### Use and misuse of a common growth metric: guidance for appropriately calculating and reporting specific growth rate

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### Abstract

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# Introduction

Growth is one of the most commonly calculated vital rates in aquaculture and fisheries management. Growth is often related to the other vital rates, survival (Garvey et al., 1998; Olson, 1996; Post and Evans, 1989) and fecundity (Danylchuk and Fox, 1994; Michaletz, 1998), and is a critical component determining yield from a fishery (Ricker, 1975). Fish growth is of great interest to production aquaculture and commercial fisheries management because of its importance to yield, and to sportfish management because if its impact on population size structure. Growth is the net result of energy intake and expenditure and, as such, is usually influenced by environmental conditions such as prey availability (Crane and Einhouse, 2016; Hoxmeier et al., 2006; Michaletz, 2014), predation risk (Shoup et al., 2003; Westerberg et al., 2004), turbidity (Shoup and Lane, 2015; Tomcko and Pierce, 2001), temperature (Michaletz, 2014; Weber et al., 2015), and water chemistry (Shoup et al., 2007; Tomcko and Pierce, 2001). Growth can be expressed in many ways (e.g., relative growth, instantaneous growth, size-specific growth), but all growth metrics requires knowledge of the size of fish at two or more points in time, either from direct or indirect (e.g., back calculation, modeling mean length at age, etc.) measurements (Shoup and Michaletz, 2017). The time interval between size measurements can range from days to decades depending on the species and question of interest.

It is often assumed that weight of fish, especially small fish, increases exponentially over short periods of time (e.g., hours, days, weeks, or a few years). With this assumption, the instantaneous growth rate () is defined as

where and are fish weights at times and (with ), respectively. Instantaneous growth rates are difficult to interpret because the units for are log weight units per unit time (Elliott and Hurley, 1995). For this reason, may be converted to a specific growth rate (SGR) with

which has units of percent per time unit (of weight). However, several widely used texts (Busacker et al., 1990; Moyle and Cech, 2004; Shoup and Michaletz, 2017; Wootton, 1990), and highly cited reviews on growth of fishes and research publications (Hopkins, 1992; Cook et al., 2000; Lugert et al., 2016) have defined the SGR as

and incorrectly claimed that this had the same units as the SGR in eq. 2.

Most criticism of SGR has focused on whether or not an exponential model is an appropriate model to describe fish growth (thoroughly reviewed in Dumas et al. (2010) and Lugert et al. (2016)), which we will not address here. Our objectives here are to (1) demonstrate through a review of the fisheries literature that the incorrect equation of eq. 3 is commonly used instead of the correct equation of eq. 2 and (2) illustrate how using eq. 3 instead of eq. 2 can lead to errors in interpretation.

# Literature review

## Paper selection and data extraction

We reviewed the fisheries literature to determine the extent to which SGR is used, the rate at which the typical SGR (equation 1) and the correct SGR (equation 2) equations are used, and other characteristics related to the use of SGR (described below). To estimate the overall use of SGR, we recorded the number of results returned by GoogleScholar (hereafter, GS) using the search criteria ‘”specific growth rate” AND fish’ for each year from 2009 to 2018. We then obtained a sample of approximately 1000 results each year from this search using PublishOrPerish (Harzing, 2007). To reduce any ranking bias related to the GS search algorithm, we randomized the results from each year and then examined as many results as needed to obtain a sample of 30 results per year that met the following criteria: a result must be a journal article (i.e., a “paper”), be electronically accessible to us via the internet or our library subscriptions, be written in English, be peer-reviewed, not be a synthetic review, specifically mention “specific growth rate” or “SGR” and have SGR be a substantive portion of the paper, be about fish (shellfish were excluded), provide the specific SGR equation, and not use the mass-specific SGR (Ostrovsky, 1995; Sigourney et al., 2008). We recorded the reasons why a paper was not included in our sample and the number of papers that we examined each year to reach 30 included papers. For papers included in our sample we recorded whether the correct, typical, or some other equation was used for the SGR; the reference (if any) provided for the SGR equation used; whether lengths or weights were used in the SGR; units reported for the SGR; and whether the SGR was used primarily in the context of an aquaculture or ecological study. For papers where either the correct or typical equation was not used, we recorded whether it appeared that the authors used the typical equation but presented it with typographical errors (e.g., missing or mismatched parentheses), did not multiply by 100 (i.e., presented as a proportion rather than a percentage), or did not use logarithms, or they appeared to use some other equation that was not at all similar to the typical SGR equation.

## Statistical analyses

We estimated the proportion of papers per year that did not meet our inclusion criterion with , where is the total number of papers we examined in year . We then estimated the total number of papers returned by GS that would have met our inclusion criterion with , where is the total number of results returned by GS. We used simple linear regression models to examine linear trends in either or from 2009 to 2018. Confidence intervals for percentages computed from binomial results (e.g., whether the paper had an aquaculture or ecological context) were computed with the method of Wilson (1927) as suggested by Agresti and Coull (1998), whereas those computed from multinomial results (e.g., type of equation used) used the method of May and Johnson (2000). All statistical analyses were conducted in the R environment (R Core Team, 2019) and using binom.wilson() of the epitools package (Aragon, 2017) and multinomialCi() from the multinomialCI package (Villacorta, 2012). Significance was determined when <0.05 and 95% confidence was used when presenting confidence intervals (CI).

## Rate of SGR usage in fisheries literature

The total number of articles returned by GS that met our search criteria increased significantly () from 1830 articles in 2009 to 3170 articles in 2018, an average increase of 142 (CI:92-193) articles per year (Figure 1). Between 38.8% (in 2016) and 68.1% (in 2009) of GoogleScholar results per year did not meet our inclusion criterion. The primary reason for not being included was because the article did not meet our seach criterion of being about fish (54.8% of excluded articles) or about SGR (8.8%). An additional 12.0% were excluded because the article did no present the SGR equation. The total number of articles that would have met our inclusion criteria increased significantly () from 584 in 2009 to 1865 in 2018, an average increase of 132 (CI:84-181) articles per year (Figure 1).

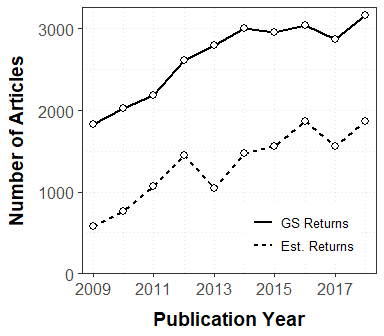


Figure 1: Number of articles returned from a GoogleScholar search using ‘specific growth rate’ AND fish and the estimated number of articles that met our inclusion criteria by year from 2009-2018.

## Characteristics of SGR usage

The vast majority of papers that used SGR were related to aquaculture (92.6%; CI: 89.1-95.1%) as compared to general fish ecology, and used weight (96.0%; CI: 93.1-97.7%) rather than length as the measure of size. Only 10 of the 300 papers (3.3%; CI: 1.8-6.0%) that we examined from 2009 to 2018 used the correct equation for SGR, all of which used the correct units of %/day. Six of the 10 papers that used the correct equation for SGR provided a reference for the equation, with five citing Houde and Schekter (1981) and one citing Ricker (1975). The typical SGR equation was used in 85.7% (CI: 81.2-89.2%) of the papers. Additional papers appeared to attempt to use the typical equation, but 4.7% (CI: 2.8-7.7%) presented the equation with a likely typographical error, 2.3% (CI: 1.1-4.7%) did not multiply by 100, and 1.7% (CI: 0.7-3.8%) did not use logarithms. Of the 290 papers that did not use the correct SGR equation, 19.7% (CI: 15.5-24.6%) either did not present units for the SGR or different units appeared throughout the paper. Of the 233 papers that did not use the correction SGR equation and provided consistent units for the SGR, 71.7% (CI: 65.6-77.1%) used %/day and 17.2% (CI: 12.9-22.5%) used %, with the remaining 11.2% (CI: 7.7-15.8%) using a variety of incorrect units.

# Correct versus common SGR equation

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We argue that the SGR equation is incorrectly formulated, and therefore incorrectly reported as a percent change in daily growth. Because the SGR equation actually represents instantaneous growth, the units are log weight per unit time (Elliott & Hurley 1995) not percent weight per unit time. However, it has become convention in the aquaculture and fisheries literature to multiply the instantaneous growth rate by 100 and report the value as a percentage change in weight per unit time. Although this method for reporting specific growth rate is included in several widely used texts (Busacker et al. 1990; Wooten 1990, Moyle & Cech 2004; Shoup and Michaletz 2017), and highly cited reviews on growth of fishes and research publications (e.g., Hopkins 1992; Cook et al. 2000; Lugert et al. 2014), it is only an approximation of percent change in weight and is negatively biased (Hopkins 1992). The conventional SGR equation (eq. 1) uses an instantaneous rate to approximate a finite rate (% weight/day). Therefore, error is affected by both the total change in body size (numerator) and duration of the study (denominator). For a given size fish, the difference between the instantaneous and true exponential growth rate decreases as t increases because the estimate of the slope of the secant line is based on smaller and smaller intervals (i.e., the linear secant line better approximates the curved exponential line as the interval between two points decreases). Similarly, for a given duration of study (t), greater changes in weight will result in increased bias of growth rates compared the true exponential growth rate.

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# Conclusions and recommendations

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### Conflict of interest

Authors declare they have no conflict of interest.

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