Postprint: Ecological Footprint Distance of Fruit Consumption in Beijing

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Abstract

Employing the ecological footprint distance indicator methodology system, this study investigates the ecological footprint distance of fruit consumption in Beijing from 2009 to 2012. The results indicate that over the four-year period: the cross-regional transferred ecological carrying capacity quality distance increased year by year from 11.5×10^8 t·km in 2009 to 17.01×10^8 t·km in 2012, representing a total increase of 47.91%; the ecological footprint distance remained relatively stable between 886.66 km and 1073.55 km; and the per capita ecological footprint distance increased overall from 4.39×10^4 km in 2009 to 5.55×10^4 km in 2012, with a total increase of 26.42%. From a categorical perspective, bananas exhibited the largest average annual ecological footprint distance (2072 km), while apples showed the smallest (476 km); watermelons demonstrated the largest average annual cross-regional transferred biocapacity quality distance (4978×10^8 kg·km), whereas bananas displayed the smallest (518×10^8 kg·km); and the four-year average per capita ecological footprint distance was highest for watermelons (17.7×10^4 km) and lowest for bananas (1.92×10^4 km). During its rapid urbanization phase, Beijing' s external ecological dependency range has expanded rapidly, exceeding the rate of population growth.

Full Text

Study on Ecological Footprint Distance of Fruit Consumption in Beijing

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Abstract: The ecological footprint method, proposed in 1992 and subsequently improved, is widely applied in sustainable development assessment through its comparison with bio-capacity. While ecological footprint is an area-based indicator demonstrating human impact on natural capital, the ecological footprint distance indicator builds upon this foundation to describe a city' s ecological dependence distance, offering a valuable supplement and improvement to ecological footprint and bio-capacity theory. This study analyzed Beijing' s fruit consumption ecological footprint distance using population data and resident fruit consumption statistics from the *Beijing Statistical Yearbook* and *Chinese Migrants Development Report* (2008–2012), supplemented by market investigations. Results show an overall increasing trend in Beijing' s fruit ecological footprint distance, imported fruit mass, and per capita fruit ecological footprint distance. From 2009 to 2012, the distance of imported fruit mass increased by 47.91% (to 17.01×10 t·km). The fruit ecological footprint distance remained relatively stable between 886.66 km and 1073.55 km, while per capita ecological footprint distance increased by 26.42% (to 5.55×10 km). By category, bananas showed the maximum annual average ecological footprint distance (2072 km) and apples the minimum (476 km). Watermelon had the maximum imported bio-capacity mass (4978×10 kg·km) and bananas the minimum (518×10 kg·km). The maximum average annual ecological footprint distance was observed for watermelon (17.7×10 km) and the minimum for bananas (1.92×10 km). These findings demonstrate that Beijing' s rapid urbanization has enlarged the ecological cost of fruit consumption and expanded the scope of bio-capacity suppliers, with this expansion exceeding population growth rates. Study limitations include: (1) fruit products were used as representatives of all ecological resources due to data constraints; (2) appropriate weighting should be assigned to each fruit type when calculating the indicator. Future research should: collect diverse industrial, agricultural, and service product data; develop models to determine distance weight sets for all products; and select more cities of varying population and economic scale as research targets to obtain more comprehensive and convincing city ecological footprint distance indicators.

Keywords: ecosystem services; Ecological Footprint Distance; spatial and temporal variation; urbanization

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Ecosystems provide diverse services including water supply, waste assimilation, and various raw materials and food products. Human sustainable development faces increasingly severe challenges as global population growth, rapid economic development, and rising aspirations for higher quality of life intensify ecological pressures. As China enters a rapid urbanization phase, massive population influx into metropolitan areas makes urban sustainability increasingly dependent on external ecosystem service supplies, facing growing ecosystem service scarcity. Canadian scholars Wackernagel and Rees proposed the ecological footprint concept and measurement method in 1992, using biologically productive space (global hectares, abbreviated as ghm) as an effective tool to measure human consumption of natural assets. By comparing ecological footprint with bio-capacity, researchers can calculate natural asset supply and consumption capacity at different regional scales and determine ecological deficits to assess regional sustainability pressures. However, this area-based approach cannot answer how far a region’ s ecological dependence extends.

International research on “food miles” has examined imported food and associated carbon emissions. Kissinger studied Canada’ s international trade-related food miles; Schnell investigated local eating and community-supported agriculture; Caputo explored carbon border tax implementation; and López assessed food miles, carbon footprint, and global value chain impacts in Spanish agriculture. These studies primarily focused on reducing transport distances. Building on this work, Xie and Chen proposed the ecological footprint distance indicator to account for urban dependence on external ecological resources, reflecting both the degree and distance of dependence (Ecological Footprint Distance, EFD). The greater the distance, the higher the ecological cost for sustainable development. This study treats the target region as a relatively independent ecological unit to examine the distance and distribution patterns of occupied external bio-capacity, providing a useful supplement to traditional ecological footprint theory.

As a megacity with 21.705 million permanent residents in 2015, Beijing consumes enormous quantities of ecological resources daily. Fruit, providing essential vitamins and organic acids, represents a major food category. Research by Tao et al. indicates that with rising urban living standards, Beijing residents’ per capita fruit consumption is increasing and may eventually stabilize between 50–90 kg. Despite developed logistics networks, fruit production exhibits clear seasonal and regional patterns in China. Without rational cross-regional allocation, urban residents cannot access affordable, quality seasonal fruits. This study of Beijing’ s fruit consumption ecological footprint distance reveals both the city’ s dependence on external fruit supplies and the impact scope, providing scientific support for government guidance on cross-regional fruit resource allocation.

1 Concept and Connotation of Ecological Footprint Distance

To clarify the ecological footprint distance concept for fruit consumption, we define three sub-concepts:

Bio-capacity Mass Distance (Dmi): The sum of the product of distance from each source region to Beijing and the mass of fruit transferred. Comparing Dmi values reveals the ecological impact magnitude on external regions at different geographic locations during fruit consumption.

Ecological Footprint Distance (Def): The weighted average linear distance per unit of external fruit consumed by the target region, calculated as Dmi divided by total external fruit mass. Def comparisons indicate the difficulty of obtaining specific fruit resources. Local resource consumption is assigned a Def of 0.

Average Ecological Footprint Distance per Capita (Aef): The weighted total linear distance of all external fruit resources consumed per capita in the target region annually, calculated as per capita external fruit consumption mass multiplied by Def. Aef changes reflect variations in average ecological costs for residents to obtain fruit resources.

2 Data Sources and Classification

Analyzing Beijing' s fruit consumption ecological footprint distance (2009-2012) required population data, fruit consumption data, and source region data. The first two categories came from the *Beijing Statistical Yearbook* and *Chinese Migrants Development Report*, showing populations of 26.2266, 26.5091, 28.8757, and 30.6425 million respectively. Source region data came from market investigations at Beijing' s Xinfadi Agricultural Products Wholesale Market, which accounts for over 60% of Beijing' s fruit trade volume. The study examined four major fruit categories: Red Fuji apples, domestic bananas, oranges, and watermelon (all domestic sources, excluding foreign and Hong Kong/Macau/Taiwan regions).

2.1 Basic Assumptions

Due to constraints and for simplification, calculations were based on three assumptions: (1) Red Fuji apples, domestic bananas, oranges, and watermelon represent Beijing' s main fruit consumption varieties, with Xinfadi' s source characteristics representing Beijing' s overall fruit sources; (2) Xinfadi' s proportional quantities by source region represent Beijing' s proportional relationships; (3) Xinfadi's spatiotemporal patterns represent Beijing's overall patterns. These assumptions are reasonable given Xinfadi' s 60-70% market share and these four fruits' consistent share (59.2%, 54.8%, 63.3%, 57.4% in 2003, 2009, 2010, and 2011 respectively).

2.2 Calculation Model

For target object X consuming external fruit resources from source set S = {S , S , ···, S }, the bio-capacity mass distance Dmi is calculated as:

Dmi = Σ [m × d] for i = 1 to n

where m and d are mass and linear distance functions for each fruit type. For qualitative research, we used the GCS-Beijing-1954 coordinate system in ArcGIS to calculate straight-line distances between provincial capitals and Beijing, then derived Def and Aef.

3 Results

3.1 Interannual Dynamics of Fruit Ecological Footprint Distance

3.1.1 All Fruit Categories Table 1 shows Beijing' s fruit consumption indicators from 2009–2012, with cross-regional transfer quantities calculated using Xinfadi' s trade volume and market share (averaging 66.7% annually).

TABLE:1 Ecological Footprint Distance of Beijing' s External Fruit Consumption (2009–2012)

Indicator Type	2009	2010	2011	2012
Total Consumption (10 t)	80.83	82.35	83.95	94.87
Per Capita Consumption (kg)	21.83	24.24	27.61	31.18
External Dependency (%)	57.41	60.88	63.78	69.47
Total Imported Mass (10 t)	46.41	50.14	53.53	62.59
Per Capita Imported Mass (kg)	12.17	13.29	15.46	19.18
Bio-capacity Mass Distance (10 t • km)	11.5	14.27	17.01	17.01
Ecological Footprint Distance (km)	944.87	1073.55	944.51	886.66
Average EF Distance per Capita (10 km)	4.39	5.55	5.55	5.55

Total fruit consumption increased to 94.87×10 t (30.24% growth), while per capita consumption rose from 80.83 kg to 90.1 kg (11.47% increase). The bio-capacity mass distance of cross-regional transfers increased to 17.01×10 t • km (47.91% growth). Ecological footprint distance remained relatively stable between 886.66 km and 1073.55 km, while per capita ecological footprint distance increased from 4.39×10 km to 5.55×10 km (26.42% growth). External dependency rose from 57.41% to 69.47%. These trends indicate that Beijing residents' fruit consumption is expanding its ecological impact on external regions, though the dependence distance remains relatively stable while per capita ecological costs increase significantly.

3.1.2 Major Fruit Categories Table 2 presents ecological footprint distance parameters for the four major fruits. While average ecological footprint distances for individual fruits showed small fluctuations, the comprehensive distance for all four categories increased rapidly.

TABLE:2 Ecological Footprint Distance and Per Capita Cross-regional Transfer of Four Major Fruit Categories (2009–2012)

Indicator	Apple	Banana	Orange	Watermelon	Average
2009					
Dmi (10 kg · km)	1.726	0.528	1.049	4.603	-
Def (km)	441	2078	1049	1136	1078
Per Capita Transfer (kg)	10.34	1.06	5.3	12.36	-
Aef (km)	1.72×10	0.52×10	1.05×10	1.84×10	1.35×10
2012					
Dmi (10 kg · km)	1.449	0.508	2.854	5.839	-
Def (km)	440	1972	1462	1420	1138
Per Capita Transfer (kg)	11.39	0.96	10.84	16.74	-
Aef (km)	1.63×10	0.47×10	3.03×10	3.54×10	1.77×10

All indicators showed increasing trends. From 2009–2012, per capita cross-regional transfers were 28.09 kg, 23.17 kg, 33.91 kg, and 36.08 kg for apples, bananas, oranges, and watermelon respectively. The increases were driven by rapid urbanization and total population growth (16.8%).

Apple: Dmi decreased by 19.7% to 1.449×10 kg · km; Def fluctuated slightly, decreasing overall by 0.23% to 440 km; per capita transfer increased from 10.34 kg to 11.39 kg. Beijing's apple consumption showed decreasing ecological impact on external regions.

Banana: Dmi decreased by 9.78% to 5.08×10 kg · km; Def stabilized around 2000 km, decreasing 5.1% to 1972 km; per capita transfer decreased from 1.06 kg to 0.96 kg (24.53% total decrease). Banana consumption is relatively small and declining.

Orange: Dmi increased 172.07% to 2.854×10 kg · km; Def increased 39.37% to 1462 km; per capita transfer rose from 5.3 kg to 10.84 kg (104.5% increase). Orange consumption' s ecological impact distance increased substantially.

Watermelon: Dmi increased 26.85% to 5.839×10 kg · km; Def increased 24.91% to 1420 km; per capita transfer grew from 12.36 kg to 16.74 kg (35.4% increase). Watermelon shows the largest consumption and increasing ecological impact.

3.2 Provincial Distribution of Beijing' s Fruit Consumption Ecological Footprint Distance

Beijing' s fruit consumption ecological footprint distance exhibits spatial distribution patterns at the provincial level.

FIGURE:1 Provincial Distribution of Beijing' s Fruit Consumption Ecological Footprint Distance (2009)

FIGURE:2 Provincial Distribution of Beijing' s Fruit Consumption Ecological Footprint Distance (2012)

3.2.1 Classification of External Ecological Dependence Based on Dmi values (10 t · km) for the four fruits, external dependence is classified as:

2009: - Extreme dependence: Guangdong (192), Shandong (186), Hainan (165) - Heavy dependence: Guangxi (120), Xinjiang (95) - Moderate dependence: Hubei (56), Yunnan (38), Hebei (17), Liaoning (15), Shaanxi (13), Henan (12), Gansu (12) - Light dependence: 17 other provinces

2012: - Extreme dependence: Shandong (189), Guangdong (165), Hainan (120) - Heavy dependence: Guangxi (95), Xinjiang (52) - Moderate dependence: Hubei (51), Yunnan (46), Hebei (14), Liaoning (12), Shaanxi (10), Henan (9), Gansu (7) - Light dependence: 17 other provinces

3.2.2 Cross-regional Bio-capacity Transfer **Apple**: Major suppliers in 2009 were Shandong (39.8% share), Shaanxi, and Shanxi (combined 22.7%). By 2012, Shandong' s share rose to 46.9% while other regions' shares declined.

Banana: Major suppliers were Guangdong, Guangxi, and Hainan, with consumption relatively small and declining.

Orange: Major suppliers in 2009 were Hubei, Hunan, and Jiangxi (74.1% combined). By 2012, Hubei' s share reached 46.9%, with Guangdong, Jiangxi, and Guangxi combining for 93.8%.

Watermelon: Major suppliers in 2009 were Hainan, Guangxi, and Shandong (77.5% combined). By 2012, sources became more dispersed, with Xinjiang emerging as a major supplier.

Overall, apple and orange sources are relatively concentrated, while watermelon sources show decentralization. Beijing' s cross-regional fruit transfers (apples, oranges, watermelon) increased by 22.7%, 140.7%, and 58.3% respectively—exceeding population growth (16.8%).

4 Discussion and Conclusions

4.1 Conclusions

This study set local fruit resources' ecological footprint distance to 0, so calculated values are conservative. Key findings:

1. Fruit resource cross-regional bio-capacity mass distance increased from 11.5×10 t · km to 17.01×10 t · km (47.91% growth), far exceeding population growth (16.8%). Beijing' s rapid urbanization is rapidly expanding the ecological impact of fruit consumption.
2. Fruit consumption ecological footprint distance fluctuated between 886.66 km and 1073.55 km, indicating relatively stable dependence distance on external fruit resources.

3. Per capita ecological footprint distance increased from 4.39×10 km to 5.55×10 km (26.42% growth), exceeding population growth rates and showing rising ecological costs for residents.

4. From a resource occupation perspective, Beijing' s urbanization ecological costs are increasing. Beijing' s fruit ecological footprint distance covers over half of China' s provinces, with relatively concentrated supply sources (except for watermelons showing decentralization).

5. By category, average annual ecological footprint distances ranked: banana (2072 km) > orange (1385 km) > watermelon (1138 km) > apple (476 km). Imported bio-capacity mass ranked: watermelon (4978×10 kg·km) > orange (1837×10 kg·km) > apple (1523×10 kg·km) > banana (518×10 kg·km). Per capita ecological footprint distance ranked: watermelon (17.7×10 km) > orange (6.4×10 km) > apple (5.4×10 km) > banana (1.92×10 km). These values correlate with source distance and market share.

4.2 Discussion

This study' s limitations include: (1) using only fruit products cannot fully represent all urban consumption, so results serve as qualitative references; (2) current ecological footprint distance research in China remains scarce. Future studies should select more product types representing regional supply-demand relationships and assign appropriate weights to obtain accurate comprehensive indicators.

Despite limitations, results support scientific decision-making for cross-regional fruit allocation. Recommendations include:

1. Implementing scientific bio-capacity allocation measures (e.g., proximity-based allocation) to reduce environmental costs from long-distance transport, while considering product quality differences.

2. Establishing a national ecological footprint distance database for major ecological resources to inform national ecological compensation policies. Market transactions already reflect some ecological compensation, but specific measures should integrate transfer quality, distance, mode, market prices, expert opinions, and supplier compensation willingness surveys.

3. Conducting specialized research on ecological footprint distance to develop and improve national databases for major ecological resource products, with adequate funding for cross-regional bio-capacity collaboration systems to alleviate China' s mounting ecological resource pressures.

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Note: Figure translations are in progress. See original paper for figures.