**Intensity of Freshwater Use for Aquaculture**

 **in Different Countries**

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**Abstract**

 The intensity with which 172 countries use freshwater for aquaculture was estimated by dividing annual, freshwater aquaculture production (tonne/yr) by annual total natural renewable freshwater (km3/yr). The freshwater aquaculture production:renewable freshwater ratio (AFR) varied among countries from 0 to 15,000 tonne/km3. Country-level AFRs were assigned to AFR classes as follows: no freshwater aquaculture, 0 tonne/km3; low, < 100 tonne/km3; medium, 100-1,000 tonne/km3; high, > 1,000 tonne/km3. The number of countries in each AFR class follows: no freshwater aquaculture, 35; low, 80; medium, 45; high, 12. There seems to be adequate renewable freshwater to allow considerable expansion of freshwater aquaculture – especially outside of Asia.

**Introduction**

 Statistics provided by the Fisheries Department of the Food and Agriculture Organization of the United Nations (FAO) (www.fao.org), reveal that total aquaculture production was 55.1 million tonne/yr in 2009, and freshwater aquaculture accounted for 35.0 million tonne/yr of this production (63.5%).

 The current world population of 6.91 billion consumes about 118 tonne/yr of fisheries products, and a population of 9.15 billion that is predicted by 2050 would need about 156 million tonne/yr (an additional 34 million tonne/yr). Because capture fisheries are not projected to increase, aquaculture must supply the entire future increase in demand for fisheries products. Aquaculture production will need to be around 93 million tonne/yr by 2050 to allow the population to continue to consume fisheries products at the current rate. Assuming that freshwater and marine aquaculture grow at the same rate, freshwater aquaculture needs to increase to around 54 million tonne/yr by 2050.

 The purpose of the present study was to determine the extent to which different countries use their freshwater for aquaculture.

**Materials and Methods**

 Estimates of total natural renewable freshwater – the sum of surface runoff within a country, all surface water flowing into the country from neighboring countries, and the country’s renewable groundwater – were obtained from Gleick (2009) for 172 of the world’s 224 countries. Freshwater aquaculture production data were obtained for these countries from FAO fisheries statistics (www.fao.org/fishery/statistics/global-aquaculture-production/query/en). An indicator of the intensity of water use for freshwater aquaculture – referred to here as the freshwater aquaculture production to renewable freshwater ratio – was estimated for each country using the following equation:

$$AFR= \frac{AP}{RF} ×100$$

where AFR = freshwater aquaculture production to renewable freshwater ratio (tonne/km3); AP = freshwater aquaculture production (tonne/yr); RF = total renewable freshwater (km3/yr).

**Results and Discussion**

 Of the 172 countries for which renewable freshwater data were available, 35 had no freshwater aquaculture production, or if they did, it was not reported. For the 137 countries reporting freshwater aquaculture production, AFR ranged from < 1 tonne/km3 in several countries to 7,344 tonne/km3 in China, 11,324 tonne/m3 in Israel, and 15,000 tonne/km3 in Kuwait (Table 1). Notice that the two highest AFR values were for small, water-restricted countries.

 The AFR values were initially placed in five classes as follows: countries with AFR = 0 (no freshwater aquaculture); 80 countries with AFR < 100 tonne/km3; 45 countries with AFR > 100 tonne/km3 but < 800 tonne/km3, ten countries with AFR > 1,000 tonne/km3 but < 10,000 tonne/km3; two countries with AFR > 10,000 tonne/km3. However, it did not seem appropriate to assign the two countries – Israel and Kuwait – with AFR > 10,000 tonne/km3 to a separate class, because they represent an insignificant proportion of world freshwater aquaculture production (19,546 tonne/yr or 0.062%). Thus, countries were placed into four AFR classes: no reported aquaculture (AFR = 0 tonne/km3); low (AFR < 100 tonne/km3); medium (AFR = 101-1,000 tonne/km3); high (AFR > 1,000 tonne/km3).

Many of the countries in the no aquaculture and low AFR classes (Table 1) need additional protein that could be obtained by increasing the amount of aquaculture. There also are countries in the medium and high AFR classes that need more protein. An example of the effect of increasing freshwater aquaculture on AFR in a country with a low FCR will be provided. Guatemala has a rapidly growing population that is expected to increase from 14,362,000 in 2010 to 22,995,000 in 2050. Suppose that Guatemala increased its freshwater aquaculture production from 3,000 tonne/yr at present to 10,000 tonne in 2050. The renewable freshwater in Guatemala is estimated at 111.3 km3/yr (Gleick 2009); thus, AFR would rise from 27.0 tonne/km3 to 89.8 tonne/km3 – the country would still have a low AFR. In many Asian countries, and especially in China, increasing the amount of aquaculture will result in higher AFRs in a region where values are already much greater than in the rest of the world. Nevertheless, the data provided in Table 1 suggest that many countries could greatly increase aquaculture production without increasing AFR values to the levels found in Asia.

The main negative issues related to a large amount of freshwater aquaculture production (high AFR) at the country level are competition with other water uses and water pollution resulting from aquaculture (Pillay 2004; Boyd et al. 2007; Tucker and Hargreaves 2008). However, there are no studies revealing the extent to which aquaculture interferes with other water uses or contributes to water pollution at the country level. Based on regional studies of individual aquaculture industries such as channel catfish, (*Ictalurus punctatus*), in the southeastern United States (Boyd et al. 2000; Tucker and Hargreaves 2008), and *Pangasius* catfish in Vietnam (Bosma et al. 2009), aquaculture does not appear to be of as much concern related to water use conflicts and water pollution as many other activities. Thus, there should be opportunity to greatly increase aquaculture production in many countries, and especially those outside Asia, without resulting in major water use competition or causing serious water pollution. Nevertheless, aquaculture producers should strive to increase production per unit of water use – Verdegem and Bosma (2009) suggested that productivity could be tripled without increasing current freshwater use. Moreover, governments should pay more attention to the effects of aquaculture on the environment and require producers to comply with either discharge standards, best management practices, or both.

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| Table 1. Country-level estimates of annual total natural renewable freshwater (TNRF) (Gleick  |
| 2008), annual freshwater aquaculture production (AP), (www.FAO.org) and the freshwater |
| aquaculture production:renewable freshwater ratio (AFR). |  |  |  |
|   |   | TNRF | AP |   | AFR |
| Region and country |  | (km3/yr) | (tonne/yr) |  | (tonne/ km3) |
| AFRICA | Algeria | 14.3 | 2215 |   | 154.00 |
|  | Angola | 184 | 190 |   | 1.03 |
|  | Benin | 25.8 | 180 |   | 6.98 |
|  | Botswana | 14.7 | 0 |   | 0.00 |
|  | Burkina Faso | 17.5 | 405 |   | 23.14 |
|  | Burundi | 3.6 | 200 |   | 55.56 |
|  | Cameroon | 285.5 | 340 |   | 1.19 |
|  | Cape Verde | 0.3 | 0 |   | 0.00 |
|  | Central African Republic | 144.4 | 0 |   | 0.00 |
|  | Chad | 43 | 0 |   | 0.00 |
|  | Comoros | 1.2 | 0 |   | 0.00 |
|  | Congo | 832 | 65 |   | 0.08 |
|  | Congo, Democratic Republic (Zaire) | 1283 | 2970 |   | 2.31 |
|  | Cote D'Ivoire | 81 | 1150 |   | 14.20 |
|  | Djibouti | 0.3 | 0 |   | 0.00 |
|  | Egypt | 86.8 | 98833 |   | 1138.00 |
|  | Equatorial Guinea | 26 | 0 |   | 0.00 |
|  | Eritrea | 6.3 | 0 |   | 0.00 |
|  | Ethiopia | 110 | 0 |   | 0.00 |
|  | Gabon | 164 | 124 |   | 0.76 |
|  | Gambia | 8 | 0 |   | 0.00 |
|  | Ghana | 53.2 | 5594 |   | 105.15 |
|  | Guinea | 226 | 0 |   | 0.00 |
|  | Guinea-Bisseau | 31 | 0 |   | 0.00 |
|  | Kenya | 30.2 | 4452 |   | 147.42 |
|  | Lesotho | 5.2 | 91 |   | 17.50 |
|  | Liberia | 232 | 0 |   | 0.00 |
|  | Libya | 0.6 | 10 |   | 16.67 |
|  | Madagascar | 337 | 2830 |   | 8.40 |
|  | Malawi | 17.3 | 1700 |   | 98.27 |
|  | Mali | 100 | 821 |   | 8.21 |
|  | Mauritania | 11.4 | 0 |   | 0.00 |
|  | Mauritius | 2.2 | 61 |   | 27.73 |
|  | Morocco | 29 | 1185 |   | 40.86 |
|  | Mozambique | 216 | 90 |   | 0.42 |
|  | Namibia | 45.5 | 15 |   | 0.33 |
|  | Niger | 33.7 | 40 |   | 1.19 |
|  | Nigeria | 286.2 | 143207 |   | 500.37 |
|  | Reunion | 5 | 0 |   | 0.00 |
|  | Rwanda | 5.2 | 388 |   | 74.62 |
|  | Senegal | 39.4 | 160 |   | 4.06 |
|  | Sierra Leone | 160 | 0 |   | 0.00 |
|  | Somalia | 15.7 | 0 |   | 0.00 |
|  | South Africa | 50 | 1202 |   | 24.04 |
|  | Sudan | 154 | 2000 |   | 12.99 |
|  | Swaziland | 4.5 | 0 |   | 0.00 |
|  | Tanzania | 91 | 12 |   | 0.13 |
|  | Togo | 14.7 | 126 |   | 8.57 |
|  | Tunisia | 4.6 | 1117 |   | 242.83 |
|  | Uganda | 66 | 52250 |   | 791.67 |
|  | Zambia | 105.2 | 5640 |   | 53.61 |
|  | Zimbabwe | 20 | 2450 |   | 122.50 |
|  |  |  |  |  |  |
| N & C AMERICA |  |  |  |  |
|  | Antigua and Barbuda | 0.1 | 0 |   | 0.00 |
|  | Bahamas | nd | 0 |   | 0.00 |
|  | Barbados | 0.1 | 0 |   | 0.00 |
|  | Belize | 18.6 | 1865 |   | 100.27 |
|  | Canada | 3300 | 9314 |   | 2.82 |
|  | Costa Rica | 112.4 | 21768 |   | 193.67 |
|  | Cuba | 38.1 | 27771 |   | 728.90 |
|  | Dominica | nd | 0 |   | 0.00 |
|  | Dominican Republic  | 21 | 140 |   | 6.67 |
|  | El Salvador | 25.2 | 3606 |   | 143.10 |
|  | Guatemala | 111.3 | 3000 |   | 26.95 |
|  | Haiti | 14 | 0 |   | 0.00 |
|  | Honduras | 95.2 | 20494 |   | 215.27 |
|  | Jamaica | 9.4 | 5812 |   | 618.30 |
|  | Mexico | 457.2 | 10618 |   | 23.22 |
|  | Nicaragua | 196.7 | 1388 |   | 7.06 |
|  | Panama  | 148 | 462 |   | 3.12 |
|  | St. Kits and Nevis | 0.02 | 0 |   | 0.00 |
|  | Trinidad and Tobago | 3.8 | 0 |   | 0.00 |
|  | United States of America | 3069 | 323905 |   | 105.54 |
|  |  |  |  |  |  |
| SOUTH AMERICA  |  |  |  |  |
|  | Argentina | 814 | 2465 |   | 3.03 |
|  | Bolivia | 622.5 | 631 |   | 1.01 |
|  | Brazil | 8233 | 211766 |   | 25.72 |
|  | Chile | 922 | 8717 |   | 9.45 |
|  | Colombia | 2132 | 46100 |   | 21.62 |
|  | Ecuador | 432 | 22120 |   | 51.20 |
|  | Guyana | 241 | 211 |   | 0.88 |
|  | Paraguay | 336 | 2100 |   | 6.25 |
|  | Peru | 1913 | 14987 |   | 7.83 |
|  | Suriname | 22 | 10 |   | 0.45 |
|  | Uruguay | 139 | 36 |   | 0.26 |
|  | Venezuela  | 1233.2 | 2625 |   | 2.13 |
|  |  |  |  |  |  |
| ASIA |  |  |  |  |  |
|  | Afghanistan | 65 | 0 |   | 0.00 |
|  | Bahrain | 0.1 | 0 |   | 0.00 |
|  | Bangladesh | 1210.6 | 894205 |   | 738.65 |
|  | Bhutan | 95 | 0 |   | 0.00 |
|  | Brunei | 8.5 | 4 |   | 0.47 |
|  | Cambodia | 476.1 | 38359 |   | 80.57 |
|  | China | 2829.6 | 20781065 |   | 7344.17 |
|  | India | 1907.8 | 3342039 |   | 1751.78 |
|  | Indonesia | 2838 | 908693 |   | 320.19 |
|  | Iran | 137.5 | 150607 |   | 1095.32 |
|  | Iraq | 96.4 | 19246 |   | 199.65 |
|  | Israel | 1.7 | 19250 |   | 11323.53 |
|  | Japan | 430 | 39874 |   | 92.73 |
|  | Jordan | 0.9 | 330 |   | 366.67 |
|  | Korea DPR | 77.1 | 3700 |   | 47.99 |
|  | Korea Republic | 69.7 | 19150 |   | 274.75 |
|  | Kuwait | 0.02 | 300 |   | 15000.00 |
|  | Laos | 333.6 | 78000 |   | 233.81 |
|  | Lebanon | 4.8 | 803 |   | 167.29 |
|  | Malaysia | 580 | 95843 |   | 165.25 |
|  | Maldives | 0.03 |   |   | 0.00 |
|  | Mongolia | 34.8 |   |   | 0.00 |
|  | Myanmar  | 1045.6 | 617859 |   | 590.91 |
|  | Nepal | 210.2 | 27250 |   | 129.64 |
|  | Oman | 1 | 86 |   | 86.00 |
|  | Pakistan | 233.8 | 135000 |   | 577.42 |
|  | Philippines | 479 | 311059 |   | 649.39 |
|  | Qatar | 0.1 | 36 |   | 360.00 |
|  | Saudi Arabia | 2.4 | 3753 |   | 1563.75 |
|  | Singapore | 0.6 | 283 |   | 471.67 |
|  | Sri Lanka | 50 | 5172 |   | 103.44 |
|  | Syria | 46.1 | 8595 |   | 186.44 |
|  | Taiwan | 67 | 161027 |   | 2403.39 |
|  | Thailand | 409.9 | 516405 |   | 1259.83 |
|  | Turkey | 234 | 66557 |   | 284.43 |
|  | United Arab Emirates | 0.2 |   |   | 0.00 |
|  | Vietnam | 891.2 | 1771000 |   | 1987.21 |
|  | Yemen | 4.1 |   |   |   |
|  |  |  |  |  |  |
| EUROPE |  |  |  |  |  |
|  | Albania | 41.7 | 558 |   | 13.38 |
|  | Austria | 84 | 2087 |   | 24.85 |
|  | Belgium | 20.8 | 126 |   | 6.06 |
|  | Bosnia and Herzegovina | 37.5 | 7360 |   | 196.27 |
|  | Bulgaria | 19.4 | 4562 |   | 235.15 |
|  | Croatia | 105.5 | 4458 |   | 42.26 |
|  | Cyprus | 0.4 | 57 |   | 142.50 |
|  | Czech Republic | 16 | 20395 |   | 1274.69 |
|  | Denmark | 6.1 | 22661 |   | 3714.92 |
|  | Estonia | 21.1 | 813 |   | 38.53 |
|  | Finland | 110 | 2159 |   | 19.63 |
|  | France | 189 | 41340 |   | 218.73 |
|  | Germany | 188 | 36973 |   | 196.66 |
|  | Greece | 72 | 3991 |   | 55.43 |
|  | Hungary | 120 | 15687 |   | 130.73 |
|  | Iceland | 170 | 381 |   | 2.24 |
|  | Ireland | 46.8 | 850 |   | 18.16 |
|  | Italy | 175 | 39916 |   | 228.09 |
|  | Luxembourg | 1.6 |   |   | 0.00 |
|  | Macedonia | 6.4 | 1331 |   | 207.97 |
|  | Malta | 0.07 |   |   | 0.00 |
|  | Netherlands | 89.7 | 8575 |   | 95.60 |
|  | Norway | 381.4 | 90 |   | 0.24 |
|  | Poland | 63.1 | 36813 |   | 583.41 |
|  | Portugal | 73.6 | 941 |   | 12.79 |
|  | Romania | 211.9 | 12532 |   | 59.14 |
|  | Slovakia | 80.3 | 1071 |   | 13.34 |
|  | Slovenia | 32.1 | 1041 |   | 32.43 |
|  | Spain | 111.1 | 22281 |   | 200.55 |
|  | Sweden | 179 | 4016 |   | 22.44 |
|  | Switzerland | 53.3 | 1214 |   | 22.78 |
|  | United Kingdom | 160.6 | 10563 |   | 65.77 |
|  | Serbia-Montenegro (Yugoslavia) | 208.5 | 0 |   | 0.00 |
|  | Russia | 4498 | 115234 |   | 25.62 |
|  | Armenia | 10.5 | 2001 |   | 190.57 |
|  | Azerbaijan | 30.3 | 89 |   | 2.94 |
|  | Belarus | 58 | 4150 |   | 71.55 |
|  | Estonia | 12.8 | 813 |   | 63.52 |
|  | Georgia | 63.3 | 180 |   | 2.84 |
|  | Kazakhstan | 109.6 | 321 |   | 2.93 |
|  | Kyrgyzstan | 46.5 | 92 |   | 1.98 |
|  | Latvia | 49.9 | 584 |   | 11.70 |
|  | Lithuania | 24.5 | 3008 |   | 122.78 |
|  | Moldova | 11.7 | 4700 |   | 401.71 |
|  | Tajikistan | 99.7 | 26 |   | 0.26 |
|  | Turkmenistan | 60.9 | 16 |   | 0.26 |
|  | Ukraine | 139.5 | 15027 |   | 107.72 |
|  | Uzbekistan | 72.2 | 3418 |   | 47.34 |
|  |  |  |  |  |  |
| OCEANIA |  |  |  |  |  |
|  | Australia | 398 | 1127 |   | 2.83 |
|  | Fiji | 28.6 | 217 |   | 7.59 |
|  | New Zealand | 397 | 0 |   | 0.00 |
|  | Papua New Guinea | 801 | 80 |   | 0.10 |
|  | Solomon Islands | 44.7 |   |   | 0.00 |

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