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[Article]

A Method for Correcting the Relative Weight (W_r) Index for Seasonal Patterns in Relative Condition (K_n) with Length as Applied to Walleye in Wisconsin

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Abstract.—We determined whether the relative weight (W_r) model for walleye *Sander vitreus* was representative of populations in Wisconsin and if relative weight varied with length seasonally. We then developed standard condition (K_n) models that correct for seasonal variation in body condition. We compiled data from 54,657 walleyes sampled during 640 surveys of 202 lakes in 30 Wisconsin counties. Weight–length relationships and mean relative weight varied more widely for Wisconsin populations than for North American populations overall. Weight–length relationships and mean relative weight varied significantly among seasons, with the highest slope (lowest intercept) and mean relative weight in spring, lowest slope (highest intercept) and mean relative weight in early summer, and intermediate slopes (and intercepts) and mean relative weights in late summer and autumn. Mean relative weight increased with length in spring, decreased with length in early summer, and did not change with length in late summer, autumn, or over all seasons combined. For samples collected in spring or early summer, we found that relative weight did not accurately index body condition or estimate trends in body condition with length. We propose a new index, adjusted relative weight (the product of W_r and a seasonal K_n model, $W_r \cdot K_n$) that adjusts relative weight for life-history-based seasonal trends in body condition with length.

Indices of body condition have been widely used to index relative plumpness of fish because the relative plumpness of individuals in a population or group of interest is thought to reflect conditions for feeding and growth, and thus, population density (Murphy et al. 1991; Anderson and Neumann 1996). Indices of body condition are most often used for comparing groups of individuals with an expectation of what is considered to be normal for the population or species of interest. Whenever a group of individuals is below normal in their body condition, then management actions can be taken to remedy the problem(s) that gave rise to the abnormal body condition. For example, low (poor) body condition is expected for populations that are high in density relative to their prey supply, and may lead to high natural mortality because individuals in the population are less fit. Therefore, if body condition of a population of interest is low, the population may benefit from management actions (such as reduced stocking) that reduce overall density.

Indices of body condition include Fulton's index (K), relative condition (K_n), and relative weight (W_r; Murphy et al. 1991; Anderson and Neumann 1996). Fulton's index relates individual weight to length cubed ($K = W/L^3$), but changes with length when growth is allometric, which is usually true. Consequently, K must be used to index the body condition of fish of similar length, which is most appropriate for evaluating the body condition of a single life stage, as in many hatchery applications. Relative condition relates individual weight to a standard *population* weight ($K_n = W/\alpha L^\beta$), which must be specified for a population or region of interest (Le Cren 1951). Consequently, K_n is limited to comparisons of individuals in a population of interest with a standard population. For example, Swingle (1965) and Swingle and Shell (1971) developed standard weight–length models for use in evaluating the body condition of fishes within Alabama. Relative weight relates individual weight to a standard *species* weight ($W_r = 100 \times W/\alpha L^\beta$), which must be specified for each species

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throughout its range (Wege and Anderson 1978). Consequently, W_r can be compared among individuals anywhere within the species' range. Relative weight has been widely applied to most important fish species, but does not account for seasonal changes in body condition.

Relative weight has become the most popular index of body condition, and standard weight equations have now been derived for nearly 70 North American species of fish (D. W. Willis, South Dakota State University, unpublished data). Relative weight models are normally derived by (1) compiling weight–length data from populations of a species throughout its range, (2) estimating slopes and intercepts of weight–length relationships for all populations included in the sample, and (3) statistically deriving a standard weight–length equation from the sample of equations (Murphy et al. 1991; Anderson and Neumann 1996). The mean relative weights of a representative sample of populations from throughout their range are centered near 100, most populations falling between 95 and 105 (Wege and Anderson 1978). Therefore, any population whose mean relative weight falls outside the objective range could be a population in need of a management remedy or further study. Unfortunately, relative weight models do not account for seasonal changes in body condition related to reproduction, so the timing of sampling can greatly affect the pattern with which relative weight changes with length. Ideally, a change in relative weight with length would reflect a trend in feeding conditions rather than a seasonal trend in gonad weight, but a single relative weight model cannot be used to differentiate these two mechanisms for a single sample of fish from a population.

Our objectives were to (1) determine whether the relative weight model for walleye *Sander vitreus* developed by Murphy et al. (1990) represented walleye populations in Wisconsin, (2) determine whether relative weight varies with length seasonally, and (3) develop standard weight–length models for walleyes that correct for seasonal variation in body condition. Murphy et al. (1990) developed a standard weight–length model for walleyes from a compilation of data for 114 populations across North America. For the eight Wisconsin walleye populations included in the compilation by Murphy et al. (1990; Balsam Lake, Big McKenzie Lake, Lake Chippewa, Grindstone Lake, Yates Lake, Wisconsin River, Round Lake, and Lake Superior), mean W_r averaged 95 (SD = 5.3) and ranged from 87 (Wisconsin River) to 104 (Lake Superior). Therefore, we sought to determine if the standard weight equation depicted typical Wisconsin walleye populations. We also sought to determine if relative weight varied seasonally and if we could adjust relative weight for seasonal trends in body condition with length that are expected based on population biology, but do not reflect underlying conditions for feeding and growth.

Methods

To derive standard seasonal weight–length models for estimating relative condition (K_n) of walleyes in Wisconsin, we compiled weight–length data for populations from a statewide database of fisheries (fish and creel) surveys during 1944–2002. Multiple data sets from the same lake were treated as separate samples, as in the compilation by Murphy et al. (1990). First, we classified each survey according to the season in which the survey was completed (January–May, June–July, August–September, or October–December) so we could develop seasonal weight–length models. Next, we excluded any survey for which too few fish were weighed to accurately estimate the parameters of the weight–length equation ($N < 10$ fish) and restricted the data to fish longer than 150 mm (Murphy et al. 1990). Second, we used linear regression to estimate parameters for the weight-length relationship, $W = \alpha L^{\beta}$, from the $\log_{10}$ transformed version of the equation $\log_{10}(W) = \log_{10}(\alpha) + \beta\log_{10}(L) + \varepsilon$. Third, we tested the significance of seasonal patterns in weight–length relationships using analysis of variance (ANOVA), with the slope of survey weight–length relationships as the dependent variable and season as the factor. Fourth, we estimated the arithmetic mean slope and intercept from the sample of slopes and intercepts as parameters for a standard overall walleye weight–length model (over all seasons) and for standard weight–length models for each season.

To evaluate seasonal patterns in mean relative weight (W_r) of walleyes in Wisconsin, we expressed predicted weights at length from our seasonal and standard weight–length equations (K_n) in relation to the standard weight–length equation for the species (W_s). First, we calculated the predicted weight for each 1.0-in length-class for the standard weight–length relationship (W_s) developed by Murphy et al. (1990). Next, we calculated the predicted weight for each 1.0-in length-class for our average seasonal and standard weight–length models (K_n) for walleyes in Wisconsin.

Next, we divided the predicted weight for each 1.0-in length-class for our seasonal and standard weight–length models by the associated predicted weights for the standard weight–length model by Murphy et al. (1990). Next, we plotted the resulting mean predicted relative weight against each 1.0-in length-class for each of our seasonal models and our overall model to evaluate seasonal trends in relative weight with length. Last, we tested the significance of seasonal patterns in mean relative weight using ANOVA (mean relative weight for each survey as the dependent variable and season as the factor).

To correct for seasonal trends in relative weight (W_r) of walleyes in particular Wisconsin waters, we modified the standard weight–length model using the appropriate seasonal model for the season in which specific weight–length data were collected. First, we estimated relative condition, K_n, for each 1.0-in length-class for the population of interest with our appropriate season-specific model. Next, we estimated relative weight, W_r, for each 1.0-in length class using the species-specific standard equation, W_s, for the species (Murphy et al. 1990). Last, we estimated ''adjusted relative weight'' ($K_n \cdot W_r$) as the product of K_n and W_r for each 1.0-in length-class. Resulting patterns in adjusted relative weight with length reflected trends that were not associated with expected reproductive seasonal trends. We illustrate the method for two lakes: (1) Lake Nebagamon—914 acres, Douglas County, low-density population (2.58 adults per acre), sampled June–July 1994; and (2) Ballard Lake—505 acres, Vilas County, high-density population (5.17 adults/acre), sampled on 21 April 1991.

Results

We compiled data from 54,657 walleyes, which were sampled during 640 surveys in 202 lakes in 30 Wisconsin counties. Of the 54,657 walleyes and 640 surveys, 77% of the fish and 54% of the surveys were in spring (January–May), 9% of the fish and 19% of the surveys were in early summer (June–July), 8% of the fish and 15% of the surveys were in late summer (August–September), and 6% of the fish and 12% of the surveys were in autumn (October–December). In addition, 39% of the 640 surveys were from lakes with only one survey, 38% were from lakes with 2–4 surveys, and 23% were from lakes with 5–16 surveys. Lakes with weight–length data represented 6% of the 3,292 lakes in Wisconsin, and counties in which those lakes lay represented 42% of 72 Wisconsin counties with at least one lake. The spatial distribution of lakes surveyed for weight–length data approximated the spatial distribution of lakes in Wisconsin (Figure 1).

FIGURE 1.—Map showing the locations of Wisconsin walleye populations for which weight–length data were used to evaluate relative weight as an index of body condition.

Weight–length relationships and mean relative weight varied more widely for Wisconsin walleye populations than for those analyzed by Murphy et al. (1990). Slopes of weight–length relationships for our analyses ranged from 1.46 to 5.76 (mean = 3.20; SD = 0.48), whereas those analyzed by Murphy et al. (1990) ranged from 2.34 to 3.91 (mean = 3.15; SD = 0.24; Figure 2). Intercepts of weight–length relationships for our analyses ranged from −6.89 to −1.62 (mean = −3.74; SD = 0.59), whereas those analyzed by Murphy et al. (1990) ranged from −4.60 to −2.71 (mean = −3.64; SD = 0.30; Figure 2). Mean relative weight for our analyses ranged from 39 to 118 (mean = 86; SD = 10.4), whereas those analyzed by Murphy et al. (1990) ranged from 73 to 116 (mean = 93; SD = 7.6; Figure 3). Mean relative weight fell between 95 and 105 for only 13% of all surveys in our analysis, but did so for 35% of the surveys analyzed by Murphy et al. (1990).

Weight–length relationships, mean relative weight (W_r), and relationships between mean relative weight and length varied among seasons for Wisconsin walleye populations. Weight–length relationships varied significantly among seasons ($F_{3,}$

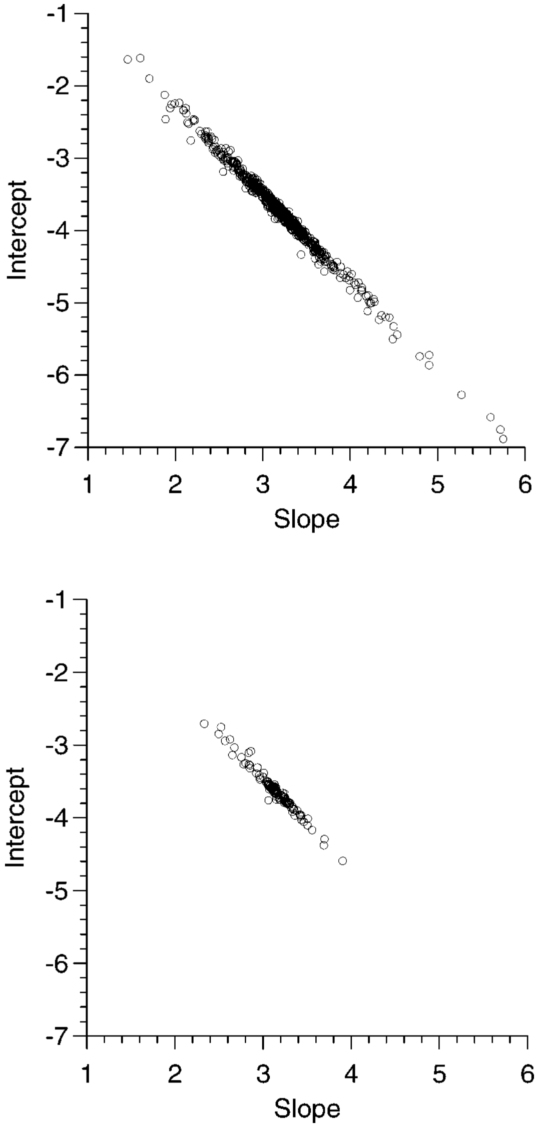

FIGURE 2.—Intercepts versus slopes for weight–length relationships of walleyes in Wisconsin (upper panel; this study) and in North America (lower panel; Murphy et al. 1990).

$_{636} = 2.97$; $P = 0.03$), with the highest slope (lowest intercept) in spring (January–May), lowest slope (highest intercept) in early summer (June–July), and intermediate slopes (and intercepts) in late summer (August–September) and autumn (October–December; Table 1). Similarly, mean W_r varied significantly among seasons ($F_{3,\,636} = 7.28$; $P < 0.001$); highest mean W_r was in spring (January–May), lowest mean W_r was in early summer (June–July), and intermediate mean W_r was in late summer (August–September) and autumn (October–December; Figure 4). Mean W_r varied with length differently among seasons as W_r increased with length in spring (January–May), decreased with length in early summer (June–July), and did not change with length in late summer (August–September), autumn (October–December), or overall (Figure 5).

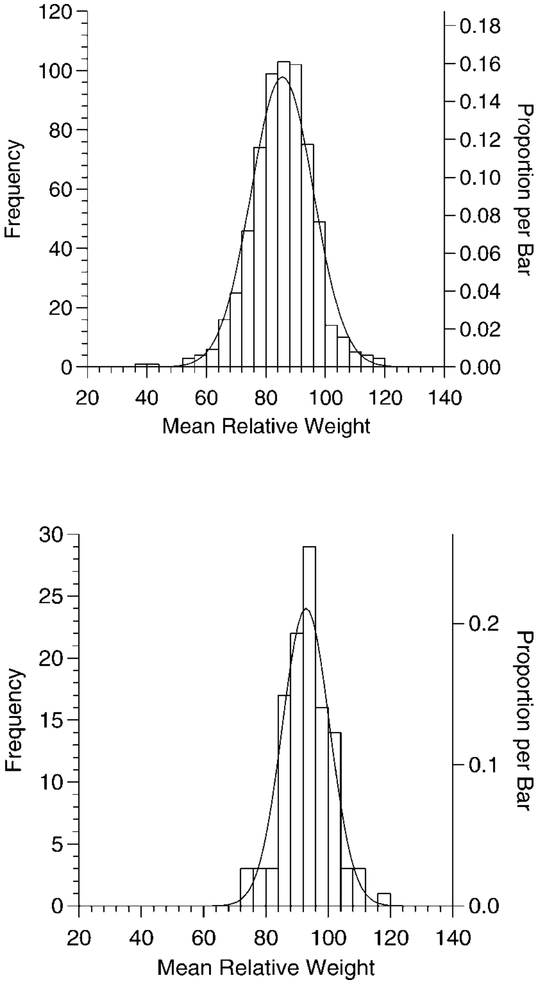

FIGURE 3.—Distribution of mean relative weight (bars) and the associated normal curve of the distribution (curve) for walleye populations in Wisconsin (upper panel; this study) and in North America (lower panel; Murphy et al. 1990).

Mean relative weight of walleyes increased with length in spring in Ballard Lake and decreased with length in early summer in Lake Nebagamon, and both trends were biased by relative weight when not corrected for seasonality of length-related trends in body condition (Figure 6). In Bal-

TABLE 1.—Intercept and slope parameter estimates and SEs of weight–length relationships for walleye populations in Wisconsin in spring (January–May), early summer (June–July), late summer (August–September), and autumn (October–December).

Season	Surveys	Intercept Estimate	Intercept SE	Slope Estimate	Slope SE
January–May	346	−3.786	0.026	3.243	0.021
June–July	121	−3.629	0.059	3.093	0.048
August–September	97	−3.730	0.081	3.188	0.068
October–December	76	−3.726	0.069	3.188	0.055
Overall	640	−3.741	0.023	3.200	0.019

lard Lake, mean relative weight was estimated too high for small fish and too low for large fish, and the increase in relative weight with length was estimated too shallow when not corrected for the spring sampling period (adjusted relative weight), when body condition increases steeply with length prior to spawning. In Lake Nebagamon, mean relative weight was estimated too high and the decline with length was estimated too shallow when not corrected for the early summer sampling period (adjusted relative weight), when body condition declines steeply with length following spawning.

Discussion

We found that the range of weight–length relations and the mean relative weight of walleyes in Wisconsin exceeded those of the populations used to develop the standard equation for walleyes in North America, which suggests that the standard equation may not represent the full range of growth potential for walleyes in North America. Murphy et al. (1991) suggested that a relative weight model should be developed from a sample of populations that represents the full range of growth potential for the species. We were surprised to find that parameters of weight–length equations and mean relative weight ranged more widely for Wisconsin than for North America because the standard equation was developed from weight–length data for 114 populations in 35 states and four provinces in North America (Murphy et al. 1990). The wider range of weight–length relations and mean relative weight in our study was not caused by the inclusion of small samples or small fish in samples because we used the same criteria for minimum sample size (10 fish) and minimum length (150 mm) used by Murphy et al. (1990). Therefore, we conclude that walleye populations in Wisconsin range more widely in body condition than populations analyzed by Murphy et al. (1990). The wider range

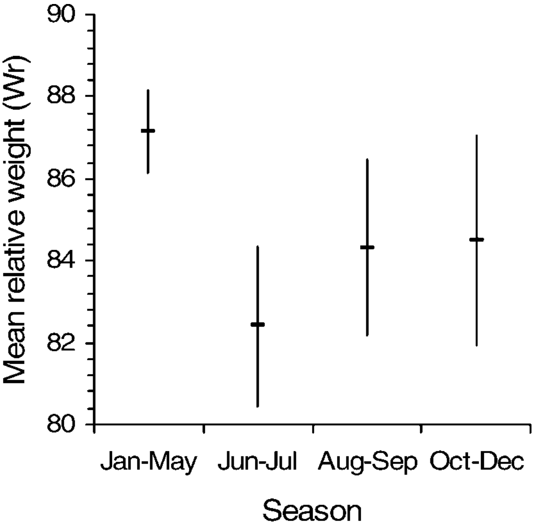

FIGURE 4.—Mean relative weight ± 95% confidence intervals for walleyes in Wisconsin during spring (January–May), early summer (June–July), late summer (August–September), and autumn (October–December).

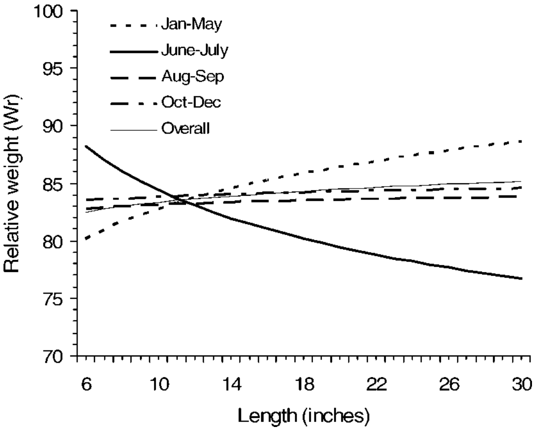

FIGURE 5.—Mean relative weight versus length for walleyes in Wisconsin during spring (January–May), early summer (June–July), late summer (August–September), autumn (October–December), and over all months (Overall).

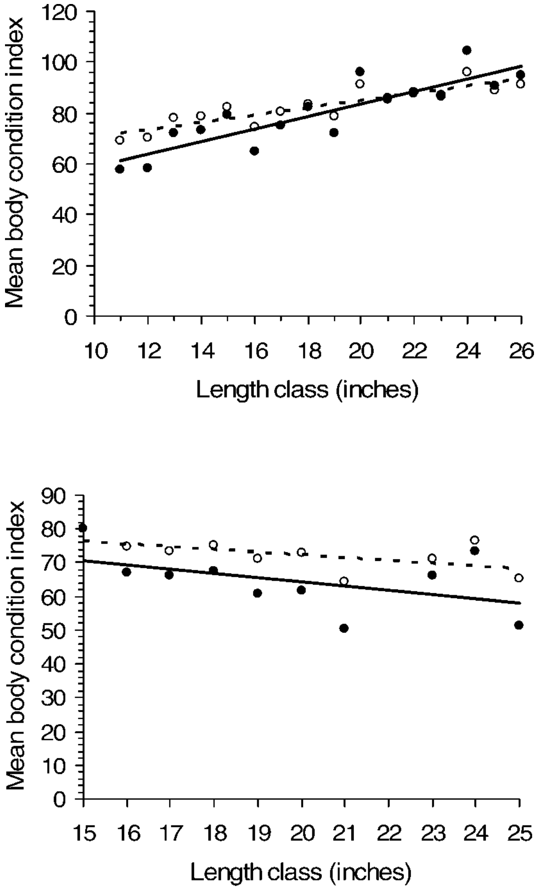

FIGURE 6.—Mean body condition index for each length-class of walleyes in Ballard Lake, Vilas County, Wisconsin, 21 April 1991 (upper panel) and Lake Nebagamon, Douglas County, Wisconsin, June–July 1994 (lower panel). Solid dots with solid trend lines indicate adjusted relative weight ($W_r \cdot K_n$, where K_n is relative conditioin) and open dots with dotted trend lines indicate relative weight (W_r).

in weight–length models in our analysis does not negate the usefulness of the standard weight model for walleyes because relative weight is intended to model better-than-average growth of a species, which may not be met by the inclusion of weight–length models for populations in stunted or crowded conditions (i.e., evident as weight–length models with slopes less than 3.0; Murphy et al. 1991).

We found that the relative weight of walleyes sampled increased with length in early spring and decreased with length in late spring, which suggests that the relative weight model was not a robust index of body condition for walleyes sampled in all seasons of the year. Murphy et al. (1991) suggested that a relative weight model should not exhibit length-related biases because such biases negate one of the primary uses of relative weight (i.e., to evaluate how body condition changes with length in relation to food availability for fish of various sizes). Length-related biases in relative weight may be caused by the method used for developing the standard weight equation (Murphy et al. 1991), though the method used for developing the standard weight equation for walleyes was relatively free of any length-related bias (Murphy et al. 1990). For walleyes sampled in late summer, autumn, and overall, we found that relative weight exhibited no length-related bias, which confirms that the standard weight equation for walleyes is suitable for evaluating body condition from fish collected during some seasons or throughout the year. However, for samples of walleyes collected in spring and early summer, we found that relative weight was subject to length-related bias, which was likely associated with seasonal trends in body condition caused by gonad development. Therefore, we conclude that relative weight should not be used for evaluating the body condition of walleyes if samples are taken from the population in spring prespawning or early summer postspawning periods.

We found that the relative weight of walleyes could be adjusted for seasonal trends in body condition with length using season-specific relative condition models (i.e., adjusted relative weight). Murphy et al. (1991) recommended that relative weight models should not be developed for particular waters or regions where the relative weight model does not seem representative, but instead that local or regional weight–length summaries be used to develop relative condition models. We combined relative condition and relative weight models to correct for seasonal trends in body condition with length, while retaining the usefulness of relative weight as an index of body condition for walleyes in Wisconsin. If such a correction were not incorporated into an analysis of relative weight, samples from prespawning or postspawning periods for any species would not reflect the meaningful trend in body condition with length that is sought by the analysis (i.e., as an index of well-being and predator–prey balance). By merging seasonal relative condition models with an existing relative weight model, an analysis of body condition can be useful even when samples are taken during seasons when body condition changes with length because of trends in gonad development with length.

We found that mean relative weight for only

13% of Wisconsin walleye population surveys fell between 95 and 105, which suggests that the objective range for relative weight was lower than suggested, at least for this species in our region (Wege and Anderson 1978; Anderson 1980). In contrast to our findings, Murphy et al. (1990) found that 35% of 114 populations used to develop the standard equation for walleyes fell between 95 and 105. In Wisconsin, quartile values were 79 (25th quartile), 86 (50th quartile), and 92 (75th quartile), whereas in North America, quartile values were 86 (25th quartile), 94 (50th quartile), and 103 (75th quartile; Murphy et al. 1990). We suggest that the relative weight of walleyes in Wisconsin, and perhaps in other states of the upper Midwest region, should be judged in relation to an objective range of 86–92 until further analysis suggests an objective range that is based on a more thorough understanding of ecological balance between walleyes and their predominant prey in north temperate lakes and rivers. In addition, relative weight should be used in conjunction with other indices of population and community status (such as size structure, recruitment, growth, mortality, and population density) before prescribing management actions.

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