

The Klamath Ocean Harvest Model (KOHM): Model Specification

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Overview

The text of this section is taken verbatim from Mohr (2006a).

The Klamath Ocean Harvest Model (KOHM) is used annually by the PFMC to forecast the impacts of ocean and river fisheries on KRFC, and the expected number of KRFC natural area spawners as a result of these fisheries. The model component relationships are based on about twenty years of estimates provided by the cohort reconstructions. Goldwasser et al. (2001, Fig. 1) provides a schematic of the general flow of information into and out of the KOHM. The KOHM assesses the impacts of ocean salmon-directed fisheries between Cape Falcon, OR, and Point Sur, CA (Klamath River fall Chinook recoveries to the north and south of this region are uncommon). Fishery management of this area primarily takes the form of time-area openings and closures rather than through the use of quotas. This form of management requires an impact forecast model that is spatially and temporally explicit consistent with the management sub-areas and time-periods for which the regulations are developed.

The KOHM consists of projecting the age-specific (ages 3, 4, 5) preseason (Sept. 1) ocean forecast abundance through the various ocean fisheries by month. Fishery-area-month-age-specific ocean impact rates are applied to the age-month-specific ocean abundance. Following that an age-month-specific natural mortality rate is applied, and this alternating cycle of fishery impact rates followed by natural mortality rates is applied from September 1 (of the previous year) to the end of August (current year). At the end of August, the age-specific river return is forecast as the age-specific number of surviving fish times the age-specific maturation rate times the complement of the age-specific out-of-basin stray rate. The river tribal and recreational fisheries are quota-managed, and the model assumes that

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these fisheries take their full harvest allocation. The age-composition of the river harvest is a function of the age-composition of the run and the fishery-specific gear selectivity. The river age-specific impacts are deducted from the age-specific river return, and the remaining fish constitute the projected number of fish that will spawn. The age-specific spawning abundance is apportioned to the hatcheries and natural areas according to the age-specific forecast of the proportion of these fish in natural areas.

The sum of the age-3, age-4, and age-5 natural area spawners is the forecast number of adult natural area spawners, E , under the fishery management measures being evaluated. The PFMC FMP conservation objective for KRFC requires that $E \geq 35,000$. It also requires that $SRR \leq 2/3$, where SRR is the spawner reduction rate due to fisheries. This portion of the objective is evaluated by using the KOHM to also forecast the number of natural area spawners that would result if all fisheries were closed, E^0 , from which $SRR = 1 - E/E^0$.

Here, we provide a detailed specification of the KOHM in its current form. The symbolic notation used in this report is defined in Table 1.

Ocean Submodel

Table 2 lists the required inputs for the KOHM ocean submodel.

Proportion legal-size

The proportion of fish that are legal size is determined as

$$p = \Pr\{\text{length} \geq \mathcal{L} | \mu, \sigma^2\} \tag{1}$$

$$= 1 - \Phi(\mathcal{L}; \mu, \sigma^2), \tag{2}$$

where $\Phi(\cdot)$ is the Gaussian cumulative distribution function, and μ and σ^2 depend on age and month as provided by (Goldwasser et al., 2001).

Fishing effort

Sep-Dec previous year fall fisheries. Since these fisheries have already occurred and the associated sample data has been processed prior to the conduct of the annual assessment, f for these fisheries is estimated directly from the sample data, as described by Goldwasser et al. (2001).

Jan-Aug current year fisheries: days-open management. Effort expended in this type of fishery is assumed to be proportional to the number of days the fishery is open

$$f_{\sigma k x}^{\mathcal{D}} = \beta_{\sigma k x z}^{f \mathcal{D}} \times \mathcal{D}_{\sigma k x}, \tag{3}$$

Table 1. Notation used in this report.

Symbol	Description
a	subscript denoting age, $a \in \{3, 4, 5\}$
A	total Chinook harvest (all-stocks)
β^{cf}	contact rate per unit effort
$\beta^{f\mathcal{D}}$	effort per day open
c	contact rate (C/N)
C	contacts
d	dropoff mortality rate
D	dropoff mortality
$\mathcal{D}$	fishery days open
E_h, E_n	spawner escapement to <i>h</i> atcheries and <i>n</i> atural areas, respectively
f	effort
$f^{\mathcal{D}}$	effort: days-open fishery
$f^{\mathcal{Q}}$	effort: quota fishery
g	proportion of spawners using natural areas (versus hatcheries)
h	harvest rate (H/N)
H	harvest
i	impact rate (I/N)
I	impacts ($H + S + D$)
j	subscript denoting fishery, $j \in \{o, r, t\}$
o	ocean
r	river recreational
t	river tribal
k	subscript denoting ocean mgt. area, $k \in \{\text{NO, CO, KO, KC, FB, SF, MO}\}$
$\mathcal{L}$	minimum size-limit
μ, σ^2	mean, variance: size-at-age
m	maturation rate
M	mature fish (end of Aug)
ν	natural mortality rate
N	abundance (ocean-wide) at beginning of month
$\mathcal{P}_t$	harvest allocation: tribal relative to total ($H_t/[H_o + H_t + H_r]$)
$\mathcal{P}_r$	harvest allocation: river recreational relative to nontribal ($H_r/[H_o + H_r]$)
p	proportion of cohort that are legal size ($\geq \mathcal{L}$)
ϕ	age-composition of river harvest
$\mathcal{Q}$	quota
R	mature fish that return to the Klamath basin
s	hook-and-release (shaker) mortality rate
S	hook-and-release (shaker) mortality
τ	subscript denoting month, $\tau \in \{\text{Sep, Oct, } \dots, \text{Aug}\}$
θ	proportion of harvest that are KRFC (H/A)
v	vulnerability relative to age 4
w	out-of-basin stray rate
W	out-of-basin strays
x	subscript denoting ocean fishery sector, $x \in \{\text{commercial, recreational}\}$
z	fishery-type (pertains to effort transfer)

Table 2. KOHM ocean submodel: inputs.

Input	Description
Assessment	
$\{A_{o\tau kx}\}$	$\tau \in \{\text{Sep, Oct, Nov, Dec}\}$ (STT, 2006a)
$\{\beta_{o\tau kx}^{cf}\}$	(Mohr, 2006d)
$\{\beta_{o\tau kxz}^{fD}\}$	(Mohr, 2006d)
d_o	$= 0.05$, applied to contacts (STT, 2000)
$\{H_{o\tau kx}\}$	$\tau \in \{\text{Sep, Oct, Nov, Dec}\}$ (KRTAT, 2006b)
$\{\mu_{o\tau}, \sigma_{o\tau}^2\}$	(Goldwasser et al., 2001)
$\{m_a\}$	$=$ long-term average, provided by CDFG Ocean Salmon Project (Mohr, 2006d)
$\{\nu_{o\tau}\}$	$(1 - \nu_{o\tau})^{12} = \begin{cases} 0.5, & \leq \text{age 3 Apr (KRTT, 1986)} \\ 0.8, & \geq \text{age 3 May (KRTT, 1986)} \end{cases}$
$\{N_{o\tau}\}$	$\tau = \text{Sep}$ (KRTAT, 2006b)
$\{\rho_{o\tau k, \text{mooch}}\}$	proportion of harvest caught by “mooching”, year-month-area-specific; $=$ 5-year average, provided by CDFG Ocean Salmon Project
$\{s_{o\tau kx}\}$	$\begin{cases} 0.26, \\ 0.14, \\ (\rho_{o\tau k, \text{mooch}} \times 0.422) + ((1 - \rho_{o\tau k, \text{mooch}}) \times 0.14), \end{cases}$ $x = \text{commercial (STT, 2000)}$ $x = \text{recreational, } k \in \{\text{NO, CO, KO, KC, FB}\}$ (STT, 2000) $x = \text{recreational, } k \in \{\text{SF, MO}\}$ (STT, 2000; Grover et al., 2002)
$\{\theta_{o\tau kx}\}$	$\tau \in \{\text{Jan, Feb, Mar, Apr, May, Jun, Jul, Aug}\};$ $=$ long-term average scaled for current year abundance forecasts, provided by CDFG Ocean Salmon Project
Management	
$\{\mathcal{D}_{o\tau kxz}\}$	Pacific Fishery Management Council (STT, 2006d)
$\{\mathcal{L}_{o\tau kx}\}$	Pacific Fishery Management Council (STT, 2006d)
$\{\mathcal{Q}_{o\tau kx}\}$	Pacific Fishery Management Council (STT, 2006d)

where $\beta_{\sigma\tau kxz}^{f\mathcal{D}}$ is the effort per day. Historical effort and days-open data are used to estimate the $\{\beta_{\sigma\tau kxz}^{f\mathcal{D}}\}$, as described in Mohr (2006d).

Jan–Aug current year fisheries: quota management. Management by quota is uncommon during this time period, and when used the quotas are relatively small (typically 1,000–3,000 Chinook). Assuming the quota will be reached, the number of KRFC harvested is expected to be $Q_{\sigma\tau kx} \times \theta_{\sigma\tau kx}$. Under the basic cohort model, this is equal to $\sum_a N_{oa\tau} \times c_{oa\tau kx} \times p_{oa\tau kx}$ for the appropriate set of contact rates. Assuming that contact rates are proportional to effort, $c_{oa\tau kx} = \beta_{oa\tau kx}^{cf} \times f_{\sigma\tau kx}^Q$, the expected effort necessary to reach the quota is thus

$$f_{\sigma\tau kx}^Q = \frac{Q_{\sigma\tau kx} \times \theta_{\sigma\tau kx}}{\sum_a N_{oa\tau} \times \beta_{oa\tau kx}^{cf} \times p_{oa\tau kx}}. \quad (4)$$

Usually, a given area, month, fishery, is either days-open managed, or quota managed, but not both. Occasionally, however, both are used but during non-overlapping time periods within τ . In any case, the total effort expected is

$$f_{\sigma\tau kx} = f_{\sigma\tau kx}^{\mathcal{D}} + f_{\sigma\tau kx}^Q. \quad (5)$$

Contact rates

Sep–Dec previous year fall fisheries. Since these fisheries have already occurred and the associated sample data has been processed prior to the conduct of the annual assessment, the contact rate is based on the CWTs actually recovered in these fisheries. After these CWTs are expanded for sampling and mark-rate (providing an estimate of the KRFC hatchery production harvest), an age-specific natural production multiplier is applied to estimate the total KRFC harvest, $H_{oa\tau kx}$. The natural production multiplier is brood-specific and estimated as that year’s river return per hatchery-origin fish in that return (KRTAT, 2006b). The number of contacts is then estimated as $H_{oa\tau kx}/p_{oa\tau kx}$, and dividing this by the month-specific cohort abundance gives the contact rate

$$c_{oa\tau kx} = \frac{H_{oa\tau kx}/p_{oa\tau kx}}{N_{oa\tau}}, \quad (6)$$

where the $\{N_{oa\tau}\}$ are determined as described in the section below “Projection of cohorts”.

Jan–Aug current year fisheries. Contact rates are assumed to be proportional to effort

$$c_{oa\tau kx} = \beta_{oa\tau kx}^{cf} \times f_{\sigma\tau kx}, \quad (7)$$

where $\beta_{oa\tau kx}^{cf}$ is the contact rate per unit of effort. Historical contact rates and effort data are used to estimate the $\{\beta_{oa\tau kx}^{cf}\}$, as described in Mohr (2006d).

Projection of cohorts

Each cohort ($a = 3, 4, 5$) is projected sequentially through the ocean fisheries using the following equations. For each age a and month τ , the following are calculated for all k and x .

$$C_{oa\tau kx} = N_{oa\tau} \times c_{oa\tau kx} \quad (8)$$

$$H_{oa\tau kx} = C_{oa\tau kx} \times p_{oa\tau kx} \quad (9)$$

$$S_{oa\tau kx} = (C_{oa\tau kx} - H_{oa\tau kx}) \times s_{oa\tau kx} \quad (10)$$

$$D_{oa\tau kx} = C_{oa\tau kx} \times d_o \quad (11)$$

$$I_{oa\tau kx} = H_{oa\tau kx} + S_{oa\tau kx} + D_{oa\tau kx} \quad (12)$$

For month τ as a whole, the age a impacts are

$$I_{oa\tau} = \sum_{k,x} I_{oa\tau kx} , \quad (13)$$

and the abundance at the beginning of the following month is

$$N_{oa(\tau+1)} = (N_{oa\tau} - I_{oa\tau})(1 - \nu_{oa\tau}) , \quad \tau \neq \text{Aug}. \quad (14)$$

The number of age a fish that survive the Sep–Aug fisheries and mature are

$$M_a = (N_{oa\tau} - I_{oa\tau})(1 - \nu_{oa\tau})m_a , \quad \tau = \text{Aug} \quad (15)$$

Table 3 lists the KOHM ocean submodel outputs. The associated harvest and impact rates are

$$h_{oa\tau kx} = H_{oa\tau kx}/N_{oa\tau} , \quad h_{oa\tau} = H_{oa\tau}/N_{oa\tau} , \quad h_{oa} = H_{oa}/N_{oa(\text{Sep})} \quad (16)$$

$$i_{oa\tau kx} = I_{oa\tau kx}/N_{oa\tau} , \quad i_{oa\tau} = I_{oa\tau}/N_{oa\tau} , \quad i_{oa} = I_{oa}/N_{oa(\text{Sep})} \quad (17)$$

River Submodel

Table 4 lists the required inputs for the KOHM river submodel.

Harvest allocation

The Yurok and Hoopa Tribes are allocated a specified fraction $\mathcal{P}_t = 0.50$ of the KRFC overall harvest, and the Klamath River recreational fishery is allocated a fraction $\mathcal{P}_r$ of the KRFC non-tribal harvest specified annually by the California Fish and Game Commission.

Table 3. KOHM ocean submodel: outputs.

Input	Description
$\{A_{o\tau kx}\}$	total Chinook harvest (all-stocks) by month, area, fishery
$\{c_{oa\tau kx}\}$	contact rate by age, month, area, fishery
$\{C_{oa\tau kx}\}$	contacts by age, month, area, fishery
$\{D_{oa\tau kx}\}$	dropoff mortality by age, month, area, fishery
$\{f_{o\tau kx}\}$	effort: total ($f^{\mathcal{D}} + f^{\mathcal{Q}}$) by month, area, fishery
$\{f_{o\tau kx}^{\mathcal{D}}\}$	effort: days-open fishery by month, area, fishery
$\{f_{o\tau kx}^{\mathcal{Q}}\}$	effort: quota fishery by month, area, fishery
$\{H_{oa\tau kx}\}$	harvest by age, month, area, fishery
$\{I_{oa\tau kx}\}$	impacts by age, month, area, fishery
$\{M_a\}$	mature fish (end of Aug) by age
$\{N_{oa\tau}\}$	abundance (ocean-wide) at beginning of month by age, month
$\{S_{oa\tau kx}\}$	hook-and-release (shaker) mortality by age, month, area, fishery

Given a proposed ocean fishery configuration, the KOHM ocean submodel is used to forecast H_o , and if the harvest allocations are to be met, this implies

$$H_t = H_o \left[\frac{\mathcal{P}_t}{(1 - \mathcal{P}_t)(1 - \mathcal{P}_r)} \right] \quad (18)$$

$$H_r = H_o \left[\frac{\mathcal{P}_r}{(1 - \mathcal{P}_r)} \right]. \quad (19)$$

Harvest age-composition

The number of out-of-basin strays and river returns at age a are given by

$$W_a = M_a \times w_a \quad (20)$$

$$R_a = M_a \times (1 - w_a). \quad (21)$$

Because the bulk of the river harvest is landed in areas where the tribal and recreational fisheries are both operating, the river fisheries harvests are modeled as a simultaneous event, rather than as two sequential events. The age-composition of the tribal and recreational harvests depend not only on the age-composition of the river run, but also on the age-specific

Table 4. KOHM river submodel: inputs.

Input	Description
Assessment	
d_r	$= \begin{cases} 0.02, & \text{applied to impacts (KRTT, 1986)} \\ 0.02/(1 - 0.02), & \text{applied to harvest (KRTAT, 2006a)} \end{cases}$
d_t	$= \begin{cases} 0.08, & \text{applied to impacts (KRTT, 1986)} \\ 0.08/(1 - 0.08), & \text{applied to harvest (KRTAT, 2006a)} \end{cases}$
$\{g_a\}$	(KRTAT, 2006b)
$\{v_{ta}\}$	(Mohr, 2006d)
$\{v_{ra}\}$	(Mohr, 2006d)
$\{w_a\}$	= long-term average, provided by CDFG Ocean Salmon Project (Mohr, 2006d)
Management	
H_o	KOHM ocean submodel output
$\{M_a\}$	KOHM ocean submodel output
$\mathcal{P}_t$	Pacific Fishery Management Council (STT, 2006d)
$\mathcal{P}_r$	California Fish and Game Commission, through PFMC (STT, 2006d)

relative vulnerability of the fish to these respective fisheries.

$$\phi_{ta} = \frac{R_a \times v_{ta}}{\sum_a R_a \times v_{ta}} \quad \phi_{ra} = \frac{R_a \times v_{ra}}{\sum_a R_a \times v_{ra}} . \quad (22)$$

Projection of cohorts

Assuming that no landed adult ($a = 3, 4, 5$) fish are released, the age-specific fishery mortalities are then forecast as

$$H_{ta} = H_t \times \phi_{ta} , \quad H_{ra} = H_r \times \phi_{ra} \quad (23)$$

$$D_{ta} = H_t \times d_t , \quad D_{ra} = H_r \times d_r \quad (24)$$

$$I_{ta} = H_t + D_t , \quad I_{ra} = H_r + D_r . \quad (25)$$

The number of age a fish that survive the river fisheries to spawn in natural areas or return

to the hatcheries are forecast as

$$E_a = R_a - I_{ta} - I_{ra} \quad (26)$$

$$E_{na} = R_a \times g_a \quad (27)$$

$$E_{ha} = R_a \times (1 - g_a) \quad (28)$$

The totals for all of the above quantities are obtained by summing the respective quantity across ages.

Table 5 lists the KOHM river submodel outputs. The associated harvest and impact rates are

$$h_{ta} = H_{ta}/R_a, \quad h_{ra} = H_{ra}/R_a \quad (29)$$

$$i_{ta} = I_{ta}/R_a, \quad i_{ra} = I_{ra}/R_a. \quad (30)$$

Table 5. KOHM river submodel: outputs.

Input	Description
$\{D_{ta}\}, \{D_{ra}\}$	dropoff mortality for <i>tribal</i> and <i>recreational</i> fisheries by age
$\{E_{ha}\}, \{E_{na}\}$	spawner escapement to <i>hatcheries</i> and <i>natural</i> areas by age
$\{H_{ta}\}, \{H_{ra}\}$	harvest for <i>tribal</i> and <i>recreational</i> fisheries by age
$\{I_{ta}\}, \{I_{ra}\}$	impacts for <i>tribal</i> and <i>recreational</i> fisheries by age
$\{R_a\}$	river run by age

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