

SE D A R

Southeast Data, Assessment, and Review

SEDAR 27-DW03 Life History-Based Estimates of Natural Mortality for Gulf Menhaden

Prepared by
Amy M. Schueller
NOAA Fisheries
Beaufort, North Carolina

March 2011

SEDAR is a Cooperative Initiative of:
The Caribbean Fishery Management Council
The Gulf of Mexico Fishery Management Council
The South Atlantic Fishery Management Council
NOAA Fisheries Southeast Regional Office
NOAA Fisheries Southeast Fisheries Science Center
The Atlantic States Marine Fisheries Commission
The Gulf States Marine Fisheries Commission

SEDAR
The South Atlantic Fishery Management Council
4055 Faber Place #201
North Charleston, SC 29405
(843) 571-4366

Introduction

Age-structured models attempt to reconstruct the fish population and fishing mortality rates by age and year, where total instantaneous mortality rate (Z) is the sum of instantaneous rates of fishing (F) and natural (M) mortality. Historically, natural mortality has been assumed to be constant over ages and years. In many stock assessments, constant values for M have been obtained from life history analogies (e.g. maximum age, growth rate parameters, etc.). Because younger fish are thought to be more vulnerable to predation, natural mortality may decline with size or age. Several approaches have been considered to provide size-varying estimates of natural mortality. For purposes of stock assessments, sizes are related to age to provide age-varying estimates of natural mortality.

First, an overview of natural mortality is provided. Predation mortality is probably the greatest component of natural mortality because gulf menhaden are abundant in coastal waters and are a common prey species to many predatory fishes, sea birds, and marine mammals (Vanderkooy and Smith 2002). This high rate of mortality is particularly acute among the youngest age classes, due to mouth gape limitation of most piscivorous fishes. Gulf menhaden are valuable forage for many commercial and recreationally important Gulf of Mexico fishes. Gulf menhaden are known to be preyed upon by a variety of predators such as several gar species, ladyfish, red drum, spotted seatrout, bluefish, and mackerels (Vanderkooy and Smith 2002). Given the importance of gulf menhaden as a forage species and the assumed high predation that presumably occurs on young of the year and juvenile fish, age-varying natural mortality rates may be more appropriate for this species.

Poorly understood sources of natural mortality for gulf menhaden include pollution, habitat degradation, parasites, and diseases. Coastal pollution and habitat degradation threaten marine fish species, such as gulf menhaden, which spend their first year of life in estuarine waters and the rest of their life in both the Gulf of Mexico proper and estuarine waters. Examples of gulf menhaden parasites are an isopod, which has been observed attached to gulf menhaden gill filaments, as well as a copepod that feeds on the gills and flesh (Vanderkooy and Smith 2002). Trematodes, flukes, and tapeworms also have been found to parasitize gulf menhaden (Vanderkooy and Smith 2002). Several bacterial species have been shown to cause skin ulcers and hemorrhaging.

Another source of natural mortality for gulf menhaden (and many other species) may be "red tide". The term refers to the color of water caused by the rapid multiplication, or "bloom", of single-celled planktonic organisms called dinoflagellates, which produce a toxic compound. The toxin accumulates in the tissues of filter-feeding animals, which ingest the dinoflagellate. Red tides occur in the Gulf of Mexico most often occurring along the shore of Florida. In 1996, a large toxic algal bloom occurred in the northern Gulf, which caused the death of many fish (Vanderkooy and Smith 2002). Problems with toxic phytoplankton organisms may increase in

the future since their appearance has been correlated with increasing nutrient enrichment in estuarine and coastal waters that are subject to increasing organic pollution (Smayda 1989).

An additional source of mortality are fish "kills", which occur when schools of menhaden enter enclosed inshore bodies of water in large numbers and consume all available oxygen and suffocate. High water temperatures, which increase the metabolic rate of the fish, accelerate oxygen depletion. Concurrently, oxygen is less soluble in warm water. In the Gulf of Mexico just west of the Mississippi River delta, a large hypoxic zone called the dead zone may tend to concentrate schools of menhaden (Smith 2001). Other species are not nearly as susceptible simply because they do not enter enclosed inshore waters in such large numbers.

Life-History Based Approaches

Age-Constant M Approaches

Several methods are available to determine an age-constant *M* based on life history characteristics, notably maximum age (*t*_{max}), von Bertalanffy growth parameters (*K*, *L*_∞), and average water temperature (T°C; **Table 1**).

Methods used to determine a constant natural mortality rate over age and time.

Source	Equation
Alverson and Carney (1975)	$M = 3K / (exp(0.38 * t_{max} * K) - 1)$
Hoenig (1983; <i>F</i> ~ 0)	$M = exp(1.46 - 1.01 * ln(t_{max}))$
Jensen (1996)	$M = 1.5 * K$
Pauly (1980)	$M = exp(-0.0152 + 0.6543 * ln(K) - 0.279 * ln(L_{\infty}, cm) + 0.4634 * ln(T^{\circ}C))$
“Rule of thumb” (Hewitt & Hoenig 2005)	$M = 3 / t_{max}$

The maximum age used in calculations was age 6. Mean environmental temperature (T°C), or mean annual water temperature where fish were caught, used here was 23°C. Quinn and Deriso (1999) have converted Pauly’s equation from base 10 to natural logarithms as presented above. Growth coefficients used were estimated in S27-DW2 as 0.41 for *K* and 26.36 (cm) for *L*_∞. The growth coefficients were based on the overall fit of the observed data from 1964-2010 to the von Bertalanffy growth equation. The “rule of thumb” method has a long history in fisheries science, but its source has been difficult to identify. Hewitt and Hoenig (2005), recently compared the rule of thumb approach to that of Hoenig (1983) and noted that the Hoenig (1983) method provides an estimate of *M* only when fishing mortality can be assumed small (*F* ~ 0) and otherwise should be used as an upper bound on *M*.

Natural mortality was also estimated using growth coefficients for the most recent time period of 2000 to 2010. Average growth coefficients used were estimated in SEDAR27-DW02

as 0.46 for K and 22.87 (cm) for L_{∞} . Annual values of M were also calculated for those equations above for which we have annual values of input parameters (i.e., Alverson and Carney (1975), Jensen (1996), and Pauly (1980); **Figure 1**).

Age Varying M Approaches

Several approaches have been developed to provide age-varying estimates of M (Peterson and Wroblewski 1984, Boudreau and Dickie 1989, Lorenzen 1996). All use an inverse relationship between size and natural mortality (M). To apply these methods, weight at age is calculated for the middle of the calendar year (July 1). Because the middle of the fishing year is approximately July 1, or 6 months into the calendar year, the fraction 1/2 (6 months), was added to each age in the von Bertalanffy growth equation to calculate corresponding length on July 1, then converted to weight using a corresponding weight-length relationship.

The method of Peterson and Wroblewski (1984) recently was used to describe natural mortality for young-of-year Atlantic menhaden (Heimbuch et al. 2007), and uses a dry weight as its independent variable. The method of Boudreau and Dickie (1989) has been applied in several assessments, notably for gulf menhaden in Vaughan et al. (2007). However, the method of Lorenzen (1996) has gained favor in recent years, especially in the SEDAR arena (e.g., S10, S15, S17, S18, and S24). When applying the method of Lorenzen (1996), estimates of age-varying M can be scaled such that cumulative survival from age 1 through the maximum age is equal to 1.5%. This cumulative survival value comes from the fixed M method of Hoenig (1983) as described in Hewitt and Hoenig (2005). The resulting M from Peterson and Wroblewski (1984), Boudreau and Dickie (1989), and the unscaled Lorenzen (1996) provide similar results (**Figure 2**).

A range in Hoenig-based estimates of M can be used to rescale the Lorenzen estimates of M so as to provide a range of age-varying M for use by the SEDAR 27 Assessment Workshop. The Hoenig-based estimate of M is 0.70, which produces a scaling to 1.5% survival from age 0 through age 6. Corresponding percentages can be developed to scale M to other survival rates. Unscaled age-varying estimates of M are summarized for ages 0-6 (**Table 2**), as well as the scaled Lorenzen. Mean natural mortality rate across ages over time was provided for the methods of Peterson and Wroblewski, Boudreau and Dickie, and Lorenzen (**Figure 3**).

Estimates Based on Tagging

The only “field” estimate of natural mortality known for gulf menhaden was based on tagging data (Ahrenholz 1981). Adult fish were tagged with internal ferro-magnetic tags from 1969 to 1971 (Ahrenholz 1981); later tags were recovered on magnets at commercial reduction plants. The number of tags recovered was adjusted for tag loss. Estimates of M varied between 0.69 and 1.61 for the western, central, and eastern Gulf of Mexico after adjusting for a 20% tag

loss rate and had a mean M of 1.10. Ahrenholz (1981) estimated natural mortality, $M = 1.05$, for gulf menhaden using tagging data from 1969-1971 for the entire area with upper and lower confidence intervals of 1.09 and 1.01, respectively.

Age varying natural mortality rates could also be scaled to M estimated from tagging studies. The Lorenzen scaled to the mean and upper and lower range of M estimated from the tagging data is in **Table 3**. The range from 0.69-1.61 was used to provide estimates that would encompass the full uncertainty surrounding estimates of natural mortality. Any of the age varying estimates of natural mortality can be rescaled using the tagging data, the Lorenzen was provided as an example. Vaughan et al. (2007) scaled Boudreau and Dickie estimates of M in this manner for the most recent gulf menhaden stock assessment.

References

- Ahrenholz, D.W. 1981. Recruitment and exploitation of Gulf menhaden, *Brevoortia patronus*. Fish. Bull. 79(2): 325-335.
- Alverson, D.L., and M.J. Carney. 1975. A graphic review of the growth and decay of population cohorts. J. Cons. Int. Explor. Mer 36:133-143.
- Boudreau, P.R., and L.M. Dickie. 1989. Biological model of fisheries production based on physiological and ecological scalings of body size. Can. J. Fish. Aquat. Sci. 46:614-623.
- Heimbuch, D.G., E. Lorda, D. Vaughan, L.W. Barnthouse, J. Uphoff, W. Van Winkle, A. Kahnle, B. Young, J. Young, and L. Kline. 2007. Assessing coastwide effects of power plant entrainment and impingement on fish populations: Atlantic menhaden example. No. Amer. J. Fish. Manage. 27:569-577.
- Hewitt, D.A., and J.M. Hoenig. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fish. Bull. 103:433-437.
- Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82:898-903.
- Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Can. J. Fish. Aquat. Sci. 53:820-822.
- Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: A comparison of natural ecosystems and aquaculture. J. Fish. Biol. 49:627-647.
- Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer 39:175-192.
- Peterson, I., and J.S. Wroblewski. 1984. Mortality rate of fishes in the pelagic ecosystem. Can. J. Fish. Aquat. Sci. 41:1117-1120.
- Quinn, T.J. II, and R.B. Deriso. 1999. Quantitative Fish Dynamics. Oxford Press, 542 p.

- Smayda, T.J. 1989. Primary production and the global epidemics of phytoplankton blooms in the sea: a linkage? pp. 449-483 *In*: E.M. Cosper, V.M. Bricelj, and E.J. Carpenter (eds). Novel "Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms". Coastal and Estuarine Studies No. 35. Springer-Verlag, New York, N.Y.
- Smith, J.W. 2001. Distribution of catch in the gulf menhaden, *Brevoortia patronus*, purse seine fishery in the northern Gulf of Mexico from logbook information: are there relationships to the hypoxic zone? In Rabalais, N.N., Turner, R. (Eds.), Coastal Hypoxia: Consequences for Living Resources and Ecosystems. American Geophysical Union, Washington, DC, pp. 311-320.
- Vanderkooy, S.J. and J.W. Smith (eds). 2002. The menhaden fishery of the Gulf of Mexico, United States: A regional management plan, 2002 revision. Gulf States Marine Fisheries Commission, Number 99.
- Vaughan, D.S., K.W. Shertzer, and J.W. Smith. 2007. Gulf menhaden (*Brevoortia patronus*) in the U.S. Gulf of Mexico: Fishery characteristics and biological reference points for management. Fisheries Research 83:263-275.

Table 1. Constant M from life history approaches, using K and L_{∞} averaged across annual values, either full period of 1964-2010 or recent period of 2000-2010. Maximum age, t_{\max} , is 6 years, and water temperature, $T^{\circ}\text{C}$, is 23. For comparison, we have included the average estimates of M from age-varying approaches for ages 1-6.

Life History	Parameters	Recent (2000-2010)	Overall (1964-2010)
<i>Fixed M Approaches:</i>	$t_{\max} = 6$ $T = 23^{\circ}\text{C}$	$L_{\infty} = 22.87 \text{ cm},$ $K = 0.46$ $t_0 = -1.14$	$L_{\infty} = 26.36 \text{ cm},$ $K = 0.41$ $t_0 = -1.03$
Alverson & Carney	K, t_{\max}	0.744	0.795
Hoening	t_{\max}	0.705	0.705
Jensen	K	0.69	0.615
Pauly	$K, L_{\infty}, T^{\circ}\text{C}$	1.06	0.943
Rule of thumb	t_{\max}	0.5	0.5
<i>Age Varying Approaches:</i>		<i>M Averaged over Ages 1-6 and then over years</i>	
Peterson & Wroblewski	W_a^{-1}	0.762	0.754
Boudreau & Dickie	W_a^{-1}	0.785	0.776
Lorenzen	W_a^{-1}	0.843	0.772

Table 2. Summaries of various age-specific estimates of M including those as inverse function of size at age [Petersen and Wroblewski (1984), Boudreau and Dickie (1989), Lorenzen (1996), and Lorenzen scaled to the Hoenig estimate of M] using the Von Bertalanffy parameters from the entire time series.

Age	Peterson & Wroblewski	Boudreau & Dickie	Lorenzen	Scaled Lorenzen
0	1.05	1.20	1.12	0.88
1	0.86	0.92	0.90	0.71
2	0.75	0.76	0.77	0.60
3	0.69	0.68	0.70	0.55
4	0.66	0.64	0.66	0.52
5	0.64	0.62	0.64	0.50
6	0.63	0.60	0.62	0.49

Table 3. Lorenzen age-specific estimates of M scaled to the mean, upper, and lower range of estimates of M from the tagging study throughout the Gulf of Mexico by Ahrenholz (1981).

Age	Scaled to mean value	Scaled to lower value	Scaled to upper value
0	1.98	1.24	2.90
1	1.60	1.01	2.35
2	1.36	0.85	1.99
3	1.24	0.78	1.81
4	1.17	0.73	1.71
5	1.13	0.71	1.65
6	1.10	0.69	1.61

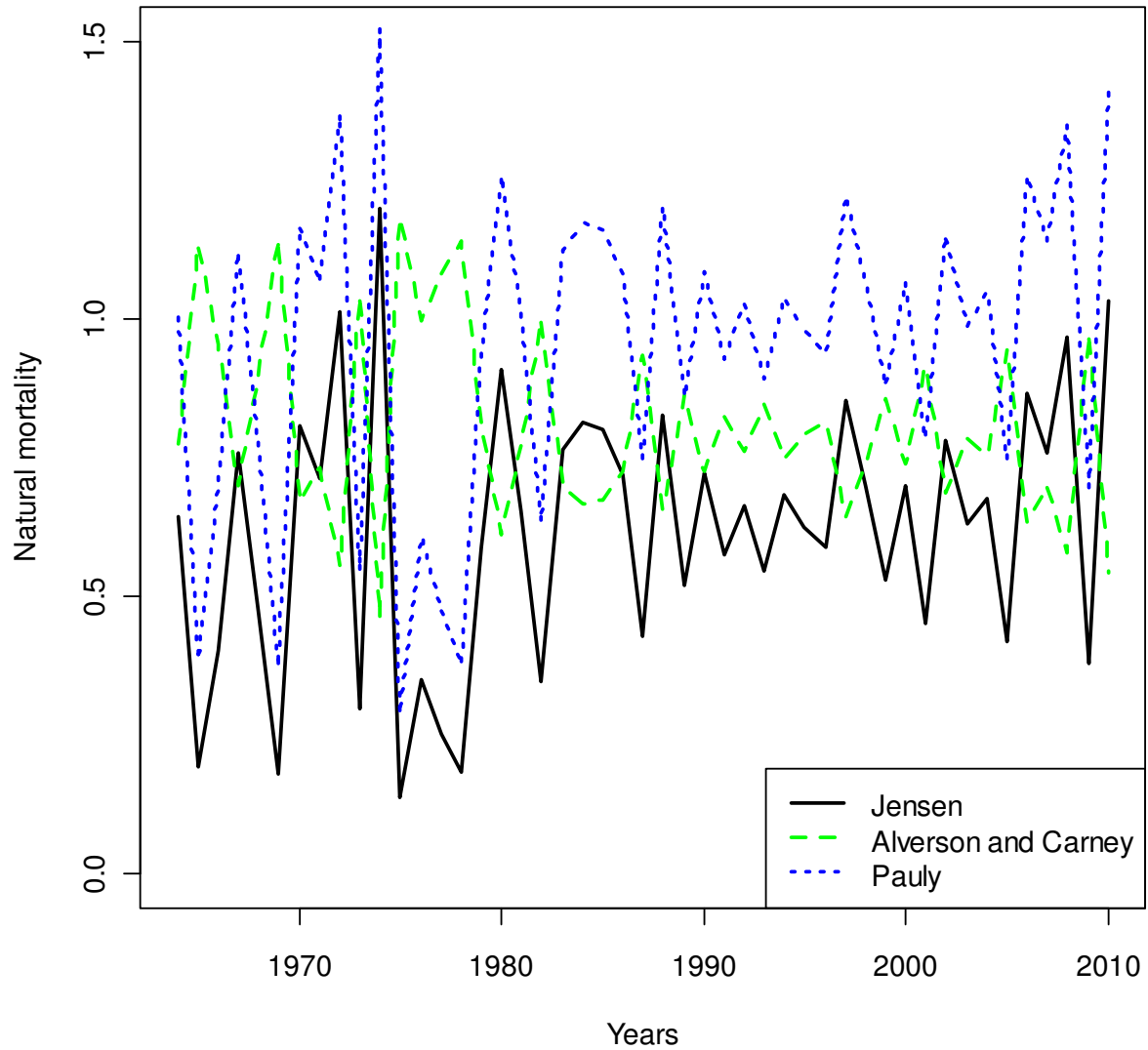


Figure 1. Annual calculated values of M using the age-constant M approaches of Jensen, Alverson and Carney, and Pauly.

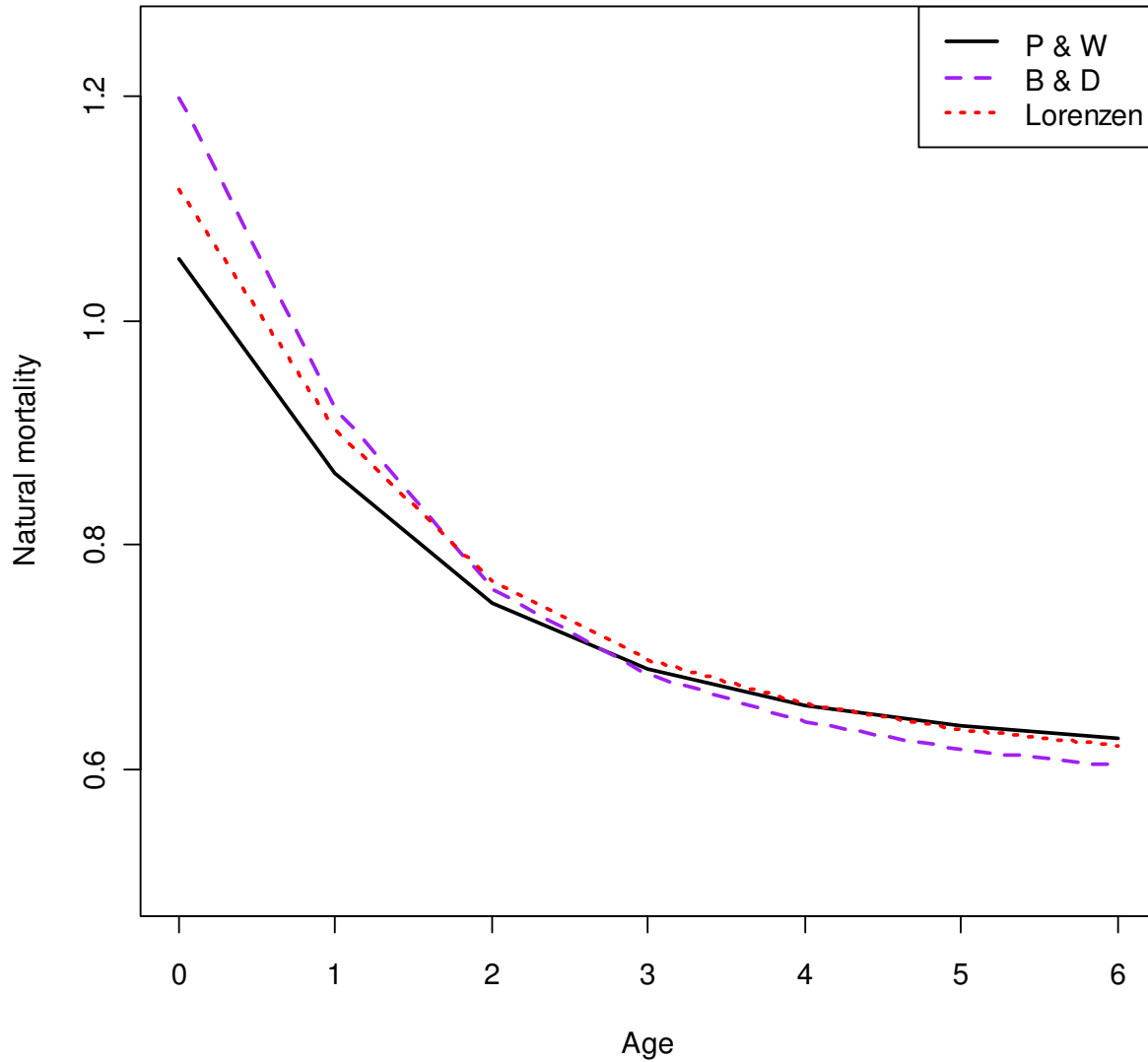


Figure 2. Age-varying estimates of M averaged across all available years for three age-varying methods based on weight at age (Boudreau & Dickie, Peterson & Wroblewski, and Lorenzen).

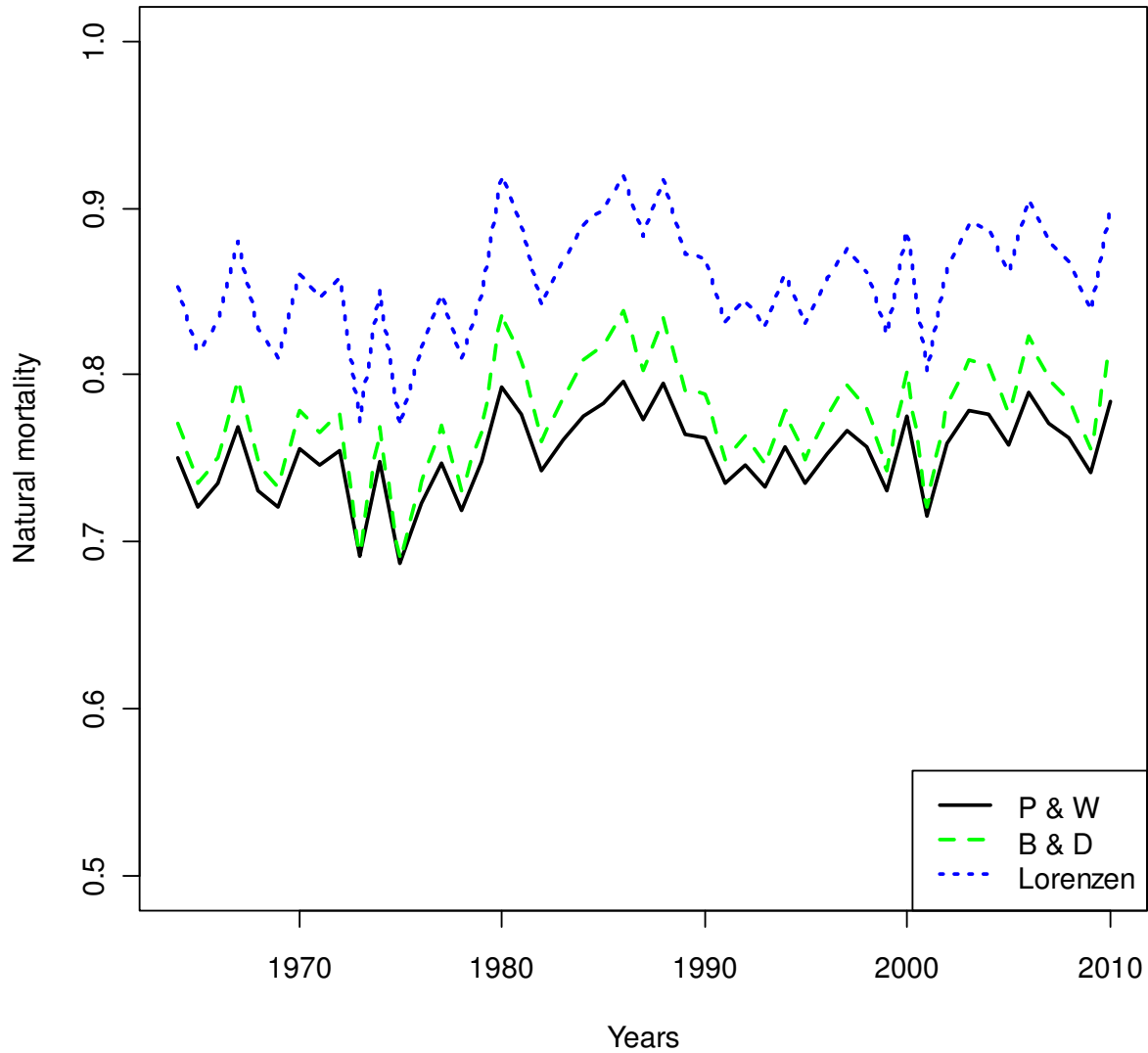


Figure 3. Comparison of several age-varying methods for estimating M including Peterson & Wroblewski, Boudreau & Dickie, and Lorenzen, where the natural mortality values are the average over ages for each year.