranx dentex*)	1

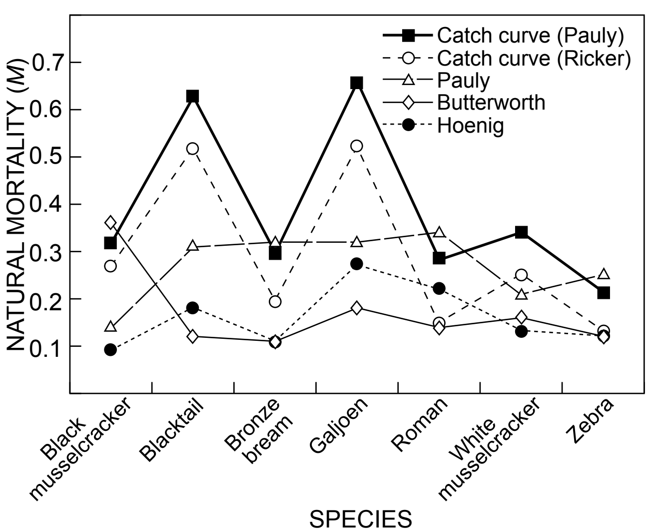

Figure 2: Natural mortality (*M*) estimates for seven shore-angling species in the Tsitsikamma National Park using five common methods

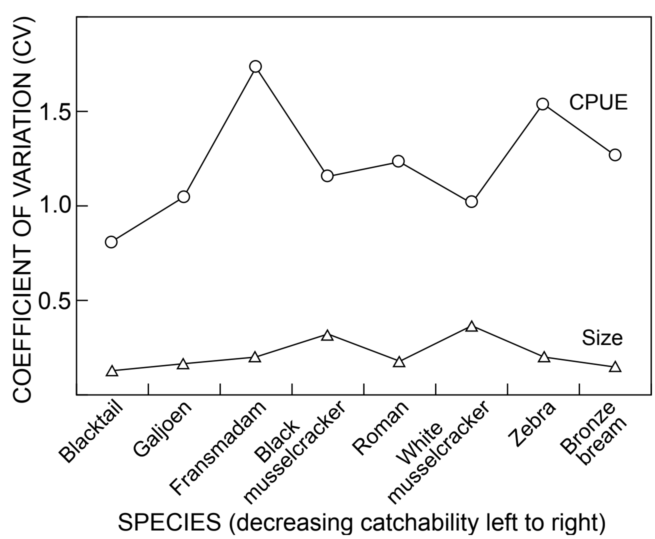

Figure 3: Coefficient of variation (CV) of CPUE and size of eight shore-angling species over an eight-year period in the Tsitsikamma National Park

from catch analysis. This can be considered to be the more robust estimate because it is based on observed data. Although Pauly's catch-curve approach makes an attempt to correct for the 'stack up' effect in larger length classes, catch curve analysis based on age–length keys provides the most robust estimate of *M*, because it uses the observed age structure of the population rather than a systematic correction.

A possible reason for the large errors in the estimates of *M* is that growth parameters for certain species were obtained from studies conducted outside the TNP study area. For example, the growth parameters for galjoen were obtained from the De Hoop marine reserve (Bennett and Griffiths 1986), an area with different habitats and about 400 km away from the TNP. Also, the growth parameters for black musselcracker and white musselcracker, as well as bronze bream (Buxton and Clarke 1989, 1991, 1992), were obtained from various locations around the TNP (encompassing more than 500 km of coastline), but not in the park itself.

Furthermore, some of the age and growth studies used here to calculate estimates of *M* were conducted in the late 1980s, a decade or so before the start of this study. Changes in the environment over that period (e.g. climate change) could have altered growth (Soto 2002). The possible influence of temporally segregated sampling periods might explain the differences in L_∞ values for blacktail, roman and zebra obtained from the TNP in past studies (Buxton 1993, Mann and Buxton 1997), which were lower than the maximum lengths measured during this study.

Other explanations for the large error of *M* could include: (i) different populations within the TNP were sampled between studies; (ii) populations are still recovering from former exploitation; (iii) otolith interpretations during past age and growth studies were incorrect as validations were not always carried out; and (vi) catch curves were different between studies because of differences in sampling methods (design and gear) and/or catchability (movement behaviour of fish). According to Mann (2000), adult black musselcracker move to deeper reefs and reproductively active black and white musselcracker undertake annual spawning migrations. All other species under study are either resident throughout their life or exhibit dispersive behaviour that is neither size nor sex related (Attwood and Cowley 2005, Cowley 1999, Cowley *et al*. 2002).

Although growth parameters obtained from the same population, in the same area and within the same time interval could reduce differences in the results from different estimation methods for *M*, this would not be practical, considering the large number of samples required. Apart from the above, the errors obtained from the models used to calculate *M* for all studied species were high.

None of the 175 fishery species used in Pauly's (1980) empirical relationship between *M*, mean sea temperature and growth belonged to the family Sparidae. Although Pauly's model revealed a significant trend, its error has a CV in the order of 200% of an absolute value. Several studies on South African fishery species (Smale and Punt 1991, Buxton 1992, Bennett 1993, Punt *et al.* 1993, Van Der Walt and Govender 1996, Booth and Buxton 1997) have used different levels of *M* and the range of estimates accounted for a CV of <80%. The consequent uncertainty in many per-recruit assessments suggests that the results should be interpreted with caution.

CPUE and size

The higher CVs for size of black and white musselcracker can be ascribed to the bimodal nature of their size frequency distributions. This could be attributed to size-related ontogenetic habitat shifts, because both species appear to undertake annual spawning migrations (Mann 2000).

The CPUE and size data presented here are useful in making recommendations for resource monitoring and assessments in areas exploited by shore-angling. The results show that fish size is a better indicator of change than CPUE, because of the lower variation in mean size estimates over time, thus allowing for a more reliable detection of trends over shorter time intervals. Such indicators are particularly useful when applying early warning procedures, and can greatly assist in making fisheries management decisions. Blacktail appears to be the most suitable indicator species to monitor fishing effects in exploited areas along the south coast (warm-temperate biogeographic region) of South Africa. Galjoen seems to be another useful indicator species, but more so for along the South-West Coast where it is more readily caught (Attwood 2003).

As a result of the high natural variability of CPUEs and fish sizes over time (see App.Figures 1–8), it is recommended that monitoring of fishery resources in exploited areas should be continuous for at least four years. Furthermore, such monitoring programmes should make measurements of relative abundance (CPUE) and mean size at repeated intervals, on a short-term basis, using the same methods, during comparable seasons and at similar locations.

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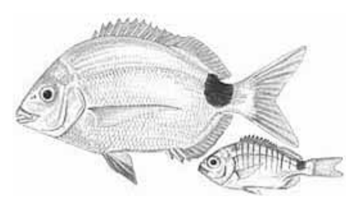
Appendix: Summary of population and fishery parameters of eight shore-angling species in the Tsitsikamma National Park, for the period 1998–2005. Fish illustrations reproduced with permission from *Coastal Fishes of Southern Africa* © SAIAB and NISC

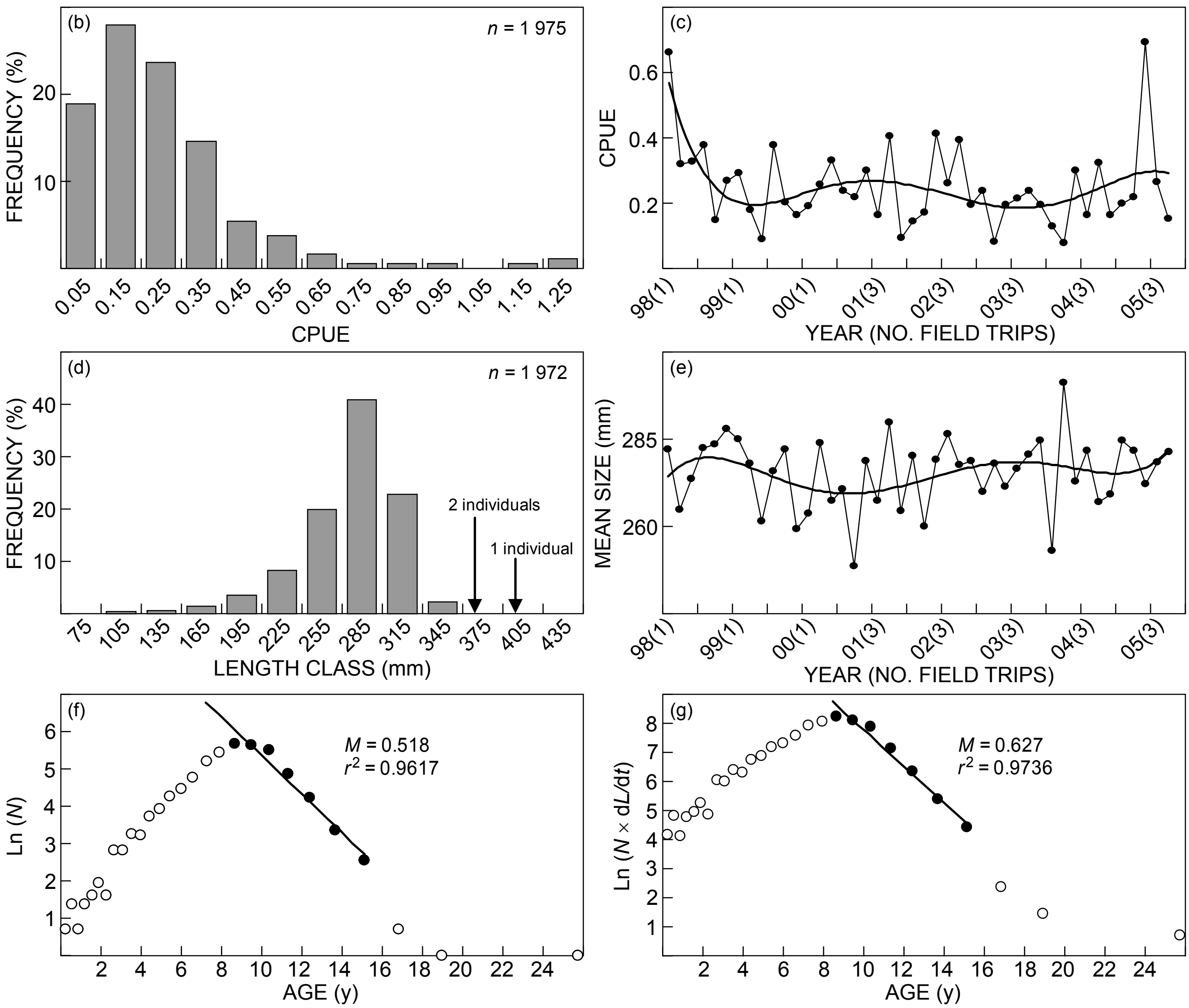
(a)

Parameter	Value	Source
Mean CPUE/σ/CV	0.252 h^{-1}/0.203 h^{-1}/0.806	TNP (this study)
Min/max CPUE	0.000 h^{-1}/1.282 h^{-1}	
Mean length/σ/CV	275 mm/35.7 mm/0.130	
Min/max length	90 mm/403 mm	
L_∞	403 mm	TNP (this study)*
K	0.142 y^{-1}	TNP (Mann and Buxton 1997)
t_0	–1.69 y	
Max age	21 y	TNP (this study; using above L_∞, K, t_0)
Pauly's M	0.31 y^{-1}	
Butterworth's M	0.12 y^{-1}	
Hoenig's M	0.18 y^{-1}	
Catch curve M (Ricker)	0.52 y^{-1}	
Catch curve M (Pauly)	0.63 y^{-1}	

* L_∞ from Mann and Buxton (1997) was lower (309 mm) than the observed maximum length (402 mm) in this study

Blacktail
(*Diplodus capensis*)



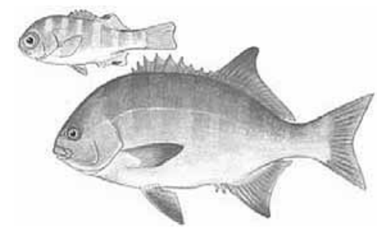


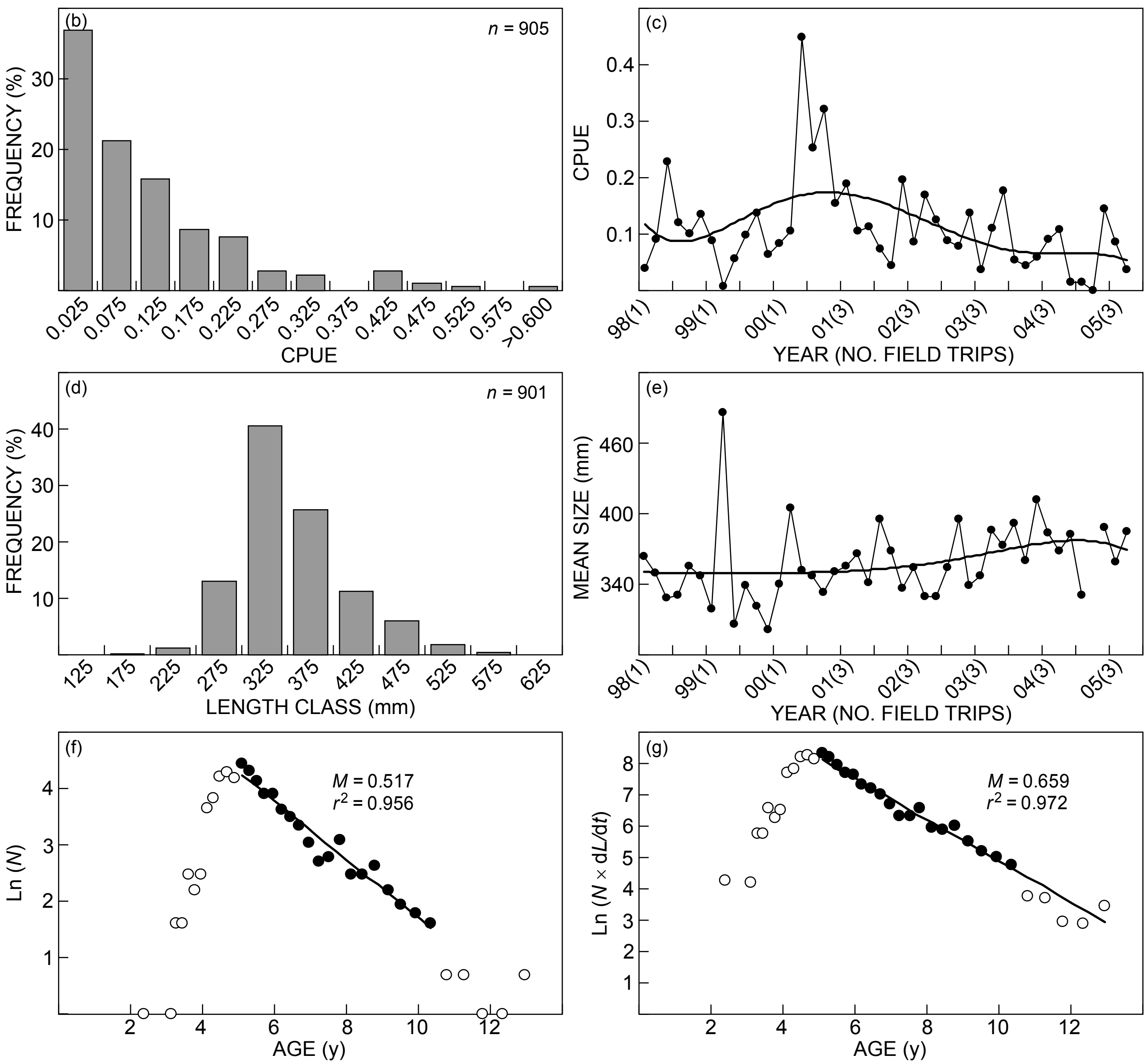
App.Figure 1: (a) Summary of population parameters for blacktail; (b) CPUE frequency distribution; (c) trends in CPUE over time, 1998–2005; (d) size frequency distribution; (e) trends in mean size over time, 1998–2005; (f) and (g) length-converted catch curves for estimation of M using Ricker's and Pauly's equations respectively using fitted lines in (c) and (e) are 5th order polynomials

(a)

Parameter	Value	Source
Mean CPUE/σ/CV	0.112 h^{-1}/0.117 h^{-1}/1.045	TNP (this study)
Min/max CPUE	0.000 h^{-1}/0.684 h^{-1}	
Mean length/σ/CV	349 mm/58.9 mm/0.169	
Min/max length	173 mm/560 mm	
L_∞	677 mm	De Hoop MPA (Bennett and Griffiths 1986)
K	0.142 y^{-1}	
t_0	0.282 y	
Max age	13 y	TNP (this study; using above L_∞, K, t_0)
Pauly's M	0.32 y^{-1}	
Butterworth's M	0.18 y^{-1}	
Hoenig's M	0.27 y^{-1}	
Catch curve M (Ricker)	0.52 y^{-1}	
Catch curve M (Pauly)	0.66 y^{-1}	

Galjoen
(*Dichistius capensis*)



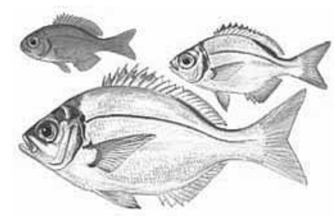


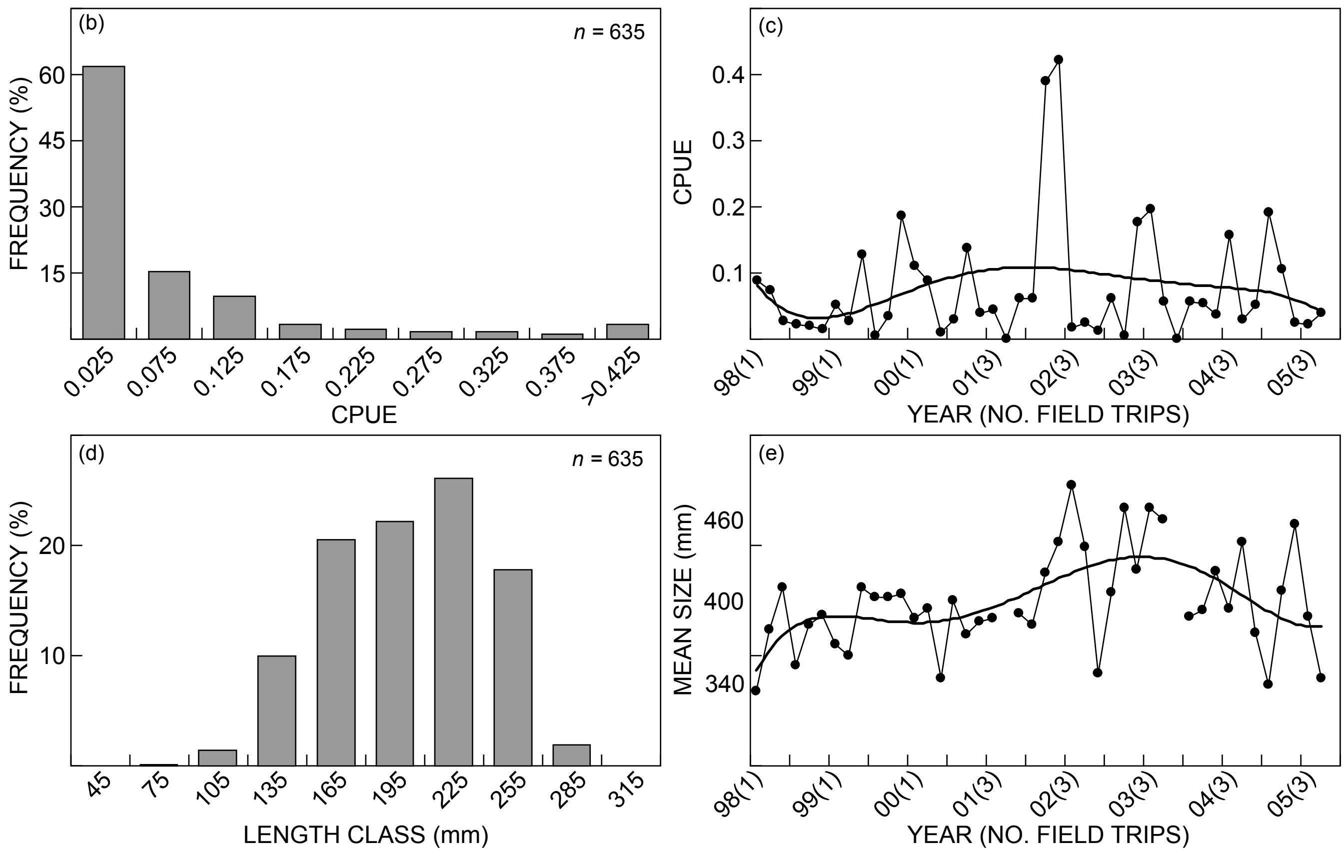
App.Figure 2: (a) Summary of population parameters for galjoen; (b) CPUE frequency distribution; (c) trends in CPUE over time, 1998–2005; (d) size frequency distribution; (e) trends in mean size over time, 1998–2005; (f) and (g) length-converted catch curves for estimation of M using Ricker's and Pauly's equations respectively using fitted lines in (c) and (e) are 5th order polynomials

(a)

Parameter	Value	Source
Mean CPUE/σ/CV	0.078 h^{-1}/0.135 h^{-1}/1.731	TNP (this study)
Min/max CPUE	0.000 h^{-1}/0.914 h^{-1}	
Mean length/σ/CV	200 mm/39.9 mm/0.200	
Min/max length	86 mm/293 mm	
L_∞	Unknown	Mann (2000)
K		
t_0		

Fransmadam
(*Boopsoidea inornata*)



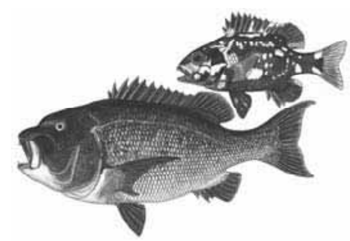


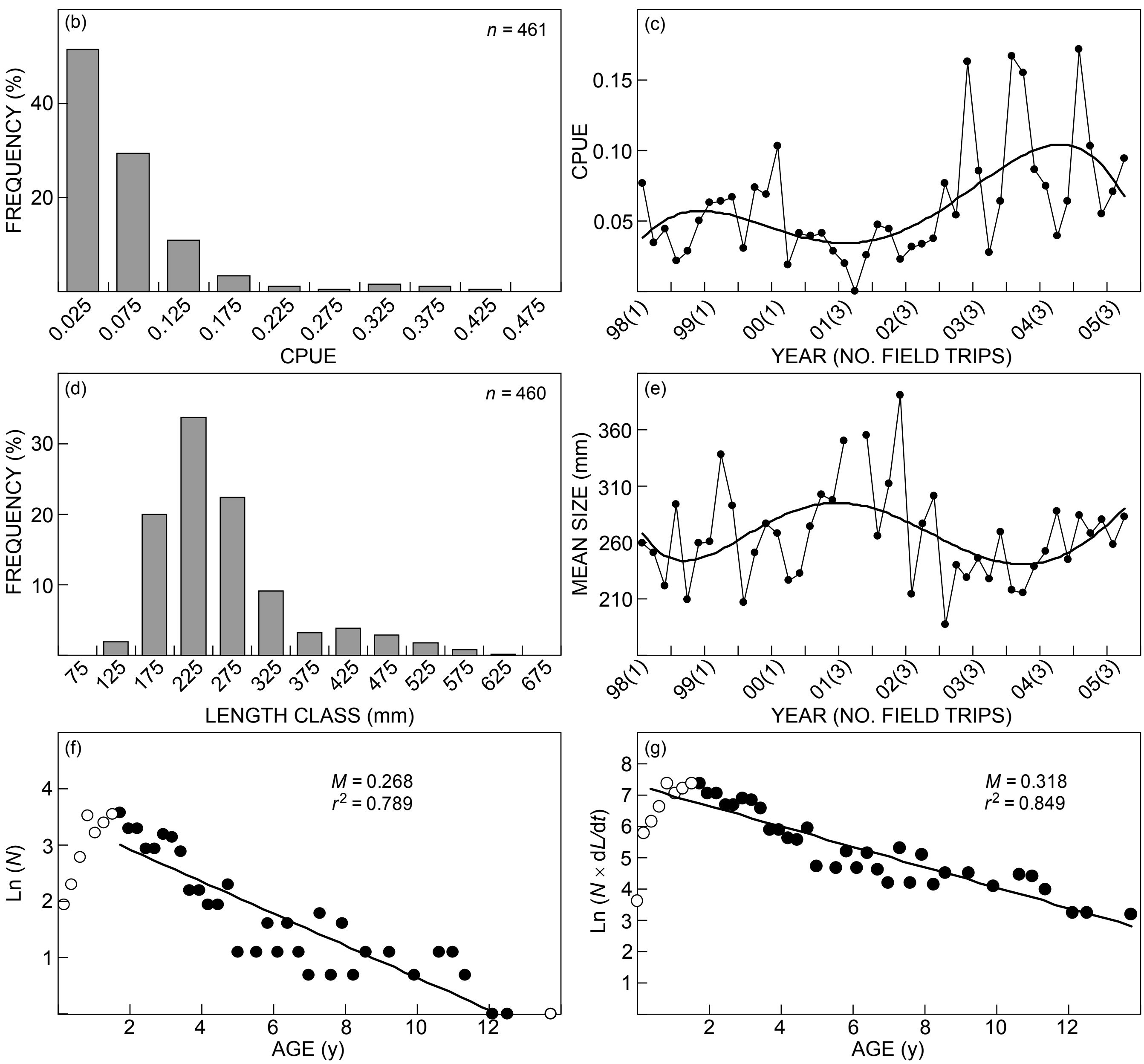
App.Figure 3: (a) Summary of population parameters for fransmadam; (b) CPUE frequency distribution; (c) trends in CPUE over time, 1998–2005; (d) size frequency distribution; (e) trends in mean size over time, 1998–2005; (f) and (g) length-converted catch curves for estimation of *M* using Ricker's and Pauly's equations respectively using fitted lines in (c) and (e) are 5th order polynomials

(a)

Parameter	Value	Source
Mean CPUE/σ/CV	0.064 h^{-1}/0.074 h^{-1}/1.156	TNP (this study)
Min/max CPUE	0.000 h^{-1}/0.450 h^{-1}	
Mean length/σ/CV	262 mm/85.6 mm/0.327	
Min/max length	105 mm/615 mm	
L_∞	1 090 mm	Port Elizabeth to Mossel Bay (Buxton and Clarke 1989)
K	0.050 y^{-1}	
t_0	–2.89 y	
Max age	45 y	TNP (this study; using above L_∞, K, t_0)
Pauly's M	0.14 y^{-1}	
Butterworth's M	0.36 y^{-1}	
Hoenig's M	0.09 y^{-1}	
Catch curve M (Ricker)	0.27 y^{-1}	
Catch curve M (Pauly)	0.32 y^{-1}	

Black musselcracker
(*Cymatoceps nasutus*)





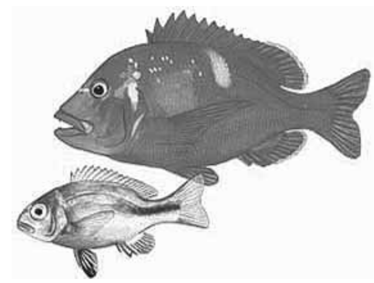
App.Figure 4: (a) Summary of population parameters for black musselcracker; (b) CPUE frequency distribution; (c) trends in CPUE over time, 1998–2005; (d) size frequency distribution; (e) trends in mean size over time, 1998–2005; (f) and (g) length-converted catch curves for estimation of M using Ricker's and Pauly's equations respectively using fitted lines in (c) and (e) are 5th order polynomials

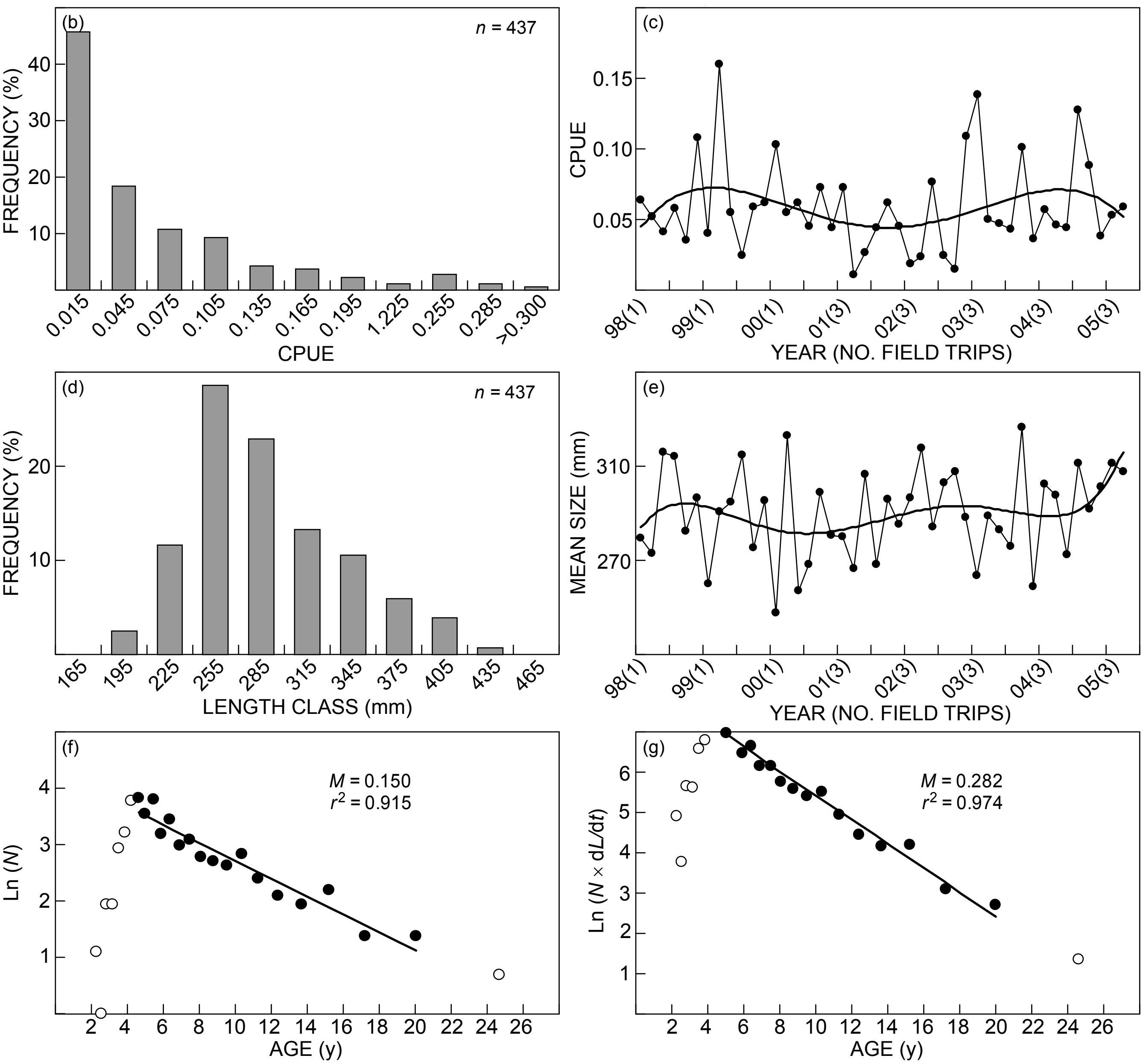
(a)

Parameter	Value	Source
Mean CPUE/σ/CV	0.060 h^{-1}/0.074 h^{-1}/1.233	TNP (this study)
Min/max CPUE	0.000 h^{-1}/0.450 h^{-1}	
Mean length/σ/CV	287 mm/50.5 mm/0.176	
Min/max length	181 mm/436 mm	
L_∞	436 mm	TNP (this study)*
K	0.13 y^{-1}	TNP (Buxton 1993)
t_0	–1.53 y	
Max age	17 y	TNP (this study; using above L_∞, *K*, t_0)
Pauly's *M*	0.34 y^{-1}	
Butterworth's *M*	0.14 y^{-1}	
Hoenig's *M*	0.22 y^{-1}	
Catch curve *M* (Ricker)	0.15 y^{-1}	
Catch curve *M* (Pauly)	0.28 y^{-1}	

* L_∞ from Buxton (1993) was lower (425 mm) than the observed maximum length (436 mm) in this study

Roman
(*Chrysoblephus laticeps*)



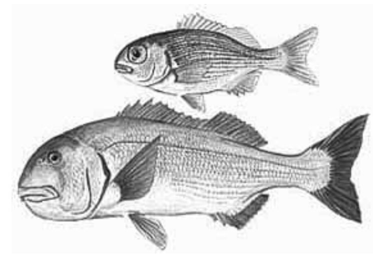


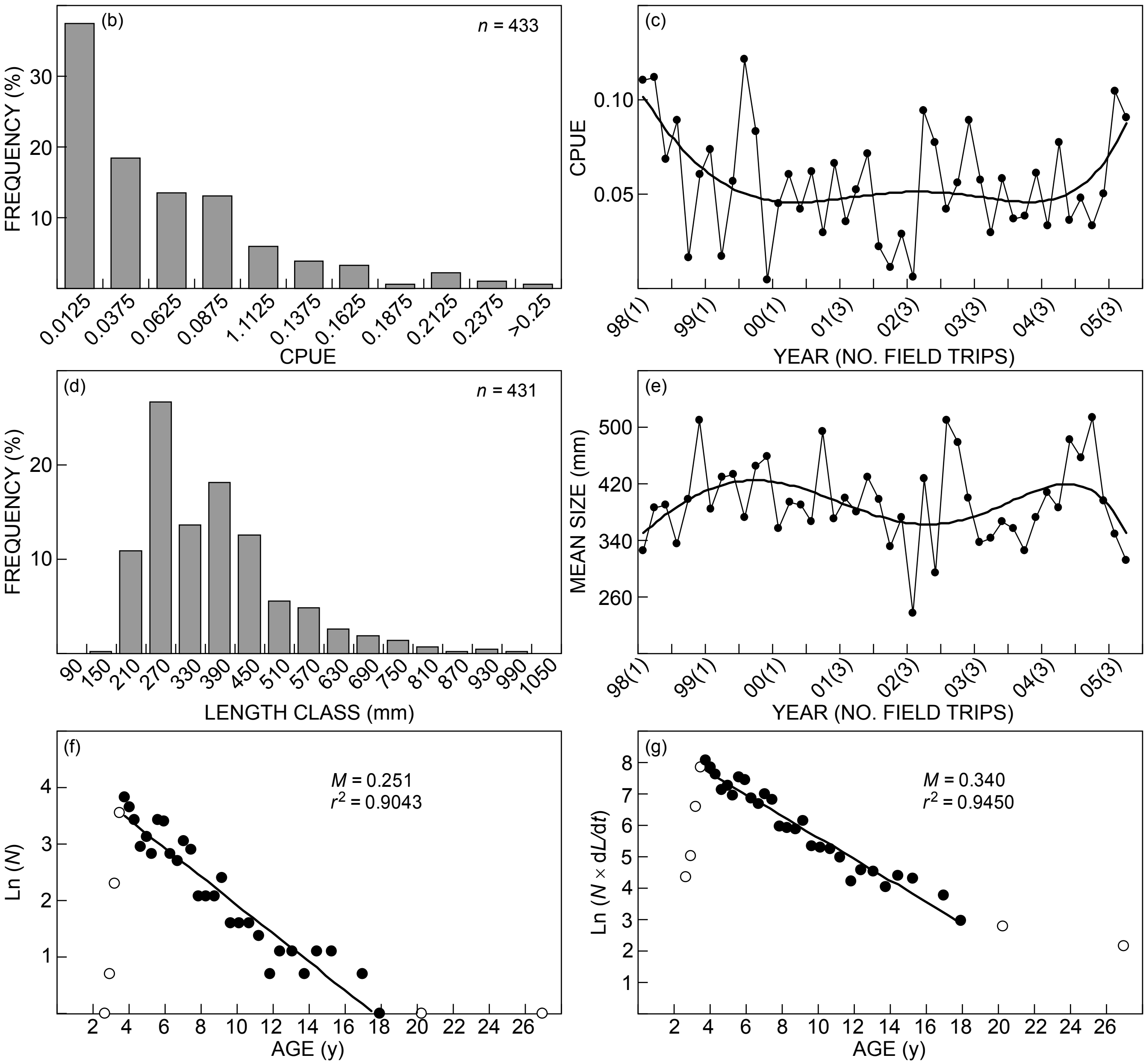
App.Figure 5: (a) Summary of population parameters for roman; (b) CPUE frequency distribution; (c) trends in CPUE over time, 1998–2005; (d) size frequency distribution; (e) trends in mean size over time, 1998–2005; (f) and (g) length-converted catch curves for estimation of *M* using Ricker's and Pauly's equations respectively using fitted lines in (c) and (e) are 5th order polynomials

(a)

Parameter	Value	Source
Mean CPUE/σ/CV	0.056 h^{-1}/0.057 h^{-1}/1.018	TNP (this study)
Min/max CPUE	0.000 h^{-1}/0.294 h^{-1}	
Mean length/σ/CV	379 mm/140.3 mm/0.370	
Min/max length	160 mm/980 mm	
L_∞	1 021 mm	Knysna to East London (Buxton and Clarke 1991)
K	0.090 y^{-1}	
t_0	0.709 y	
Max age	31 y	TNP (this study; using above L_∞, K, t_0)
Pauly's M	0.21 y^{-1}	
Butterworth's M	0.16 y^{-1}	
Hoenig's M	0.13 y^{-1}	
Catch curve M (Ricker)	0.25 y^{-1}	
Catch curve M (Pauly)	0.34 y^{-1}	

White musselcracker
(*Sparodon durbanensis*)





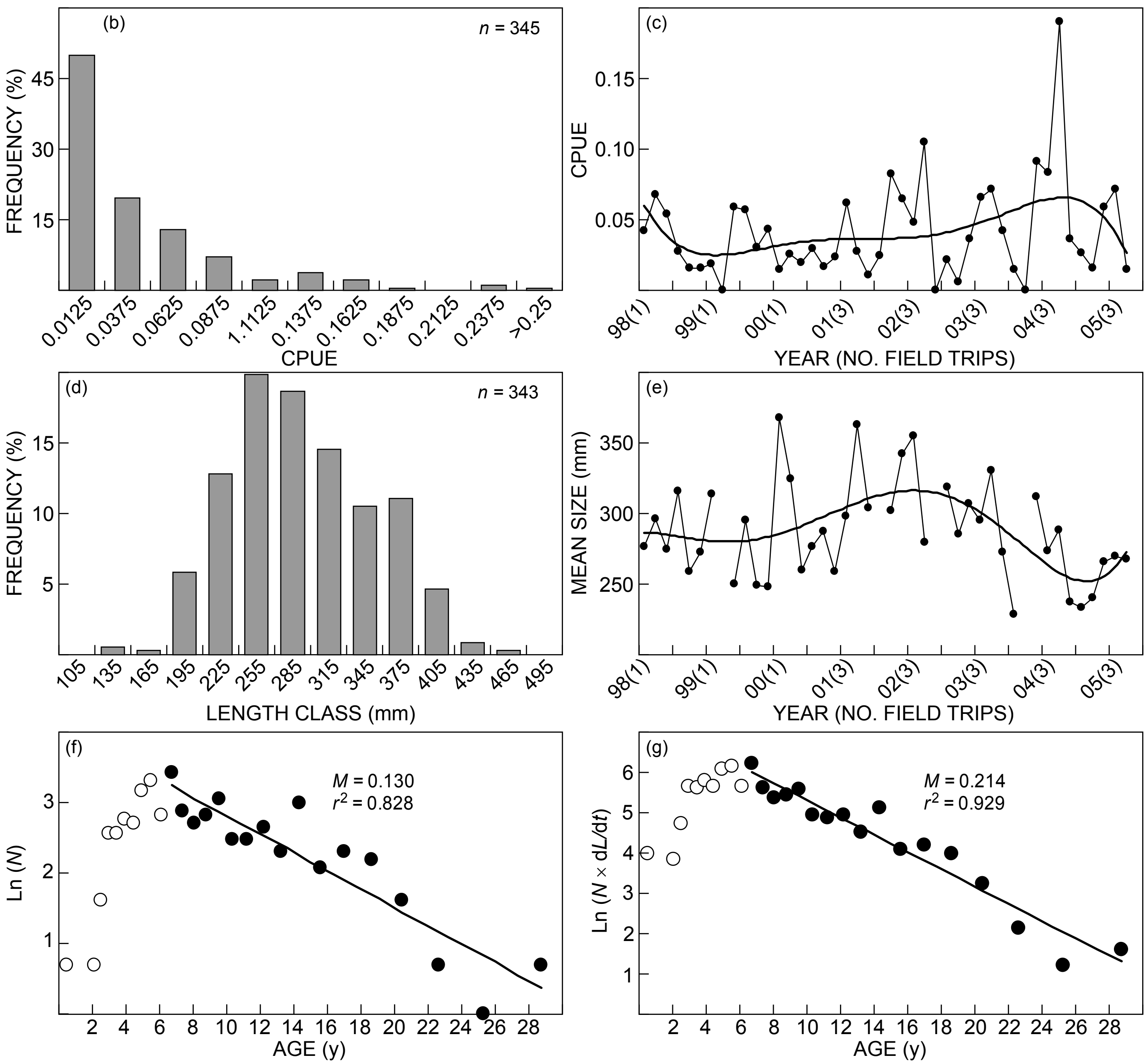
App.Figure 6: (a) Summary of population parameters for white musselcracker; (b) CPUE frequency distribution; (c) trends in CPUE over time, 1998–2005; (d) size frequency distribution; (e) trends in mean size over time, 1998–2005; (f) and (g) length-converted catch curves for estimation of M using Ricker's and Pauly's equations respectively using fitted lines in (c) and (e) are 5th order polynomials

(a)

Parameter	Value	Source
Mean CPUE/σ/CV	0.041 h^{-1}/0.063 h^{-1}/1.537	TNP (this study)
Min/max CPUE	0.000 h^{-1}/0.606 h^{-1}	
Mean length/σ/CV	290 mm/59.2 mm/0.204	
Min/max length	140 mm/465 mm	
L_∞	465 mm	TNP (this study)*
K	0.084 y^{-1}	TNP (Mann and Buxton 1997)
t_0	–3.963 y	
Max age	33 y	TNP (this study; using above L_∞, K, t_0)
Pauly's M	0.25 y^{-1}	
Butterworth's M	0.12 y^{-1}	
Hoenig's M	0.12 y^{-1}	
Catch curve M (Ricker)	0.13 y^{-1}	
Catch curve M (Pauly)	0.21 y^{-1}	

* L_∞ from Mann and Buxton (1997) was lower (397 mm) than the observed maximum length (465 mm) in this study

Zebra
(*Diplodus hottentotus*)



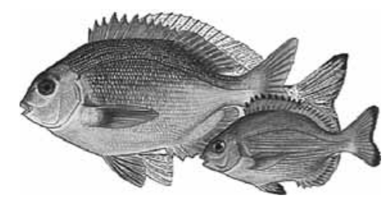
App.Figure 7: (a) Summary of population parameters for zebra; (b) CPUE frequency distribution; (c) trends in CPUE over time, 1998–2005; (d) size frequency distribution; (e) trends in mean size over time, 1998–2005; (f) and (g) length-converted catch curves for estimation of M using Ricker's and Pauly's equations respectively using fitted lines in (c) and (e) are 5th order polynomials

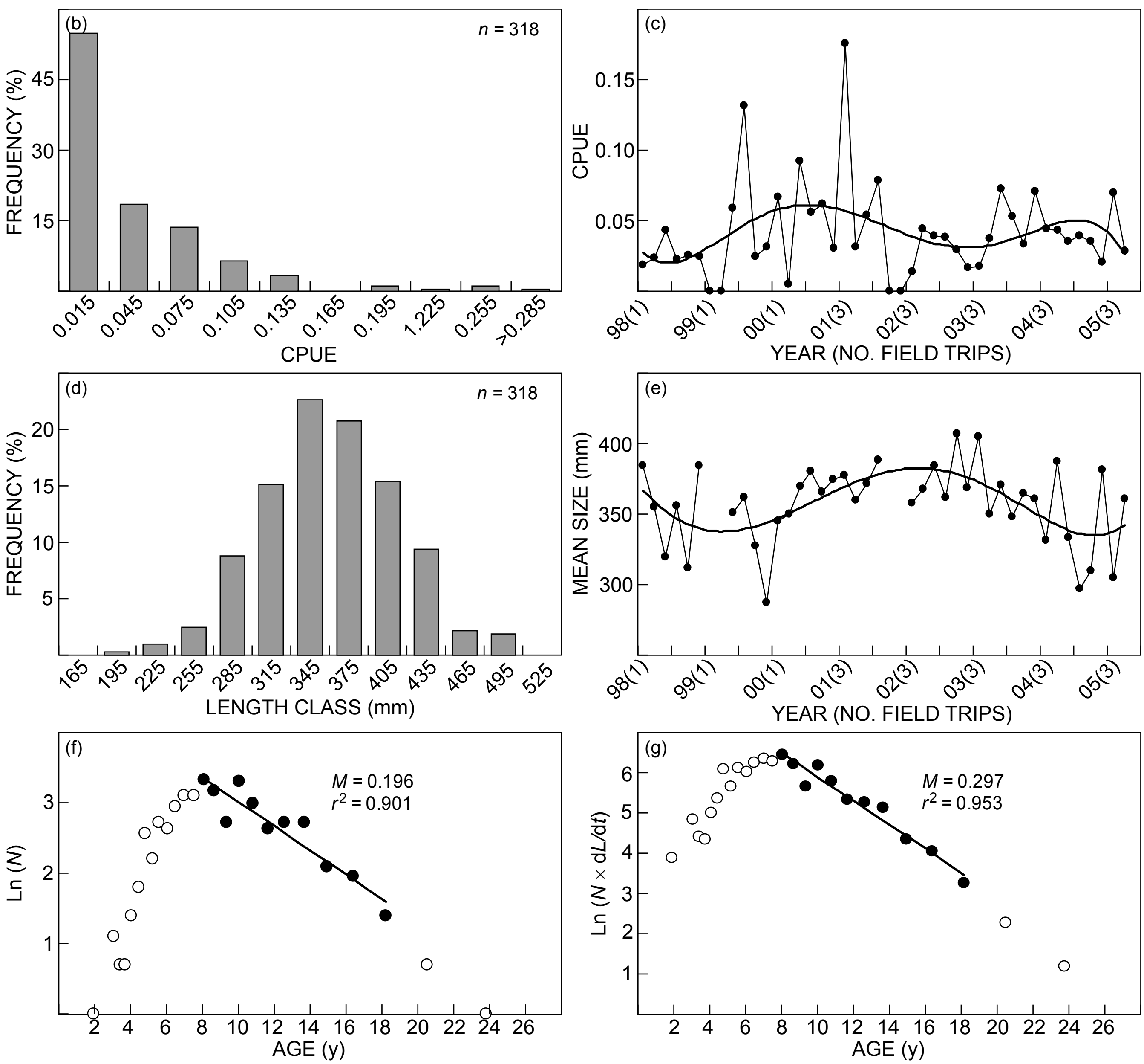
(a)

Parameter	Value	Source
Mean CPUE/σ/CV	0.041 h^{-1}/0.052 h^{-1}/1.268	TNP (this study)
Min/max CPUE	0.000 h^{-1}/0.273 h^{-1}	
Mean length/σ/CV	359 mm/52.3 mm/0.146	
Min/max length	192 mm/495 mm	
L_∞	495 mm	TNP (this study)*
K	0.12 y^{-1}	Knysna to East London
t_0	–2.11 y	(Buxton and Clarke 1992)
Max age	38 y	TNP (this study; using above L_∞, K, t_0)
Pauly's M	0.32 y^{-1}	
Butterworth's M	0.11 y^{-1}	
Hoenig's M	0.11 y^{-1}	
Catch curve M (Ricker)	0.20 y^{-1}	
Catch curve M (Pauly)	0.30 y^{-1}	

* L_∞ from Buxton and Clarke (1992) was lower (492 mm) than the observed maximum length (495 mm) in this study

Bronze bream
(*Pachymetopon grande*)





App.Figure 8: (a) Summary of population parameters for bronze bream; (b) CPUE frequency distribution; (c) trends in CPUE over time, 1998–2005; (d) size frequency distribution; (e) trends in mean size over time, 1998–2005; (f) and (g) length-converted catch curves for estimation of M using Ricker's and Pauly's equations respectively using fitted lines in (c) and (e) are 5th order polynomials