TITLE:

Seasonal and site-specific variability in terrigenous particulate organic carbon concentration in near-shore waters of Lake Biwa, Japan

AUTHOR(S):

Sakai, Yoichiro; Karube, Zin'ichi; Takeyama, Tomohiro; Kohzu, Ayato; Yoshimizu, Chikage; Nagata, Toshi; Tayasu, Ichiro; Okuda, Noboru

CITATION:

Sakai, Yoichiro ...[et al]. Seasonal and site-specific variability in terrigenous particulate organic carbon concentration in near-shore waters of Lake Biwa, Japan. *Limnology* 2013, 14(2): 167-177

ISSUE DATE:

2013-04

URL:

<http://hdl.handle.net/2433/173518>

RIGHT:

The final publication is available at link.springer.com; この論文は出版社版ではありません。引用の際には出版社版をご確認ご利用ください。 ; This is not the published version. Please cite only the published version.

1 **Title**

2 Seasonal and site-specific variability in terrigenous particulate organic carbon
3 concentration in near-shore waters of Lake Biwa, Japan

4

5 **Authors**

6 ¹Sakai Y, ²Karube Z, ³Takeyama T, ²Kohzu A, ¹Yoshimizu C, ⁴Nagata T, ¹Tayasu I and

7 ¹Okuda N

8

9 ¹Center for Ecological Research, Kyoto University, 509-3, 2-chome, Hirano, Otsu,
10 Shiga 520-2113, Japan

11 ²National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba-City, Ibaraki,
12 305-8506, Japan

13 ³Department of Biology and Geosciences, Osaka City University, 3-3-138 Sugimoto,
14 Sumiyoshi, Osaka, 558-8585, Japan

15 ⁴Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Chiba,
16 277-8564, Japan

17

18 Correspondence: Yoichiro SAKAI

- 19 Center for Ecological Research, Kyoto University, 509-3, 2-chome, Hirano, Otsu, Shiga
- 20 520-2113, Japan.
- 21 Tel: 077-549-8020
- 22 Fax: 077-549-8201
- 23 E-mail: biwaensis.2002@gmail.com
- 24

25

26 Abstract

27 Identifying sources of particulate organic matter (POM) is important for
28 clarifying fundamental mechanisms by which lake food webs are sustained. We
29 determined carbon and nitrogen stable isotope ratios of POM in near-shore waters of
30 Lake Biwa, a large, meso-eutrophic lake in Japan, to estimate relative contributions of
31 terrigenous particulate organic carbon (T-POC), plankton-derived POC (P-POC), and
32 epilithon-derived POC (E-POC) to POC in near-shore waters. Samples were collected
33 during different months (November, February, May and July) at 29 sites located near the
34 mouth of tributary rivers with different discharge and catchment land use. The data
35 revealed that POC mainly consisted of P-POC and T-POC, with relative contributions
36 varying widely over season and among locations. E-POC generally contributed little to
37 the near-shore POC. Path analyses revealed that concentration of riverine POC whose
38 isotopic signatures were similar to those of rice straws increased with a larger %paddy
39 field area in the catchment of tributary rivers, which subsequently enhanced T-POC
40 inputs to near-shore waters through riverine transportation. Furthermore, our results
41 suggested that T-POC contribution was influenced, with a time lag, by wave-driven
42 turbulence and shore topography, which appear to affect sedimentation and resuspension
43 of T-POC.

44

45 **Keywords**

46 Allochthonous input, Isotope mixing model, Land use, Path analysis, Terrigenous POM

47

48

49 Introduction

50 Particulate organic matter (POM) is a fundamental energy source for food webs
51 in lake ecosystems. POM in lake waters consists of diverse organic compounds with
52 different origins, including phytoplankton-derived POM (P-POM), epilithon-derived
53 POM (E-POM) and terrigenous POM (T-POM). Although P-POM is generally
54 considered to be a major energy source for planktonic food webs in pelagic
55 environments (Dodson 2005), E-POM and T-POM may also play an important role as
56 food resources for suspension feeders. In fact, in small to medium-sized lakes in North
57 America, some studies have revealed that terrigenous particulate organic carbon
58 (T-POC) derived from tributary rivers can subsidize pelagic food webs (Cole et al.
59 2006; Pace et al. 2007; Cole et al. 2011). Other studies, however, have suggested that
60 zooplankton growth and reproduction is slowed by the inputs of T-POM, which have
61 high C/N ratios and are low-quality food (Karlsson 2007; Brett et al. 2009). In other
62 systems, it has been reported that pelagic food webs were subsidized by benthic algal
63 products (Rautio and Vincent 2007; Karlsson and Sawstrom 2009). For aquatic
64 consumers, reliance on each of POM originated from different sources appears to vary
65 widely among lakes, depending on lake size, depth and trophic status (Chandra et al.
66 2005; Doi 2009; Vander Zanden et al. 2011). The relative contribution of POM with

67 different origins may also vary among different locations of a single lake, especially in
68 near-shore waters. For example, allochthonous input of T-POM might be large in
69 near-shore environments adjacent to river mouths, although the extent and nature of this
70 “river effect” may depend on river discharge, T-POM concentrations in river waters, and
71 physical settings of the locations (shore topography and turbulence that affect
72 sedimentation and resuspension of T-POM). Spatial and temporal variability in
73 contributions of POM with different origins within a single lake has important
74 implications for understanding mechanisms by which lake food webs are differentially
75 organized in the same species pool. Indeed, a previous work has reported that
76 allochthonous organic matter inputs to Lake Biwa from tributary catchments led to
77 spatial heterogeneity in trophic pathways within coastal macro-invertebrate
78 communities (Karube et al. 2010). However, data are highly limited to elucidate
79 mechanisms underlying spatio-temporal variability in relative contributions of P-POM,
80 T-POM and E-POM to total POM in near-shore environments.

81 Here, we measured carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) stable isotope ratios of
82 POM in near-shore water samples collected during four seasons at different locations set
83 along the shore-line of Lake Biwa. In general, C_3 terrestrial plants (T-POM) have
84 markedly different $\delta^{13}\text{C}$ (-27‰) from that of aquatic microalgae (P-POM and E-POM;

Marshall et al. 2007). Moreover, among aquatic primary producers, phytoplankton and epilithic algae have different $\delta^{13}\text{C}$, due to the CO_2 diffusion limitation within the boundary layer surrounding algal cells (Phytoplankton: -32 ± 2 (SD) ‰, epilithic algae: -17 ± 2 (SD) ‰; Fry and Sherr 1984; France 1995). In addition, $\delta^{15}\text{N}$ of aquatic primary producers may be variable among aquatic environments depending on the extent of anthropogenic nitrogen inputs (McClelland and Valiela 1998; Kohzu et al. 2008; Karube et al. 2010). The above differences in isotope signatures of POM with different origins are useful for estimating the relative contribution of P-POM, E-POM and T-POM by means of stable isotope mixing models (Fry 2006).

Lake Biwa, the largest lake in Japan, consists of two basins: the large (616 km^2), deep (average depth 41 m), mesotrophic northern basin and the small (58 km^2), shallow (average depth 4 m), eutrophic southern basin (Rossiter 2000; Somiya 2000). The lake receives water from 121 major tributary rivers and hundreds of other small creeks. The catchments of the major rivers show a wide range of land use patterns, including those prevailed by agricultural field, forest, or residence area (Somiya 2000). The 29 sampling sites of the present study covered a range of situations with variable influences of rivers that have different land use patterns in their catchments. We hypothesize that the quantity and composition of the near-shore POM can vary, on a

within-lake scale, depending on land use patterns in tributary catchments as well as on coastal physical characteristics. Assuming that POM with different origins, i.e., P-POM, E-POM and T-POM, have different stable isotopic signatures, we aim to examine what factors determine within-lake variability in relative contributions of these potential organic sources to the near-shore POM, using an isotope mixing model and a path analysis.

Materials and Methods

Sample collections

We collected POM samples at 29 sites along the shoreline of Lake Biwa in November 2005 and February 2006, May 2006, and July 2006 (Fig. 1). These sites were located near the mouth of tributary rivers, which have widely variable land use patterns (Appendix A). In most cases, the sampling sites were set within 100 m of the river mouth. For some sites, however, our research boat could not get access to the target location because these sites have a gentle coastal slope and/or are luxuriated by submerged plants. In such cases, the sampling site was set on the position of 5 m-depth contour where the distance between the site and river mouth was shortest. We measured pH and electric conductivity using a multiprofiler at each sampling site (U-22,

121 HORIBA).

122 At each sampling site, we used a water pump to collect water samples at the
123 depth of 2 m. The water samples were first filtered through a 150 μ m-mesh net to
124 remove coarse particles and then filtered through precombusted (450°C for 2 h) glass
125 fiber filters (GF/F, 0.7 μ m, Whatman). The particle size of 0.7-150 μ m covers the most
126 size range of phytoplankton found in Lake Biwa (Tsuda et al. 1992). The POMs
127 collected on the glass fiber filters were used for stable isotope analysis (see below). We
128 extracted Chlorophyll *a* from these POM samples in 90% acetone solution and
129 measured its concentration with a fluorometer (Turner Designs, 10-AU), according to
130 Wetzel and Linkens (2000). The Chlorophyll *a* concentration was used as an indicator
131 of local productivity in near-shore waters.

132 We assumed three end members (plankton, epilithon and terrigenous organic
133 matter) as primary organic sources for the near-shore POM. First, to determine isotopic
134 values of plankton-derived POM (P-POM), we collected water samples from the depth
135 of 2 m at an offshore site (Station 30, see Fig. 1) in the same months as POM sampling
136 in near-shore waters. The P-POM was filtered on precombusted GF/F filters after
137 screening with a 150 μ m-mesh net. The P-POM collected at this site was assumed to
138 have isotope signatures typical for phytoplankton-derived organic matter in the lake

because previous work has found that $\delta^{13}\text{C}$ values of POM collected there were identical to those of chlorophyll *a* extracted from offshore phytoplankton after the correction of isotope fractionation (Maki et al. 2010).

Second, to determine isotopic values of epilithon-derived POM (E-POM), epilithon samples were collected at all the sites except for some sites where boulders of appropriate size were not found (Fig. 1). At each site, epilithic organic matter scraped off, with a brush, from five boulders of moderate size (30-40 cm) which have a surface area of more than 36cm² on the upper side were mixed, filtered through precombusted GF/F filters, and served for the stable isotope analyses.

Third, we collected riverine particulate organic matter (R-POM) as a proxy of terrigenous POM (T-POM) at sites 0.5-4 km upstream from the mouth, in the same months as the near-shore sampling but in the previous year (i.e., July 2004, November 2004, February 2005 and May 2005: see Kohzu et al. 2009 for details). In general, R-POM is composed of T-POM and fluvial E-POM (Kohzu et al. 2009). In our study rivers, however, $\delta^{13}\text{C}$ of R-POM was significantly different from that of fluvial E-POM in all four months (Tukey's post-hoc test, R-POM vs. fluvial E-POM, Nov: $p < 0.001$, Feb: $p < 0.01$, May: $p < 0.01$, Jul.: $p < 0.001$) but not from C₃ terrestrial plant detritus, i.e., rice straw collected from paddy fields in any months (Tukey's post-hoc test, R-POM vs.

157 T-POM, Nov: $p=0.82$, Feb: $p=0.65$, May: $p=0.79$, Jul.: $p=0.91$), suggesting that R-POM
158 is dominated by T-POM in tributary rivers of Lake Biwa.

159 One may expect that submerged macrophytes can be a dominant source for the
160 near-shore POM. However, we did not incorporate them as an end member of our
161 mixing model for the following reasons. First, live macrophytes cannot contribute to the
162 POM pool in near-shore waters during summer growing season. It may be true that their
163 detritus contribute to the near-shore POM during decomposition process in winter,
164 especially at sampling sites in shallow south basin where macrophytes luxuriate
165 vigorously (Haga et al. 2007). However, we have little knowledge on stable isotopic
166 fractionation during their decomposition and have technical difficulty in separate their
167 detritus from a mixture of POM with different origins in the near-shore waters for the
168 stable isotope analysis. If macrophyte contribution is not much great for near-shore
169 waters of whole lake basin, we have a disadvantage to incorporate additional end
170 member into our mixing model, which will lead to low estimation accuracy for major
171 organic sources. Therefore, we did not regard submerged macrophytes as primary
172 organic sources in the near-shore water.

173 That is why we used the dominant three end members, P-POM, E-POM and
174 R-POM representative of T-POM, for our isotopic mixing model to estimate

composition of near-shore POM. All these POM samples collected on precombusted GF/F filters were exposed to 0.1 M HCl to eliminate carbonates, rinsed with distilled water, and then stored at -20°C until the stable isotope analysis.

Stable isotope analysis

The GF/F filters were dried at 60°C for 24 h, and then the residues were scraped off from the surface of filters. Carbon and nitrogen stable isotope ratios of the residues were determined using continuous-flow isotope ratio mass spectrometers (CF/IRMS; Conflo II and Delta S, Finnigan MAT, Germany and Conflo III, delta plus XP, Thermo Fisher, Germany) and their carbon content was measured using elemental analyzers (EA1108, Fisons, Italy and EA1112, Thermo Fisher, Germany). The isotope ratios were expressed as the per mil deviation from standards as follows:

$$\delta^{13}\text{C} \text{ or } \delta^{15}\text{N} = (R_{\text{sample}} / R_{\text{standard}} - 1) \times 1000 (\text{‰}),$$

where $R = {}^{13}\text{C}/{}^{12}\text{C}$ or ${}^{15}\text{N}/{}^{14}\text{N}$. Vienna Pee Dee belemnite (VPDB) and atmospheric nitrogen were used as standards for carbon and nitrogen, respectively. The analytical precision based on working standards (Tayasu et al. 2011) was $\pm 0.3\text{‰}$ for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$.

193 Isotope mixing model

194 Relative contributions of three potential organic sources (i.e., P-POM, E-POM
195 and T-POM) to POM collected at each near-shore site were estimated using an isotope
196 mixing model with $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ (IsoSource Program; Phillips and Gregg 2003). This
197 model enabled us to estimate all possible combinations of each source contribution
198 (0–100%) in 1% increments to create a set of predicted sources. The initial tolerance
199 was set at 0.1‰. If the estimated values were outliers (i.e., < 0% or > 100%), the
200 tolerance was increased in 0.1‰ steps to 2‰. The model outputs are expressed as the
201 mean value and range (minimum–maximum) for each source. From the estimated mean
202 contribution of each organic carbon source to POC concentration (mgL^{-1}) at each
203 near-shore site, we calculated the concentrations of P-POC, E-POC and T-POC
204 according to the following equation.

$$205 \quad \text{P-POC (mgL}^{-1}\text{)} = \text{POC (mgL}^{-1}\text{)} \times f_p$$

$$206 \quad \text{E-POC (mgL}^{-1}\text{)} = \text{POC (mgL}^{-1}\text{)} \times f_e$$

$$207 \quad \text{T-POC (mgL}^{-1}\text{)} = \text{POC (mgL}^{-1}\text{)} \times f_t$$

208 where f_p , f_e and f_t are the fraction of P-POC, E-POC and T-POC relative to the
209 near-shore POC (i.e., $f_p + f_e + f_t = 1$).

210 At some sites, we could not estimate each source contribution for the lack of

211 E-POC data or because the estimated contribution remained outlier for either of the
212 three sources under the above criteria for our isotopic mixing model. In the present
213 study, we present results of simulation model only for carbon source estimation but
214 analytical results on nitrogen sources were qualitatively same as the carbon source
215 estimation model.

216

217 Land use pattern and physical environments

218 Human population density (HPD in populationkm⁻²) and proportions (%) of
219 paddy field, forest, and residential areas of tributary catchment were calculated using a
220 geographical information system (GIS: Appendix A). We assumed that these indices
221 reflect the loading of terrigenous organic matter with different origins: e.g., the HPD
222 or %residential area is an indicator of organic matter derived from sewage, the %paddy
223 field area is an indicator of that from agricultural wastewater, and the %forest area an
224 indicator of that from leaf litter transported through upper streams.

225 Because there is a strong positive correlation between river discharge and
226 catchment area, we estimated the river discharge, based on the following regression for
227 tributary rivers for which discharge data are available (Shiga Prefecture1992-2002):

228 River discharge (m³ S⁻¹) = 0.0284 × catchment area^{0.9502} (R²=0.846, p<0.01)

229 where the river discharge is the average for February, May, July, and November during
230 the recent 10 years (1992-2002). Although the river discharge shows daily variation
231 depending on weather condition, its monitoring date never accorded with our sampling
232 date. Considering this variation, the inter-annual average can be a better indicator for
233 river discharge compared to single monitoring data corresponding to our sampling
234 months.

235 As physical characteristics of coastal environments, we used wave height (m),
236 wave energy flux ($\text{kg m day}^{-1}\text{m}^{-1}$), shore energy flux ($\text{kg m day}^{-1}\text{m}^{-1}$, see Nakatsuji et al.
237 2006), and coastal slope (1 d^{-1} ; d = horizontal distance from the shoreline to the point
238 with a depth of 2 m). These data are available at
239 <http://www.biwakokasen.go.jp/others/kankyoujyouhou/index.html> (Kinki Regional
240 Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism).
241 The GIS and coastal physical characteristics data are summarized in Appendix A and B.

242

243 Statistical analysis

244 We performed a nested analysis of variance (ANOVA) to test the temporal
245 variation in POC concentrations, incorporating sampling sites as a random factor into
246 the model (the nlme package of R Statistics; Pinheiro et al. 2010), which assumes that

247 error term distribution accords to gaussian distribution. If the data distribution did not
248 show normality and homoscedasticity, the dependent variable (POC concentration) was
249 $\log(x+0.5)$ -transformed satisfy the criteria for the ANOVA (Yamamura 1999). Then we
250 performed a post-hoc test for multiple comparisons using the Tukey method (the
251 multcomp package of R Statistics; Hothorn et al. 2008) to compare POC concentrations
252 among seasons. Furthermore, we performed ANOVA to compare the carbon
253 concentrations among the three organic sources (P-POC, E-POC, and T-POC) in each
254 season. All analyses were conducted using the statistical package R ver. 2.13.1 (R
255 Development Core Team 2011).

256 We performed a path analysis to examine how the land use patterns in the
257 tributary catchments and the physico-chemical characteristics of the sampling sites may
258 affect spatiotemporal variation in measured and estimated values of R-POC and T-POC
259 concentrations, respectively, incorporating GIS and environmental variables into the
260 model (see Appendix A and B). First, we screened the explanatory variables because
261 models with too many variables generate redundant information. We checked the
262 correlations among variables to remove multicollinearity and then selected the variables
263 that best accounted for the variation in R-POC and T-POC concentrations. For instance,
264 we selected wave height from among the three wave-associated variables and HPD but

265 not %residential area. Because forest and paddy field are the most dominant land use
266 types in the Lake Biwa Watershed, it is a matter of course that there is a strong negative
267 correlation between their proportional data ($R^2=0.93$, $p<0.001$). We performed two
268 preliminary models to test effects on the R-POC for each of these two land use types.
269 First, when we used %forest area solely as a GIS variable, instead of %paddy field area,
270 we found that the former showed significantly negative but not positive effects (Path
271 coefficients, Nov.: -0.44, Feb.: -0.53, May: -0.83, Jul.: -0.64, $p<0.01$). Second, when we
272 incorporated residuals of the %forest area regressed against the %paddy field area into
273 the preliminary model, we did not find any significantly positive effect of %forest area
274 on R-POC concentration, suggesting that forests cannot be a primary source of R-POC
275 loadings in catchment areas. Based on results of these preliminary analyses, therefore,
276 we excluded %forest area from a final version of our *a priori* model to reduce the
277 redundancy and the multicollinearity between potentially correlated GIS variables.

278 After screening the variables, we constructed the basic framework of an *a*
279 *priori* model consisting of two components (Fig. 3). The model was separated because
280 the data distributions were needed to be $\log(x+0.5)$ -transformed for some of explanatory
281 variables in component 2 to ensure normality and homoscedasticity for statistical
282 criteria. Component 1 was a sub-model that accounts for the variation in measured

values of R-POC (upper panel in Fig. 3). Assuming that human sewage and agricultural wastewater have strong effects on R-POC, we incorporated HPD (Path 1 in Fig. 2) and the %paddy field area (Path 2) into the model. We also assumed that the HPD and %paddy field areas have a positive interactive effect because agricultural activities are usually high in areas with a high population density and vice versa (Path 3).

Component 2 was constructed to examine which physical characteristics of coastal environments explain the site-specific variation in estimated values of T-POC concentration in near-shore waters, assuming that T-POC concentration can be affected by a dilution effect due to river discharge (Path 5), resuspension due to wave-driven turbulence (Path 6), and the potential for resuspension, which is intensified in sites with a gentle coastal slope (Path 7). These paths were assumed to have an additive effect on T-POC concentration.

The model analysis consisted of two steps. First, we conducted a simultaneous analysis of several groups, considering the four seasons as different groups. This allowed us to test for significant differences in the causal mechanisms of the seasonal dynamics of R-POC and T-POC concentrations and provided more accurate model estimation than what would have been obtained from separate analyses of each of the four groups (Arbuckle 2007). Then we selected the best-fit model, setting equality

301 constraints as a null hypothesis that the coefficient of each path is not significantly
302 different among the four seasons (Tabei 2001; Arbuckle 2007). In the initial condition,
303 the level of significance was set at 0.05 for the seasonal difference in each path
304 coefficient and was then increased up to 0.6 in intervals of 0.05. In this way, we
305 constructed a total of 12 models and compared them using the Akaike information
306 criterion (AIC). We selected the best-fit model based on the minimum AIC. The best-fit
307 model was tested using the chi-square goodness-of-fit. We also evaluated its
308 goodness-of-fit based on the root mean square error of approximation (RMSEA;
309 criterion $RMSEA < 0.05$: good, $RMSEA > 0.08$: mediocre, $RMSEA > 0.1$: not accepted,
310 Browne and Cudeck 1993). The path analysis was performed using the statistical
311 package AMOS (ver. 16, IBM-SPSS, Tokyo).

312

313 Results

314 Spatiotemporal variation in POC concentration and composition

315 Using carbon and nitrogen isotope mixing model with three end members,
316 P-POM, E-POM and R-POM, we estimated the relative contributions of three organic
317 sources (P-POC, E-POC, and T-POC) to POC at each near-shore site (Appendices
318 C&D). As indicated by a narrow range of estimated values, our isotope mixing model

319 showed high estimation accuracy (Appendix D), except for some sites (e.g., site no. 3,
320 10, 11, 13, 20 in November, 2005), in which P-POM and R-POM had similar isotopic
321 signatures (Appendix C). Based on the relative contribution of these sources, we
322 calculated the concentration of P-POC, E-POC, and T-POC (Table 1 & Fig. 4). The
323 near-shore POC concentrations differed among sites (Fig. 4) and seasons ($F_{3, 83} = 13.56$,
324 Jul. > May = Feb. > Nov., $p < 0.05$). P-POC and T-POC were the dominant organic
325 sources of the near-shore POC, whereas E-POC concentration was consistently low (Fig.
326 5). In July, the concentration of P-POC was generally higher than that T-POC (Fig. 5).
327 T-POC concentrations tended to be high at the sites located along southern and eastern
328 shores, especially in February and May (Fig. 4).

329

330 Possible factors that influences the spatiotemporal dynamics of T-POC

331 T-POC concentrations in near-shore waters showed marked spatiotemporal
332 variation at sampling sites (Fig. 4). In our path analysis, a sub-model of component 1
333 gave the best fit when the significance level for the equality constraints was set at 0.6
334 ($\chi^2=0.721$, $df=7$, $RMSEA=0.000$, $AIC=58.721$). The total effect of human land use on
335 R-POC concentration showed great seasonal variation (Fig. 6). Tributary rivers with a
336 larger %paddy field area had a consistently high R-POC concentration year-round (Path

2). In contrast, HPD did not have significantly positive effects on R-POC concentration (Path 1).

Similarly, component 2 of our path model was the best fit when the significance level was set at 0.3 ($\chi^2=0.488$, $df=42$, $RMSEA=0.057$, $AIC=140.288$). The total effect of proximate physical factors on T-POC showed great seasonal variation (Fig. 6). The allochthonous input of R-POC had a significantly positive effect on the near-shore T-POC concentration only in May (Path 4), whereas river discharge had a negative effect on the near-shore T-POC concentration in July (Path 5). Wave height always had a significantly positive effect on the near-shore T-POC concentration (Path 6), and the near-shore T-POC concentration was higher for sites with a gentle coastal slope in February and May (Path 7).

Discussion

Our data demonstrated that near-shore T-POC concentrations varied widely among sites and over season. The results of path analysis suggested that agricultural wastewater from the paddy fields was the primary driver affecting the near-shore T-POC concentration via increased inputs of R-POC. Especially in May, we detected a significant, robust path in that the %paddy field area had a positive effect on the

near-shore T-POC concentration via R-POC inputs (Path 2 & 4). Large contribution of T-POC in May could be related to agricultural practices in this season. Previous work has reported that a large quantity of paddy-derived wastewater flows into the lake basin at the onset of the rice irrigation period between late April and early May (Fujii et al. 2002; Haga and Ohtsuka 2003; Ohkubo and Azuma 2005; Hama et al. 2010). The results of the present study support the notion that agricultural activities, especially paddy irrigation, can be a significant factor that affects T-POC concentrations in near-shore environments of Lake Biwa. It is also interesting to note that %paddy field area had a positive effect on R-POC concentration even in February when paddy field activities are considered to be minimal. This suggests the possibility that organic-rich soils can be eroded from paddy fields even in winter, due to snowing and melting. Although the underlying mechanisms have not yet been poorly understood, they remain to be investigated in the future.

The results of path analysis also suggested that physical characteristics of coastal environment, including coastal slope and wave height, have significant effects on T-POC concentration in near-shore waters. We speculate that waves and gentle coastal slopes might synergistically enhance the resuspension of sedimentary T-POC, resulting in increased terrestrial contribution to the near-shore POC. This notion is

partly supported by findings of Murase and Sakamoto (2000) who reported that the near-shore sediments of Lake Biwa contained a large quantity of terrigenous organic matter. Intriguingly, in the present study, although R-POC had a positive effect on amount of near-shore T-POC only in May (Path 4), the wave effects were strongest in November, after rice field irrigation season (Fig. 6). These results suggest that agricultural wastewater loading had a time lag effect on the T-POC concentration via sedimentation and wave-driven resuspension in near-shore waters.

One might expect allochthonous inputs of R-POC to be magnified by river discharge, as well as by its concentration. However, our analysis did not support this prediction and revealed that river discharge had strongly negative effects on the near-shore T-POC concentrations in July with high precipitation. In general, flooding has the potential to increase concentration of suspended organic matter in river water and consequently organic matter loadings on near-shore waters. However, we avoided field samplings during flooding events because our interest was in land use effects on allochthonous inputs but not in physical transportation mechanisms under ordinary flow conditions. During the rainy season, discharge of larger rivers which receive larger quantity of rain waters in their larger catchment areas might have a greater dilution effect on near-shore POC.

391 In near-shore waters of Lake Biwa, POC was composed mainly of P-POC and
392 T-POC, whereas E-POC contributed little to POC regardless of the season and site. In
393 some shallow and oligotrophic lakes, it has been reported that epilithic-derived trophic
394 energy flows dominate in coastal food webs (Rautio and Vincent 2007; Karlsson and
395 Sawstrom 2009). There are two possible mechanisms in which relative contribution of
396 E-POC was low in Lake Biwa basins. One is associated with lake morphological
397 features: Lake Biwa has a deep structure with a steep slope, especially for large north
398 basin, in which the proportional area of shallow waters to the whole basin was
399 considerably small (Sakamoto 2000), suggesting that habitats are limited for epilithic
400 growth. Another mechanism is that an increase in P-POM and T-POM decreases light
401 penetration to the lake bottom, which has negative effects on epilithic growth
402 (Vadeboncoeur et al. 2001, 2003). Consistent with our observation, previous studies
403 have reported that filter-feeding macrozoobenthos and zooplankton in near-shore
404 environments of Lake Biwa relied mainly on P-POC and T-POC rather than on E-POC
405 (Karube et al. 2010). Their production reliance is also trophically transferred to that of
406 predatory fishes, characterizing food web configuration of whole communities (Okuda
407 et al. 2012).

408 In the present study, we did not consider contribution of detrital macrophytes to

409 the near-shore POM for the following two reasons. First, in Lake Biwa, especially in
410 deep north basin, the area of shallow habitats available to macrophytes is
411 disproportionately small relative to that of the whole basin, so that their total primary
412 production is much lower than that of phytoplankton and of even epilithon whose
413 euphotic zone is deeper than the macrophytes (Sakamoto 2000). Second, we have
414 technical difficulty in separating macrophyte detrital fraction from a mixture of POM
415 with different origins in the near-shore water for the stable isotope analysis and thus in
416 characterizing isotopic alteration during their decomposition in nature. To evaluate their
417 contribution, one of promising approaches is polyunsaturated fatty acid (PUFA) analysis,
418 which can quantify each of organic sources by characterizing the composition of
419 primary producer-specific polyunsaturated fatty acids (Kelly and Scheibling 2012). In
420 floodplain lakes of the central Brazilian Amazon basin, for instance, the technique
421 revealed that macrophyte detritus is a primary component of suspended POM during
422 low water season (Mortillaro et al. 2011). The application of PUFA analysis, even if it is
423 beyond our scope in the present study, will be a future challenge for better
424 understanding of seasonal changes inorganic matter flows in Lake Biwa, especially in
425 shallow south basin where submerged plants have recently luxuriated.

426 Using stable isotope approaches, we demonstrated that allochthonous inputs of

427 T-POC to near-shore waters were affected not only by the land use pattern in tributary
428 catchment areas, but also by the physical characteristics of local coastal environments.
429 This suggests that the spatiotemporal heterogeneity of food quality and quantity for
430 aquatic consumers will create a dynamic pattern of coastal food webs, altering the
431 relative importance of autochthonous grazing food chain and allochthonous microbial
432 loop in lake ecosystems.

433

434 **Acknowledgments**

435 We are grateful to Dr. T. Koitabashi and Dr. Y. Goda for field assistance. We
436 also thank to Dr. E. Nakajima for useful comments on the manuscript. Dr. T. Ohtsuka
437 provided technical advice on statistics. This study was supported by the JSPS Grant-in
438 Aid (No.23657019 and No.24370010), the CREST project, JST and The Environment
439 Research and Technology Development Fund (D-1102 and S-9) of the Ministry of the
440 Environment, Japan. This study was partly supported by the Research Project 3-1 of The
441 Research Institute for Humanity and Nature. YS, ZK and NO were also supported by
442 Global COE Program A06 “Formation of a strategic base for biodiversity and
443 evolutionary research: from genome to ecosystem” from the MEXT, Japan.

444

445

446 **Reference**

447 Arbuckle JL (2007) Amos 16.0 User's Guide. Amos Development Corporation, Spring

448 House

449 Brett MT, Kainz MJ, Taipale SJ, Seshan H (2009) Phytoplankton, not allochthonous

450 carbon, sustains herbivorous zooplankton production. Proceedings of the National

451 Academy of Sciences 106:21197-21201

452 Browne M W, and Cudeck R(1993) Alternative ways of assessing model fit. In:Bollen

453 KA and Long JS (ed.) Testing structural equation models, Sage Publications, Newbury

454 Park, pp136–162.

455 Chandra S, Vander Zanden MJ, Heyvaert AC, Richards BC, Allen BC, Goldman CR

456 (2005) The effects of cultural eutrophication on the coupling between pelagic primary

457 producers and benthic consumers. Limnology and Oceanography 50:1368-1376

458 Cole JJ, Carpenter SR, Kitchell J, Pace ML, Solomon CT, Weidel B (2011) Strong

459 evidence for terrestrial support of zooplankton in small lakes based on stable isotopes of

460 carbon, nitrogen, and hydrogen. Proceedings of the National Academy of Sciences of

461 the United States of America 108:1975-1980

462 Cole JJ, Carpenter SR, Pace ML, Van de Bogert MC, Kitchell JL, Hodgson JR (2006)

- 463 Differential support of lake food webs by three types of terrestrial organic carbon.
- 464 Ecology Letters 9:558-568
- 465 Dodson S. I. (2005) Introduction to Limnology 1st ed, McGraw-Hill Companies Inc.
- 466 New York.
- 467 Doi H (2009) Spatial patterns of autochthonous and allochthonous resources in aquatic
- 468 food webs. PopulEcol 51:57-64
- 469 France RL (1995) Carbon - 13 enrichment in benthic compared to planktonic algae -
- 470 foodweb implications. Marine Ecology-Progress Series 124:307-312
- 471 Fry B (2006) Stable Isotope Ecology. Springer, New York
- 472 Fry B, Sherr EB (1984) $\delta^{13}\text{C}$ measurements as indicators of carbon flow in marine and
- 473 fresh-water ecosystems. Contributions in Marine Science 27:13-47
- 474 Fujii S, Tanaka H, Somiya I (2002) Quantitative comparison of forests and other areas
- 475 with dry weather input loading in the Lake Biwa catchment area. Water Science and
- 476 Technology 45:183-193
- 477 Haga H, Ohtsuka T (2003) Changes in transparency (Secchi disk reading) of the pelagic
- 478 zone of the main basin of Lake Biwa over a span of 73 years (in Japanese). Japanese
- 479 Journal of Limnology 64:133-139
- 480 Haga H, Ohtsuka T, Matsuda M, Ashiya M (2007) Echosounding observations of

- 481 coverage, height, PVI, and biomass of submerged macrophytes in the southern basin of
482 Lake Biwa, Japan. *Limnology* 8:95-102
- 483 Hama T, Nakamura K, Kawashima S (2010) Effectiveness of cyclic irrigation in
484 reducing suspended solids load from a paddy-field district. *Agricultural Water*
485 *Management* 97:483-489
- 486 Hothorn. T, Bretz. F, Westfall. P (2008) Simultaneous Inference in General Parametric
487 Models. *Biometrical Journal* 50:346-363
- 488 Karlsson J (2007) Different carbon support for respiration and secondary production in
489 unproductive lakes. *Oikos* 116:1691-1696
- 490 Karlsson J, Sawstrom C (2009) Benthic algae support zooplankton growth during
491 winter in a clear-water lake. *Oikos* 118:539-544
- 492 Karube Z, Sakai Y, Takeyama T, Okuda N, Kohzu A, Yoshimizu C, Nagata T, Tayasu I
493 (2010) Carbon and nitrogen stable isotope ratios of macroinvertebrates in the littoral
494 zone of Lake Biwa as indicators of anthropogenic activities in the watershed. *Ecological*
495 *Research* 25:847-855
- 496 Kelly JR, Scheibling RE (2012) Fatty acids as dietary tracers in benthic food webs.
497 *Marine Ecology Progress Series* 446:1-22
- 498 Kohzu A, Miyajima T, Tayasu I, Yoshimizu C, Hyodo F, Matsui K, Nakano T, Wada E,

- 499 Fujita N, Nagata T (2008) Use of Stable Nitrogen Isotope Signatures of Riparian
500 Macrophytes As an Indicator of Anthropogenic N Inputs to River Ecosystems.
501 Environmental Science & Technology 42:7837-7841
- 502 Kohzu A, Tayasu I, Yoshimizu C, Maruyama A, Kohmatsu Y, Hyodo F, Onoda Y, Igeta
503 A, Matsui K, Nakano T, Wada E, Nagata T, Takemon Y (2009) Nitrogen-stable isotopic
504 signatures of basal food items, primary consumers and omnivores in rivers with
505 different levels of human impact. Ecological Research 24:127-136
- 506 Maki K, Kim C, Yoshimizu C, Tayasu I, Miyajima T, Nagata T (2010) Autochthonous
507 origin of semi-labile dissolved organic carbon in a large monomictic lake (Lake Biwa):
508 carbon stable isotopic evidence. Limnology 11:143-153
- 509 Marshall JD, Brooks JR, Lajtha K (2007) Sources of variation in the stable isotopic
510 composition of plants. In Michener R. and Lajtha K. (ed) Stable isotopes in Ecology and
511 Environmental Science, 2nd ed., Blackwell, Malden, pp 22-60
- 512 Tsuda R, Kumagai M, Kakui Y (1992) Spatial changes of phytoplanktonic size spectra
513 in Lake Biwa. Hydrobiologia 243-244:137-140
- 514 McClelland JW, Valiela I (1998) Linking nitrogen in estuarine producers to land-derived
515 sources. Limnology and Oceanography 43:577-585
- 516 Mortillaro JM, Abril G, Moreira-Turcq P, Sobrinho RL, Perez M, Meziane T (2011)

517 Fatty acid and stable isotope ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) signatures of particulate organic
518 matter in the lower Amazon River: Seasonal contrasts and connectivity between
519 floodplain lakes and the mainstem. *Organic Geochemistry* 42:1159-1168

520 Murase J, Sakamoto M (2000) Horizontal distribution of carbon and nitrogen and their
521 isotopic compositions in the surface sediment of Lake Biwa. *Limnology* 1:177-184

522 Nakatsuji T, Nakamura K, Amano K (2006) Effects of wave and geomorphology on
523 growth and distribution of lakeshore vegetation (in Japanese). *Journal of Japan Society*
524 *of Civil Engineers, Ser. G* 62:135-140

525 Ohkubo T, Azuma Y (2005) Load of turbid from the watershed of Lake Biwa and its
526 effect on the lake water quality. Memorial volume of the Lake Biwa Research Institute
527 (in Japanese) Lake Biwa Research Institute, Otsu, Shiga, Japan:55–72

528 Okuda N, Takeyama T, Komiya T, Kato Y, Okuzaki Y, Karube Z, Sakai Y, Hori M,
529 Tayasu I, Nagata T (2012) A food web and its long-term dynamics in Lake Biwa: a
530 stable isotope approach. In: Kawanabe H. et al. (ed) *Lake Biwa: Interactions between*
531 *nature and people*. Springer Academic, Amsterdam, pp205-210

532 Pace ML, Carpenter SR, Cole JJ, Coloso JJ, Kitchell JF, Hodgson JR, Middelburg JJ,
533 Preston ND, Solomon CT, Weidel BC (2007) Does terrestrial organic carbon subsidize
534 the planktonic food web in a clear-water lake? *Limnology and Oceanography*

- 535 52:2177-2189
- 536 Phillips DL, Gregg JW (2003) Source partitioning using stable isotopes: coping with too
- 537 many sources. *Oecologia* 136:261-269
- 538 Pinheiro. J, Bates. D, DebRoy. S, Sarkar. D, R Development Core Team (2010) nlme:
- 539 Linear and Nonlinear Mixed Effects Models. R package version 3.1-102.
- 540 Rautio M, F. Vincent W (2007) Isotopic analysis of the sources of organic carbon for
- 541 zooplankton in shallow subarctic and arctic waters. *Ecography* 30:77-87
- 542 R Development Core Team (2011) R: a Language and Environment for Statistical
- 543 Computing. R Foundation for Statistical Computing, Vienna, Austria.
- 544 Rossiter A (2000) Lake Biwa as a topical ancient lake In: Rossiter A, Kawanabe H (ed)
- 545 Ancient Lakes: Biodiversity, Ecology and Evolution. *Advances in Ecological Research*
- 546 31: 571-598, Academic Press, London
- 547 Sakamoto M (2000) Organisms in Lake Biwa. In: Somiya I (ed) Lake Biwa:
- 548 environment and water quality formation (in Japanese), Gihodoshuppan, Tokyo, pp
- 549 187-246
- 550 Shiga prefecture (1992-2002) White paper on the environment of Shiga Prefecture (in
- 551 Japanese). Shiga Prefecture, Japan
- 552 Somiya I (ed) (2000) Lake Biwa: environment and water quality formation (in

- 553 Japanese). Gihodoshuppan, Tokyo
- 554 Tabei A (2001) Perfect master of SPSS: Questionnaire data analysis using covariance
- 555 structure analysis (AMOS) (in Japanese). Tokyotosyoshuppan, Tokyo
- 556 Tayasu I, Hirasawa R, Ogawa N. O, Ohkouchi N, Yamada K (2011) New organic
- 557 reference materials for carbon- and nitrogen-stable isotope ratio measurements provided
- 558 by Center for Ecological Research, Kyoto University, and Institute of Biogeosciences,
- 559 Japan Agency for Marine-Earth Science and Technology. Limnology 1-6
- 560 Tsuda R, Kumagai M, Kakui Y (1992) Spatial changes of phytoplanktonic size spectra
- 561 in Lake Biwa. Hydrobiologia 243-244:137-140
- 562 Vadeboncoeur Y, Jeppesen E, Vander Zanden MJ, Schierup HH, Christoffersen K,
- 563 Lodge DM (2003) From Greenland to green lakes: Cultural eutrophication and the loss
- 564 of benthic pathways in lakes. Limnology and Oceanography 48:1408-1418
- 565 Vadeboncoeur Y, Lodge DM, Carpenter SR (2001) Whole-lake fertilization effects on
- 566 distribution of primary production between benthic and pelagic habitats. Ecology
- 567 82:1065-1077
- 568 Vander Zanden MJ, Vadeboncoeur Y, Chandra S (2011) Fish Reliance on littoral-benthic
- 569 resources and the distribution of primary production in lakes. Ecosystems 14:894-903
- 570 Wetzel RG, Likens GE (2000) Limnological analysis, 3rd edn. Springer Verlag, Berlin

- 571 Yamamura K (1999) Transformation using $(x+0.5)$ to stabilize the variance of
- 572 populations. Research on Population Ecology 41:229-234
- 573
- 574

575

576 **Figure and Table Legends**

577 **Fig. 1**

578 A map of POC sampling sites (no. 1-30) in the near-shore waters of Lake Biwa.

579 No. 30 is the reference site for P-POM. See Appendix A and B for details of site
580 information.

581

582 **Fig. 2**

583 Carbon and nitrogen isotopic signatures of near-shore POM and their potential organic
584 sources (P-POM, E-POM and R-POM). Each plot represents mean from all sampling
585 sites, and vertical and horizontal bars indicate range (also see Appendix C). Note that
586 P-POM data are derived from only a pelagic site.

587

588 **Fig. 3**

589 An *a priori* path model to explain the variation in T-POC concentrations in the
590 near-shore waters of Lake Biwa. The model consists of two components. Unidirectional
591 arrows indicate a causal effect and double headed arrows interactive effect.

592

593 **Fig. 4**

Spatiotemporal variations in the concentrations of three components, P-POC, E-POC and T-POC, of POC in the near-shore waters of Lake Biwa. The size of each circle is proportional to the POC concentration. Transparent circles represent sites where the relative contributions of three potential organic sources could not be estimated (see Materials and Methods).

Fig. 5

Seasonal changes in the composition of three potential organic sources of POC in the near-shore waters of Lake Biwa. Vertical bars are the standard deviation.

Fig. 6

The path model based on the simultaneous analysis of multiple populations with structured means. The basic framework is the same as that in Figure 2. Dark and light arrows are significant ($p < 0.05$) and not significant ($p > 0.05$) paths, respectively. Values with arrows are path coefficients. The subscripts of R-POC and $\log(T\text{-POC})$ indicate the total effect on these variables.

611

612 **Table 1**

613 Measured POC concentration and estimated P-POC, E-POC and T-POC concentrations

614 (mgL^{-1}) at each coastal site in Lake Biwa.

615

616

617

618 **Appendix A**

619 Geographic information system (GIS) data and riverine organic matter for each tributary
620 catchment area. Land use pattern is expressed as the proportional area.

621

622 **Appendix B**

623 The major environmental data and the physical characteristics of the corresponding
624 coastal site.

625

626 **Appendix C**

627 Carbon and nitrogen stable isotope ratios (‰) of POM and its three potential sources
628 (P-POM, E-POM, and R-POM) at each coastal site.

629

630 **Appendix D**

631 The relative contribution (%) of the three potential sources (P-POM, E-POM and
632 T-POM) to POM at each coastal site.

633

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Table 1

Measured POC concentration and estimated P-POC, E-POC and T-POC concentrations (mg L⁻¹) at each coastal site in Lake Biwa.

Site no.	Name of tributary rivers	Nov. 2005				Feb. 2006				May 2006				Jul. 2006			
		POC	P-POC	E-POC	T-POC	POC	P-POC	E-POC	T-POC	POC	P-POC	E-POC	T-POC	POC	P-POC	E-POC	T-POC
1	Kamo River	1.614	1.473	0.077	0.061	3.346	3.286	0.013	0.047	3.897	1.489	0.596	1.812	3.421	3.281	0.109	0.031
2	Ado R.	1.493				1.226	1.060	0.147	0.020	1.724	0.655	0.360	0.708	4.256	3.349	0.145	0.757
3	Ishida R.	1.446	0.450	0.139	0.857	0.981	0.801	0.061	0.120	1.796				6.145	5.408	0.277	0.461
4	Momose R.	2.300	1.851	0.007	0.442	1.242	1.226	0.009	0.009	2.531				5.720	3.318	0.686	1.722
5	Oura R.	1.222	1.213	0.004	0.004	2.274	1.569	0.000	0.705	0.921				7.029	5.286	0.056	1.687
6	Shiotsu-o R.	1.249	1.225	0.014	0.009	2.310	1.400	0.284	0.626	4.259				5.567	0.167	0.484	4.916
7	Chonoki R.	1.709	1.355	0.048	0.306	1.771	1.593	0.000	0.177	4.395	1.481	0.040	2.875	8.603	4.069	0.792	3.742
8	Ta R.	1.713	1.358	0.048	0.307	1.391				4.586	0.000	0.000	0.000	7.001			
9	Ane R.	1.963	1.580	0.075	0.308	1.862	1.178	0.013	0.670	2.595				6.974	6.939	0.035	0.000
10	Yone R.	1.607	0.754	0.212	0.640	2.953	1.603	0.009	1.343	3.291	0.000	0.000	0.000	10.145			
11	Amano R.	1.711	0.707	0.147	0.857	6.035	2.124	0.024	3.886	4.758				8.501	7.337	0.867	0.298
12	Seri R.	2.166	1.967	0.022	0.178	4.101	2.215	0.021	1.866	3.021	0.000	0.000	0.000	6.820	5.524	0.184	1.112
13	Inukami R.	1.866	0.507	0.140	1.216	8.151	3.831	0.000	4.320	4.348	1.991	0.009	2.348	6.617	6.432	0.119	0.066
14	Ajiki R.	2.116	0.224	0.421	1.473	9.595	2.178	0.384	7.024	3.378	0.000	0.000	0.000	6.102	5.504	0.531	0.073
15	Uso R.	4.483	4.339	0.031	0.112	6.672	3.303	0.000	3.369	4.984	3.908	0.030	1.052	6.047	5.654	0.181	0.212
16	Bunroku R.	2.601				2.533	1.824	0.000	0.709	4.699	0.000	0.000	0.000	5.470	5.054	0.284	0.137
17	Nomazu R.	2.794				3.336	2.605	0.400	0.327	6.483	3.468	0.000	3.015	9.929	9.055	0.109	0.764
18	Echi R.	3.920	3.175	0.008	0.737	2.327	1.682	0.016	0.628	3.701				12.012			
19	Nagaso R.	5.833	0.117	2.187	3.529	12.609				7.392	6.099	0.022	1.271	6.220	5.847	0.000	0.373
20	Hayama R.	6.262	1.828	0.645	3.782	21.669	1.517	1.408	18.744	8.838	0.168	2.121	6.549	9.259	9.027	0.000	0.231
21	Shin-moriyama R.	3.095	0.025	1.711	1.362	34.982	5.527	8.046	21.409	14.337	5.448	0.115	8.774	12.896	0.064	0.000	12.831
22	Yasu R.	6.179				3.684				6.571				11.995			
23	Yanomune R.	11.544				3.388	2.101	0.000	1.287	3.883	1.091	0.043	2.753	11.108	9.742	0.022	1.344
24	Hino R.	3.567	0.235	1.384	1.948	5.953	3.661	0.000	2.292	3.339	0.053	0.013	3.273	9.522	8.665	0.809	0.048
25	U R.	2.136	1.816	0.000	0.320	2.263	1.878	0.373	0.011	3.161	2.580	0.095	0.487	3.545	0.025	0.982	2.542
26	Wani R.	1.117	0.978	0.003	0.136	3.539	2.902	0.000	0.637	2.741	2.119	0.005	0.617	4.516	1.165	0.379	2.972
27	Mano R.	2.322	2.220	0.063	0.039	2.585	1.383	0.000	1.202	4.185	3.955	0.230	0.000	3.694	3.380	0.314	0.000
28	Tenjin R.	3.431	3.431	0.000	0.000	5.342	3.776	0.118	1.448	4.860	3.377	0.967	0.510	5.831	4.869	0.000	0.962
29	Fujinoki R.	2.081	0.010	2.071	0.000	8.922	3.953	0.625	4.345	6.095	2.206	3.870	0.018	6.197	4.709	0.000	1.487
Offshore reference site																	
30	Ie-1	2.38				2.22				3.01				4.73			

Appendix A

Geographic information system (GIS) data and riverine organic matter for each tributary catchment area. Land use pattern is expressed as the proportional area.

Station No.	Station Name	Human population (ind)	Human population density (ind. km ⁻²)	Catchment area (km ²)	% Paddy field	% Other crop land area	% Forest area	% Waste land area	% Residential area	% Traffic area	% Liver and Lake area	% Other area	Riverin Particulate Organic Nutrient (PON)				Riverin Particulate Organic Carbon (POC)			
													(μ mol L ⁻¹)				(μ mol L ⁻¹)			
													Nov. 2005	Feb. 2006	May 2006	Jul. 2006	Nov. 2005	Feb. 2006	May 2006	Jul. 2006
1	Kamo River	4149	89.16	46.531	18.13	0.48	74.80	1.67	1.20	0.09	2.05	1.58	1.014	2.779	2.722	2.331	9.872	29.989	22.935	20.056
2	Ado R.	8185	26.74	306.123	3.11	0.54	91.45	1.42	0.71	0.01	1.76	0.80	0.979	0.331	1.842	1.280	7.518	2.459	11.818	10.687
3	Ishida R.	5023	83.83	59.926	9.58	0.93	81.11	4.13	1.96	0.02	0.86	1.42	0.666	0.696	2.450	1.190	5.820	7.297	16.998	11.342
4	Momose R.	851	64.74	13.142	4.02	0.34	87.69	1.23	0.56	0.00	3.07	3.10	0.731	0.818	3.508	2.757	5.797	7.669	31.119	27.666
5	Oura R.	3828	97.62	39.209	11.28	1.61	78.52	2.19	2.67	0.16	0.94	2.63	7.627	9.810	4.809	4.032	96.905	136.730	45.918	46.646
6	Shiotsu-o R.	1111	55.03	20.242	6.66	0.38	86.85	1.29	1.57	1.34	1.38	0.51	11.435	9.279	2.485	1.822	143.682	148.315	21.167	19.257
7	Chonoki R.	4219	412.28	10.234	76.29	3.61	0.09	0.08	13.52	0.01	5.13	1.27	5.815	31.818	9.420	2.305	51.361	264.691	69.923	21.837
8	Ta R.	10853	301.33	36.016	46.68	2.08	37.10	0.25	9.59	1.39	1.93	0.99	11.907	12.720	5.298	9.858	118.184	133.328	44.291	120.706
9	Ane R.	22516	60.57	372.261	5.91	1.08	88.16	0.81	1.70	0.06	1.63	0.65	2.926	6.996	1.618	1.064	28.161	90.280	12.117	10.066
10	Yone R.	31047	2047.40	15.164	54.84	1.27	0.76	0.00	34.54	1.82	1.50	5.27	2.825	2.312	1.858	3.281	23.010	25.849	17.330	34.578
11	Amano R.	24994	225.70	110.935	18.48	2.48	66.31	1.49	5.82	1.44	1.97	2.01	21.215	1.770	2.883	1.538	160.075	18.646	24.513	14.668
12	Seri R.	34039	462.06	73.859	6.96	0.91	75.20	2.20	8.09	1.32	2.36	2.60	5.529	1.807	1.467	2.036	37.959	20.657	11.392	17.104
13	Inukami R.	11066	109.47	101.626	6.74	0.86	82.16	3.30	2.79	0.41	3.14	0.59	7.760	2.186	0.820	0.802	45.100	24.647	7.002	7.234
14	Ajiki R.	14870	1001.57	14.847	70.24	0.68	1.06	0.14	20.11	1.25	1.80	4.72	24.544	4.425	5.132	4.172	185.768	40.110	36.507	47.858
15	Uso R.	34452	411.42	83.740	51.72	0.97	28.60	1.22	11.05	1.58	2.41	2.45	39.132	7.403	3.870	3.420	312.742	81.385	30.546	27.136
16	Bunroku R.	8323	595.25	13.981	66.79	1.22	15.68	0.90	11.69	0.00	2.35	1.35	21.247	4.018	6.447	5.407	170.537	39.113	55.116	60.821
17	Nomazu R.	5465	757.58	7.214	65.99	0.71	3.58	0.00	20.17	1.13	2.21	6.22	14.473	2.336	4.710	4.045	119.538	24.225	38.565	36.029
18	Echi R.	22957	109.59	211.139	10.41	0.72	77.97	2.85	2.54	0.10	4.79	0.61	8.799	0.936	2.579	0.997	64.881	7.945	22.102	9.721
19	Nagaso R.	11728	3174.29	3.695	18.35	2.40	20.63	1.09	31.40	7.95	5.86	12.32	17.375	4.968	4.116	1.917	138.208	53.009	34.308	46.767
20	Hayama R.	68910	2047.95	33.648	43.70	0.59	7.52	1.19	29.70	3.18	3.53	8.75	14.215	2.556	9.411	2.274	120.184	27.370	69.935	22.470
21	Shin-moriyama R.	14426	2539.60	5.680	54.53	0.19	1.16	0.37	33.73	0.10	0.59	9.34	16.716	4.585	7.420	3.444	134.247	36.162	62.000	29.964
22	Yasu R.	126122	324.12	391.183	19.96	2.51	57.67	2.16	6.50	0.40	5.58	3.11	12.572	2.348	3.311	2.595	92.455	19.354	23.234	20.113
23	Yanomune R.	35935	858.81	41.842	52.27	1.38	19.47	2.18	15.72	0.99	3.91	4.07	22.867	3.154	7.158	4.218	179.294	27.223	61.422	43.261
24	Hino R.	76360	338.11	225.846	31.26	2.14	44.32	2.02	8.42	0.43	4.89	4.41	13.271	3.116	6.309	3.253	82.902	25.800	45.762	29.626
25	U R.	465	66.15	7.028	5.96	0.00	89.06	0.45	0.81	0.32	0.78	2.62	12.367	0.278	1.063	0.917	158.484	2.551	10.894	12.313
26	Wani R.	3203	186.48	17.174	15.96	0.12	65.86	4.66	5.42	1.89	0.93	2.67	8.895	3.876	2.124	1.292	75.623	29.538	16.125	11.239
27	Mano R.	24305	1048.33	23.184	28.45	0.33	42.77	6.63	15.60	1.96	1.13	2.99	9.137	2.074	3.458	2.101	69.424	22.013	24.245	16.789
28	Tenjin R.	5268	539.33	9.768	27.48	0.95	54.70	4.15	7.31	2.79	0.86	1.76	11.925	1.573	5.300	2.673	87.948	14.400	34.817	28.289
29	Fujinoki R.	7116	1804.68	3.943	16.19	0.53	49.08	0.28	20.76	3.49	0.27	9.39	16.805	1.161	0.896	1.596	169.476	10.000	6.440	21.301

Appendix B

The major environmental data and the physical characteristics of the corresponding coastal site.

Site no.	Name of tributary rivers	Sampling location		Wave height (m)	Wave energy flux (kg m day ⁻¹ m ⁻¹)	Lake shore energy flux (kg m day ⁻¹ m ⁻¹)	Coastal slope (1 distance ⁻	Sand beach width (m)	Reed grassfield width (m)	Chl.a of near-shore POM				Conductivity				pH			
		Latitude	Longitude							(μg l L ⁻¹)				(mS m ⁻¹)							
										Nov. 2005	Feb. 2006	May 2006	Jul. 2006	Nov. 2005	Feb. 2006	May 2006	Jul. 2006	Nov. 2005	Feb. 2006	May 2006	Jul. 2006
1	Kamo River	35°17.921'	136°02.645'	0.08	-93.08	15.82	10.72	19	0	2.145	1.168	1.565	1.872	14	14	13	13	8.040	7.340	7.900	7.170
2	Ado R.	35°19.186'	136°04.947'	0.09	15.07	14.42	8.12	8	0	1.333	0.752	1.275	1.872	13	13	13	13	7.440	7.360	6.800	7.620
3	Ishida R.	35°24.185'	136°03.058'	0.08	183.11	33.68	9.37	20	0	1.971	0.752	1.275	3.188	13	14	13	13	7.310	7.660	7.500	7.830
4	Momose R.	35°26.660'	136°03.776'	0.08	109.58	11.76	7.00	18	0	1.739	0.869	2.027	3.237	13	21	12	13	8.050	7.650	6.500	7.600
5	Oura R.	35°28.851'	136°07.307'	-	-	-	8.61	-	-	1.913	0.788	1.722	4.943	13	14	13	12	8.090	7.560	8.800	8.010
6	Shiotsu-o R.	35°30.046'	136°10.137'	-	-	-	5.33	-	-	1.101	1.217	3.980	3.237	13	18	10	13	7.260	7.360	7.700	6.810
7	Chonoki R.	35°24.611'	136°11.902'	0.14	351.31	9.86	25.82	0	13	4.931	1.333	7.948	4.895	15	15	12	14	7.520	7.180	7.100	6.790
8	Ta R.	35°24.025'	136°12.716'	0.15	430.07	11.11	32.61	0	25	5.569	1.043	5.105	5.090	15	15	13	14	7.820	7.290	6.400	6.670
9	Ane R.	35°22.969'	136°13.387'	0.08	11.51	22.08	7.69	28	0	3.016	1.558	3.480	5.821	13	13	13	14	8.160	7.310	7.100	6.650
10	Yone R.	35°21.802'	136°16.010'	0.10	23.17	4.90	25.99	0	35	3.828	1.071	3.538	7.235	25	18	18	17	8.430	8.410	7.400	6.650
11	Amano R.	35°19.405'	136°16.057'	0.23	1214.29	58.72	7.44	23	0	4.292	2.951	2.900	5.382	15	20	15	16	8.210	8.720	8.400	7.250
12	Seri R.	35°16.322'	136°14.039'	0.22	1076.3	76.30	9.07	0	0	4.640	2.900	3.248	5.723	13	17	16	15	7.990		8.200	7.330
13	Inukami R.	35°15.663'	136°12.860'	0.22	950.15	69.40	6.50	10	0	4.350	3.341	4.329	4.212	19	15	15	14	8.050	7.770	8.400	7.430
14	Ajiki R.	35°15.094'	136°12.230'	0.21	830.06	72.24	7.47	11	0	3.654	3.944	3.527	4.309	28	16	17	15	7.360	7.590	7.500	6.920
15	Uso R.	35°14.939'	136°11.881'	0.21	722.72	43.03	32.79	22	0	5.743	3.654	2.935	4.992	15	15	15	14	7.880	7.690	8.000	6.640
16	Bunroku R.	35°14.275'	136°10.378'	0.20	597.17	23.28	6.99	7	0	4.002	2.241	5.105	4.846	16	18	16	14	7.760	7.440	7.500	6.890
17	Nomazu R.	35°13.496'	136°09.118'	0.20	494.56	9.07	23.71	9	0	4.118	3.132	3.538	8.308	16	23	18	18	7.630	7.250	7.000	6.120
18	Echi R.	35°12.803'	136°06.509'	0.18	598.94	40.55	2.06	0	0	2.551	2.319	4.582	5.675	15	13	14	14	7.900	7.790	8.000	5.520
19	Nagaso R.	34°59.772'	135°54.043'	-	-	-	0.82	-	-	1.913	7.716	7.600	3.237	24	17	14	16	7.340	7.650	6.500	6.520
20	Hayama R.	35°02.765'	135°54.453'	0.14	289.63	2.68	6.79	0	21	3.248	14.390	4.060	2.457	22	19	14	14	7.200	7.670	6.800	6.510
21	Shin-moriyama R.	35°04.737'	135°56.542'	0.15	-72.41	6.06	5.20	0	0	1.797	18.887	11.720	6.016	26	26	15	17	6.990	7.810	6.700	6.670
22	Yasu R.	35°07.495'	135°58.443'	0.16	185.82	26.01	15.14	0	0	3.596	3.016	4.234	3.627	29	25	14	18	6.760	6.580	7.200	6.370
23	Yanomune R.	35°08.261'	136°00.800'	0.19	527.06	11.72	7.01	5	0	5.458	3.422	2.881	6.796	21	20	14	17	6.850	6.650	7.000	6.500
24	Hino R.	35°08.908'	136°01.725'	0.20	-881.45	9.74	12.39	105	0	6.572	2.842	4.646	6.601	16	19	14	15	8.300	6.990	7.100	6.680
25	U R.	35°15.685'	135°59.845'	0.08	-68.06	14.17	14.91	14	0	1.449	0.869		2.067	13	13	13	13	8.320	7.720	7.300	7.150
26	Wani R.	35°09.254'	135°56.317'	0.10	-104.75	1.64	20.17	38	0	2.319	2.721	1.913	2.749	14	13	15	13	8.570	7.820	7.100	7.000
27	Mano R.	35°07.434'	135°56.109'	0.07	-65.63	2.89	22.29	11	0	4.060	2.839	5.105	2.310	14	13	13	13	8.560	7.600	7.700	6.170
28	Tenjin R.	35°05.971'	135°55.531'	0.05	55.79	2.57	10.83	0	16	3.016	1.333	3.712	2.993	16	15	13	14	8.290	7.910	7.000	5.580
29	Fujinoki R.	35°03.353'	135°53.729'	0.06	-25.88	14.80	4.56	0	31	1.449	4.733	7.403	2.944	17	16	15	14	7.920	8.050	6.300	7.300
Offshore reference site																					
30	Ie-1	35°12.970'	135°59.959'							3.654	0.869	1.449	4.114								

Appendix C

Carbon and nitrogen stable isotope ratios (‰) of POM and its three potential sources (P-POM, E-POM, and R-POM) at each coastal site.

Site no.	Name of tributary rivers	Nov. 2005						Feb. 2006						May 2006						Jul. 2006					
		POM		E-POM		R-POM		POM		E-POM		R-POM		POM		E-POM		R-POM		POM		E-POM		R-POM	
		$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$
1	Kamo River	5.47	-24.13	5.23	-11.35	3.52	-28.06	12.26	-29.92	4.90	-21.97	4.15	-25.56	5.47	-25.35	6.25	-17.36	3.76	-28.78	4.42	-24.05	6.73	-9.60	6.63	-30.19
2	Ado R.	5.14	-24.73			6.30	-23.37	11.67	-28.54	3.78	-22.93	3.58	-25.18	6.90	-24.69	4.51	-25.90	7.68	-24.19	4.96	-24.57	5.96	-12.44	4.56	-24.91
3	Ishida R.	5.23	-24.96	7.99	-15.99	4.64	-26.58	11.14	-28.27	5.86	-18.68	1.96	-25.18	6.26	-29.69	4.14	-13.02	3.93	-23.23	4.83	-24.39	4.56	-10.35	2.72	-25.58
4	Momose R.	5.48	-25.66	5.00	-9.40	6.69	-29.05	13.21	-28.99	5.15	-14.19	4.27	-27.59	6.39	-30.18	3.76	-15.23	4.97	-27.62	5.36	-24.60	4.79	-12.44	6.26	-28.66
5	Oura R.	6.11	-25.10	4.18	-10.05	3.01	-28.60	9.37	-29.10	4.44	-14.00	2.21	-26.93	5.89	-28.22	4.84	-13.81	2.24	-26.85	4.75	-25.38	5.23	-12.16	3.86	-26.98
6	Shiotsu-o R.	5.99	-24.91	6.49	-12.82	2.27	-28.55	9.21	-28.05	5.40	-21.71	2.73	-27.81	4.87	-28.70	4.10	-20.21	3.25	-26.48	4.67	-26.01	5.22	-11.37	4.71	-27.51
7	Chonoki R.	5.20	-24.84	5.95	-18.71	3.56	-26.62	11.90	-29.34	5.07	-20.79	3.93	-26.84	5.01	-27.43	3.89	-22.50	3.68	-28.91	4.55	-25.07	4.00	-16.19	4.16	-27.01
8	Ta R.	5.21	-24.69	5.63	-15.90	3.64	-27.18	9.32	-27.61			3.24	-27.18	5.05	-26.68			2.80	-27.18	4.99	-24.54			3.84	-27.88
9	Ane R.	5.26	-24.31	5.33	-6.76	3.79	-26.88	9.32	-28.42	6.19	-13.93	3.08	-26.90	6.27	-27.41	6.18	-15.28	4.27	-23.34	4.75	-24.70	7.26	-10.83	5.95	-25.73
10	Yone R.	5.47	-24.00	4.96	-14.46	5.57	-26.40	9.61	-27.54	4.78	-15.07	5.76	-25.26	5.72	-27.23			6.67	-26.91	4.86	-26.35			6.71	-26.40
11	Amano R.	5.09	-24.14	4.50	-12.72	5.55	-25.57	6.77	-27.78	6.60	-17.69	5.96	-24.39	5.76	-26.87	5.72	-15.40	5.33	-22.77	4.79	-23.77	7.96	-18.08	6.18	-24.77
12	Seri R.	5.60	-24.66	7.71	-16.22	6.25	-25.79	7.53	-28.44	8.29	-20.71	4.61	-23.89	7.20	-25.43			7.26	-21.16	5.98	-24.55	7.36	-16.70	10.48	-23.63
13	Inukami R.	5.30	-24.42	6.76	-11.27	5.28	-25.87	7.49	-28.59	7.88	-18.01	5.29	-25.23	7.05	-25.71	5.92	-13.49	5.45	-25.34	5.03	-24.84	6.56	-14.89	7.90	-27.51
14	Ajiki R.	5.64	-25.59	7.44	-16.52	4.87	-28.10	6.90	-28.04	9.65	-27.87	4.90	-27.53	6.71	-25.74			6.13	-28.57	5.34	-24.27	9.13	-16.42	6.61	-27.88
15	Uso R.	6.51	-25.40	7.19	-6.52	4.63	-26.69	7.75	-28.76	8.51	-13.68	5.10	-25.56	7.47	-25.33	7.07	-15.29	6.92	-28.27	5.19	-24.60	7.01	-11.62	8.50	-25.30
16	Bunroku R.	6.27	-25.26			5.78	-27.44	9.46	-29.53	8.52	-16.31	3.89	-26.28	4.99	-26.31			5.63	-28.54	5.25	-24.52	9.27	-15.09	6.79	-26.56
17	Nomazu R.	6.07	-25.25			5.12	-29.29	9.57	-30.68	7.96	-26.82	4.39	-25.42	6.35	-26.04	9.03	-15.71	4.10	-26.67	4.74	-25.05	9.07	-21.16	4.10	-28.22
18	Echi R.	5.73	-25.72	5.18	-13.37	4.01	-28.08	9.41	-29.67	4.75	-21.91	4.75	-25.78	6.38	-26.72	4.33	-21.25	4.61	-19.26	2.95	-26.50	7.36	-16.36	7.22	-20.52
19	Nagaso R.	7.50	-25.64	8.78	-17.14	6.35	-30.83	5.16	-26.91	11.30	-19.23	8.28	-28.66	6.95	-25.13	7.88	-15.45	4.61	-28.14	4.83	-25.42	9.57	-17.95	6.42	-27.90
20	Hayama R.	4.16	-25.30	9.09	-15.93	3.94	-28.46	7.12	-26.29	8.44	-15.76	6.55	-26.84	5.12	-23.91	6.68	-14.32	5.18	-27.21	4.90	-25.17	8.64	-19.10	6.49	-26.02
21	Shin-moriyama R.	8.95	-26.15	10.20	-22.62	4.98	-28.20	7.82	-25.86	8.43	-18.18	6.29	-27.83	7.13	-26.69	7.94	-20.44	6.24	-27.43	5.91	-27.89	9.04	-21.21	5.52	-26.11
22	Yasu R.	5.88	-25.31			4.47	-28.36	8.70	-29.72			5.21	-25.12	5.49	-25.56			9.52	-24.68	3.86	-26.97			7.69	-29.62
23	Yanomune R.	7.27	-24.99			4.26	-27.63	8.38	-29.81	7.17	-17.88	4.48	-26.62	6.32	-26.19	7.04	-21.39	5.30	-26.34	4.81	-25.54	7.28	-21.01	6.25	-26.59
24	Hino R.	7.13	-24.27	8.42	-17.74	6.41	-28.86	8.75	-29.48	8.87	-19.08	6.44	-25.20	6.73	-26.95	7.47	-21.06	7.23	-26.24	5.22	-24.51	9.11	-21.45	10.12	-23.40
25	U R.	5.64	-26.07	3.90	-11.95	1.64	-29.62	11.65	-27.67	4.77	-19.70	3.84	-27.47	7.21	-24.45	5.07	-14.35	7.26	-26.81	4.02	-24.07	4.22	-13.70	4.06	-28.06
26	Wani R.	5.56	-25.32	4.58	-9.58	3.75	-29.33	9.85	-30.83	4.63	-16.30	6.54	-26.38	6.45	-24.98	5.31	-15.74	4.15	-24.28	4.51	-24.26	5.93	-11.09	4.12	-25.65
27	Mano R.	6.66	-24.64	4.63	-8.73	4.09	-29.87	7.74	-28.66	5.00	-14.21	3.94	-25.52	7.22	-23.82	5.55	-14.86	2.69	-28.75	4.95	-24.12	6.36	-15.59	8.82	-28.99
28	Tenjin R.	6.24	-24.74	4.48	-17.52	4.41	-25.91	9.48	-28.64	6.33	-23.14	3.75	-23.91	7.13	-23.38	6.58	-18.69	6.93	-25.70	5.14	-25.69	6.46	-13.85	8.83	-25.63
29	Fujinoki R.	8.29	-22.09	7.10	-23.78	5.02	-28.48	8.77	-26.95	7.76	-18.85	5.16	-25.83	6.82	-19.98	5.52	-18.34	5.87	-29.71	6.14	-25.90	8.60	-13.86	10.12	-28.07
Offshore reference site																									
30	Ie-1 (offshore reference)	5.54	-24.65					12.90	-29.44					7.25	-24.38					5.02	-25.00				

Appendix D

The relative contribution (%) of the three potential sources (P-POM, E-POM and T-POM) to POM at each coastal site.

Site no.	Name of tributary rivers	Nov. 2005						Feb. 2006						May 2006						Jul. 2006					
		P-POM		E-POM		T-POM		P-POM		E-POM		T-POM		P-POM		E-POM		T-POM		P-POM		E-POM		T-POM	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1	Kamo River	91.3	87 - 96	4.8	4 - 6	3.8	0 - 7	98.2	97 - 99	0.4	0 - 1	1.4	0 - 3	38.2	35 - 42	15.3	13 - 17	46.5	44 - 49	95.9	94 - 98	3.2	2 - 5	0.9	0 - 3
2	Ado R.							86.4	86 - 87	12.0	10 - 14	1.6	0 - 4	38.0	0 - 86	20.9	14 - 27	41.1	0 - 76	78.7	57 - 97	3.4	3 - 4	17.8	0 - 40
3	Ishida R.	31.1	0 - 69	9.6	2 - 16	59.3	29 - 85	81.6	81 - 82	6.2	5 - 7	12.2	11 - 13	-		-		-		88.0	84 - 92	4.5	4 - 5	7.5	4 - 11
4	Momose R.	80.5	79 - 83	0.3	0 - 1	19.2	17 - 21	98.7	98 - 100	0.7	0 - 2	0.7	0 - 2	-		-		-		58.0	47 - 69	12.0	9 - 15	30.1	22 - 38
5	Oura R.	99.3	99 - 100	0.3	0 - 1	0.3	0 - 1	69.0	67 - 71	0.0	0 - 0	31.0	29 - 33	-		-		-		75.2	66 - 85	0.8	0 - 2	24.0	15 - 32
6	Shiotsu-o R.	98.1	96 - 100	1.1	0 - 2	0.7	0 - 2	60.6	60 - 61	12.3	11 - 14	27.1	25 - 29	-		-		-		3.0	0 - 6	8.7	8 - 9	88.3	86 - 91
7	Chonoki R.	79.3	71 - 81	2.8	0 - 6	17.9	13 - 23	90.0	89 - 91	0.0	0 - 0	10.0	9 - 11	33.7	32 - 37	0.9	0 - 3	65.4	63 - 68	47.3	36 - 58	9.2	7 - 12	43.5	34 - 53
8	Ta R.	79.3	71 - 87	2.8	0 - 6	17.9	13 - 23																		
9	Ane R.	80.5	74 - 87	3.8	3 - 5	15.7	10 - 21	63.3	63 - 64	0.7	0 - 1	36.0	35 - 37	-		-		-		99.5	99 - 100	0.5	0 - 1	0.0	0 - 0
10	Yone R.	46.9	0 - 94	13.2	6 - 20	39.8	0 - 80	54.3	53 - 55	0.3	0 - 1	45.5	44 - 47												
11	Amano R.	41.3	0 - 95	8.6	5 - 14	50.1	0 - 91	35.2	34 - 36	0.4	0 - 1	64.4	63 - 66	-		-		-		86.3	82 - 90	10.2	9 - 12	3.5	0 - 9
12	Seri R.	90.8	82 - 100	1.0	0 - 2	8.2	0 - 17	54.0	54 - 54	0.5	0 - 1	45.5	45 - 46							81.0	79 - 83	2.7	2 - 4	16.3	15 - 18
13	Inukami R.	27.2	0 - 67	7.5	3 - 11	65.2	30 - 91	47.0	47 - 47	0.0	0 - 0	53.0	53 - 53	45.8	39 - 55	0.2	0 - 1	54.0	45 - 61	97.2	95 - 99	1.8	1 - 3	1.0	0 - 2
14	Ajiki R.	10.6	0 - 28	19.9	15 - 23	69.6	57 - 77	22.7	20 - 26	4.0	0 - 10	73.2	70 - 76							90.2	88 - 92	8.7	8 - 9	1.2	0 - 3
15	Uso R.	96.8	92 - 100	0.7	0 - 2	2.5	0 - 6	49.5	49 - 50	0.0	0 - 0	50.5	50 - 51	78.4	75 - 83	0.6	0 - 2	21.1	17 - 24	93.5	91 - 96	3.0	3 - 3	3.5	1 - 6
16	Bunroku R.							72.0	72 - 72	0.0	0 - 0	28.0	28 - 28							92.4	89 - 96	5.2	4 - 6	2.5	0 - 6
17	Nomazu R.							78.1	71 - 84	12.0	0 - 29	9.8	0 - 19	53.5	53 - 54	0.0	0 - 0	46.5	46 - 47	91.2	83 - 100	1.1	0 - 3	7.7	0 - 14
18	Echi R.	81.0	79 - 83	0.2	0 - 1	18.8	17 - 20	72.3	71 - 73	0.7	0 - 2	27.0	25 - 29	-		-		-		-		-	-	-	
19	Nagaso R.	2.0	0 - 6	37.5	36 - 40	60.5	57 - 64	-		-		-		82.5	80 - 85	0.3	0 - 1	17.2	15 - 19	94.0	93 - 95	0.0	0 - 0	6.0	5 - 7
20	Hayama R.	29.2	0 - 63	10.3	0 - 19	60.4	37 - 81	7.0	6 - 8	6.5	6 - 7	86.5	85 - 88	1.9	0 - 6	24.0	21 - 29	74.1	71 - 78	97.5	95 - 100	0.0	0 - 0	2.5	0 - 5
21	Shin-moriyama R	0.8	0 - 2	55.3	55 - 56	44.0	43 - 45	15.8	15 - 17	23.0	22 - 24	61.2	60 - 63	38.0	36 - 40	0.8	0 - 2	61.2	60 - 62	0.5	0 - 1	0.0	0 - 0	99.5	99 - 100
22	Yasu R.																								
23	Yanomune R.							62.0	60 - 64	0.0	0 - 0	38.0	36 - 40	28.1	24 - 33	1.1	0 - 3	70.9	67 - 73	87.7	85 - 91	0.2	0 - 1	12.1	9 - 15
24	Hino R.	6.6	1 - 13	38.8	37 - 41	54.6	50 - 59	61.5	61 - 62	0.0	0 - 0	38.5	38 - 39	1.6	0 - 4	0.4	0 - 1	98.0	96 - 100	91.0	91 - 91	8.5	8 - 9	0.5	0 - 1
25	U R.	85.0	85 - 85	0.0	0 - 0	15.0	15 - 15	83.0	83 - 83	16.5	16 - 17	0.5	0 - 1	81.6	63 - 100	3.0	0 - 6	15.4	0 - 31	0.7	0 - 1	27.7	27 - 28	71.7	71 - 72
26	Wani R.	87.5	84 - 92	0.3	0 - 1	12.2	8 - 15	82.0	81 - 83	0.0	0 - 0	18.0	17 - 19	77.3	52 - 96	0.2	0 - 1	22.5	3 - 48	25.8	15 - 38	8.4	8 - 9	65.8	54 - 76
27	Mano R.	95.6	92 - 100	2.7	0 - 7	1.7	0 - 5	53.5	53 - 54	0.0	0 - 0	46.5	46 - 47	94.5	94 - 95	5.5	5 - 6	0.0	0 - 0	91.5	91 - 92	8.5	8 - 9	0.0	0 - 0
28	Tenjin R.	100.0	100 - 100	0.0	0 - 0	0.0	0 - 0	70.7	70 - 72	2.2	0 - 5	27.1	24 - 30	69.5	56 - 84	19.9	16 - 23	10.5	0 - 22	83.5	82 - 85	0.0	0 - 0	16.5	15 - 18
29	Fujinoki R.	0.5	0 - 1	99.5	99 - 100	0.0	0 - 0	44.3	43 - 45	7.0	6 - 8	48.7	47 - 50	36.2	35 - 38	63.5	62 - 65	0.3	0 - 1	76.0	75 - 77	0.0	0 - 0	24.0	23 - 25