

Research on Estimation of Wetland Area Based on Spatial Sampling Method-A Case Study of Ningxia Hui Autonomous Region in China

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Abstract: Investigation and monitoring of wetland is an important and fundamental work. Wetland area estimation by systematic sampling would have higher precision than that get by traditional random sampling. In this paper, wetland areas of different types in Ningxia were estimated by spacial sampling method, based on remote sensing data from 2015 to 2016. Results showed that: 1) According to the second national wetland resource inventory database, wetland area in Ningxia was 20.72×10^4 hm², which decreased gradually from north to south, and Wuzhong had relatively largest areas of lakes and marsh wetland. 2) Based with 210 of 4 km \times 4 km quadrat sampling grids, estimation of wetland area in Ningxia was 21.70×10^4 hm², with estimation accuracy of 94.53% and sampling accuracy of 99.78%, which was reliability but the sampling accuracy would decline with the proportion decrease of sampling wetland area. 3) Based with 61 of 4 km \times 4 km quadrat sampling grids, wetland area in Wuzhong was estimated as 52320.67 hm² with estimation accuracy of 98.58%, occurred in a net increase of 731.78 hm² from 2013 to 2016. In conclusion, the spacial sampling method proposed in this research for wetland resource inventory and dynamic monitoring is available and worth of spreading within certain realms, which would improve the protection, management, restoration and sustainable development for wetland resource.

Keywords: Wetland Area, Spatial Sampling, Sampling Grids, Estimation Accuracy, Dynamic Monitoring

1. Introduction

Investigation and monitoring of wetland is an important and fundamental work. The evaluation of wetland area by remote sensing (RS) technology has a significant meaning in dynamic change, policy-making, and protection and management for national regulatory authorities [1]. From 1995 to 2003, the First National Wetland Resources Survey of China had been organized and completed, multi-subject survey system of wetland accordingly [2]. Based on the nationwide coverage RS data, and the methods of “3S” techniques combined with field survey, the Second National Wetland Resources Survey (SNWR) had been completed from 2009 to 2013. The SNWR showed that China had 276.2 thousand wetland patches, and constructed wetland database and graphics base, which would

provide types, distribution, area and other related results [3-4]. However, the necessary task of field check and confirm was time and labor consuming, on account of low-precision RS images, field survey error, type distinguish inaccuracy and other reasons. Thus, a new method of sampling investigation and monitoring using RS data was demanded to improve the efficiency of investigation and monitoring of wetland, and also balance the low-budget against the need of high-precision.

The method of spacial sampling by RS data was widely used in the investigation and monitoring of natural resources, such as land utilization [5], crop planting [6-7], forest distribution [8] and others. RS technology had been applied on field survey [1], classification & identification [9], and dynamic change [10-12] of wetland, but few

researches related to spacial sampling and analysis [13-14]. In recent years, large-scale investigations of land and forest had been a shift from traditional sampling methods to spacial sampling via grid and large plot [15-17]. Precisely because of the aggregation distribution of wetland patches, wetland area estimation by systematic sampling would have higher precision than that get by traditional random sampling [18], except that not similar study had been reported.

By taking Ningxia Rui Autonomous Region (Ningxia) as an example, this paper selected wetland inventory data (including types, area, position and other attributes) and RS images (including two phases) of Ningxia from database of the SNWR, and then adopted an optimized spacial sampling method to estimate wetland distribution. The goal of this study is to describe and compare the accuracy of different sampling methods, so as to provide information and reference for investigation and monitoring of wetland at provincial level.

2. Materials and Methods

2.1. Study Region

Ningxia is situated in the northwest of China, with an area of $5.20 \times 10^4 \text{ km}^2$. Ningxia belongs to the arid and semi-arid area, where wetland is seen as a scarce and precious resource. The Yellow River runs south-to-north through the province with a length of about 397 km, which drains 13 countries of its area, and promotes Ningxia as one of the four gravity irrigation zones in China. The four wetland types of Ningxia are river wetland (RW), lake wetland (LW), marsh wetland (MW) and constructed wetland (CW). Wetlands in the hilly region of southern Ningxia mainly includes seasonal rivers, reservoirs and barrier lakes, types in arid region of middle Ningxia are saltmarsh and salt lake, permanent river or lake and CW in northern plains [19]. As one of the 5 municipalities and a typical wetland area in Ningxia, Wuzhong across middle arid regions and northern plains, where distributes the Yellow River, Haba lake, Qingtongxia reservoir and other important wetlands [19].

2.2. Data Preparation

Our study had collected wetland inventory data of SNWR, 189 RS images of GF-1 & GF-2 with 1 m & 2 m resolution and in 2015 or 2016 (via June to September), 14 RS images of CBERS with 19.5 m resolution and in 2013 (via June to September), wetland annual monitoring results, special investigation results, occupation materials and other materials. Based on control points and Digital Elevation Model (DEM), we produced orthographs from RS images, by ortho-rectification, image fusion, mosaic and color adjustment, etc [4, 20]. RS images were divided into 2 phases, as phase_0 (2013) and phase_1 (2015 or 2016), to monitor the annual changes of wetland. Accordingly, we comparatively analysis wetland inventory data and 2 phases' RS images, and then finished the interpretation and

classification of the RS images by GIS. Afterward, the interpretation and identification of wetland and changed patches (with a minimal area as 0.067 hm^2) were deal by methods as visual interpretation, division and reclassification. In addition, some faulty interpretation signs or classification of wetland patches need to be revised or adjusted after the verification of field survey [17].

2.3. Methods

2.3.1. Spacial Sampling Method

(1) Sampling grids arrangement

According to sampling theory and method, we took all wetland of Ningxia as the sampling population, and used geography grid as basic sampling cell to arrange sampling grids.

The essential indicator of wetland spacial sampling plan was area, which was divided by sampling grids, so as to extract wetland patches and area under different quadrat sizes (with 6 types, as $1 \text{ km} \times 1 \text{ km}$, $2 \text{ km} \times 2 \text{ km}$, $3 \text{ km} \times 3 \text{ km}$, $4 \text{ km} \times 4 \text{ km}$, $5 \text{ km} \times 5 \text{ km}$ and $6 \text{ km} \times 6 \text{ km}$). Meanwhile, we calculated coefficient of variations (CV) for different sizes of sampling grids, and also statistic analysed their change regular, in order to gain the wetland area results accurately and improve the accuracy of sampling estimation up to 90%.

We computed the CV using the following equation:

$$c = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (y_i - \bar{y})^2} / \bar{y} \quad (1)$$

where c is CV, n is the quantity of sampling grids for different sizes, y_i is the percentage of wetland area of the corresponding grid size, \bar{y} is the percentage of total wetland area of all grid sizes in Ningxia.

(2) Grid size optimization

On the basis of systematic sampling principles, the more sampling cells the more closer and smaller for sampling grids, which generated a sampling result accurately to reflect the reality [21]. Similarly, a small sampling grid meant low cost of field survey. On the contrary, more sampling grids would increase the cost of field survey, and also a larger sampling grid was under the lower cost condition to attain efficient utilization of RS data, as well as reduce the quantity of sampling grids [17, 22]. According to the dynamic changes of CV under different sizes of sampling grids, the size of sampling grids was optimized as $4 \text{ km} \times 4 \text{ km}$ quadrat, which meant 3525 grids (with the interval of 4 km) were need of Ningxia.

2.3.2. Sampling Estimation

(1) Sampling grids quantity

In order to calculate the estimation error of wetland area in Ningxia, n sampling grids with $4 \text{ km} \times 4 \text{ km}$ size would be select randomly. The quantity of sampling grids was calculated directly as:

$$n = t^2 \times c^2 / E \quad (2)$$

where n is the quantity of sampling grids, t is reliability index (in the condition of 95% reliability, $t = 1.97$), c is CV, E is relative error (in the condition of 90% accuracy, $E = 10\%$).

The interval between sampling grids can be determined by the quantity of sampling grids:

$$D = (A/n)^{1/2} \quad (3)$$

where D is the interval between sampling grids, A is the total region area, n is the quantity of sampling grids.

It had been calculated that 210 sampling grids (with the interval of 15 km) were need for Ningxia wetland survey, besides 17 grids on the boundary.

(2) Wetland area estimation

Wetland area can be estimated by a series of computational formulas:

$$\hat{A}_{k,i} = \sum_{j=1}^n A_{k,i,j} \quad (4)$$

$$C_i = \hat{A}_{k,i} / \hat{A}_i \quad (5)$$

$$A_i = A \times C_i \quad (6)$$

where $\hat{A}_{k,i}$ is the wetland area of the k grid's i type, n is the quantity of wetland patches of the k grid's i type, $A_{k,i,j}$ is the wetland area of the k grid's i type and its j wetland patch, C_i is the area portion for the i type wetland, \hat{A}_i is the grid size for the i type wetland, A_i is the wetland area of the i type wetland, A is the total wetland area.

(3) Estimation accuracy

The calculation formulas of sample variation were:

$$S_{C_i}^2 = (\sum_{j=1}^n (C_{ij} - \bar{C}_i)^2) / (n-1) \quad (7)$$

$$S_{\bar{C}_i} = S_{C_i} / \sqrt{n} \quad (8)$$

where $S_{C_i}^2$ is the sample variation of area portion for the i wetland type, C_{ij} is the area portion for the i type's j wetland patch, \bar{C}_i is the average of area portion for the i wetland type, $S_{\bar{C}_i}$ is the standard deviation of area portion for the i wetland type.

The formula for obtaining estimation accuracy was:

$$P = (1 - t_a S_{\bar{C}_i} / \bar{C}_i) \times 100\% \quad (9)$$

where P is estimation accuracy, $t_a = 1.97$.

3. Results

3.1. Wetland Area and Distribution

By statistical data obtained from wetland inventory data of

SNWR, wetland area of Ningxia was $20.72 \times 10^4 \text{ hm}^2$, which covered 3.98% of the total land, and showed a decreasing trend from north to south of Ningxia. In terms of wetland types (Figure 1a), river had the largest area of 97904.89 hm^2 (with 47.26% land coverage of Ningxia, the same below), lake had the smallest area of 33500.14 hm^2 (16.17%). Besides, marsh and constructed wetland were in the middle of river and lake, and nearly equal to areas as 38067.84 hm^2 (18.38%) and 37698.52 hm^2 (18.19%).

As may be seen from the diagram (Figure 1b), Among regions of 5 municipalities and their 22 counties, Pingluo country had the largest area of $3.70 \times 10^4 \text{ hm}^2$, following with Yanchi country $2.24 \times 10^4 \text{ hm}^2$ and Qingtongxia $1.71 \times 10^4 \text{ hm}^2$ [2, 23]. On the summary to 5 municipalities, Shizuishan had the largest wetland area of $55\,038.28 \text{ hm}^2$ (26.57%), Gushi had the smallest area of $11\,905.45 \text{ hm}^2$ (5.75%). Wetland area of the other 3 municipalities as Yinchuan, Wuzhong and Zhongwei were $53\,112.51 \text{ hm}^2$, $51\,588.89 \text{ hm}^2$ and $35\,526.26 \text{ hm}^2$, the land coverage were 25.64%, 24.90% and 17.15%. Specially, Wuzhong had more wetland area of lake and marsh.

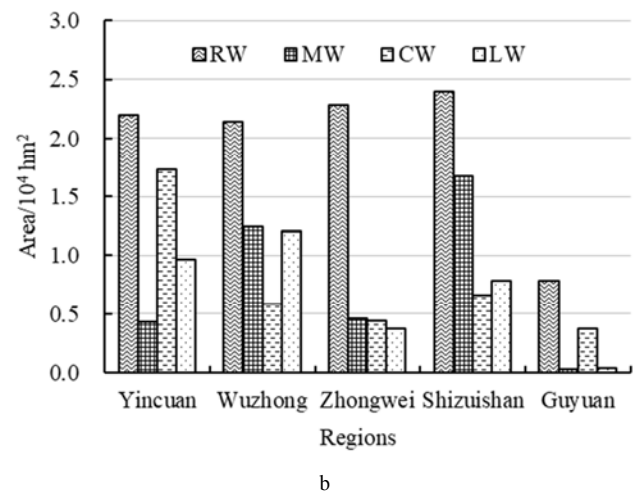
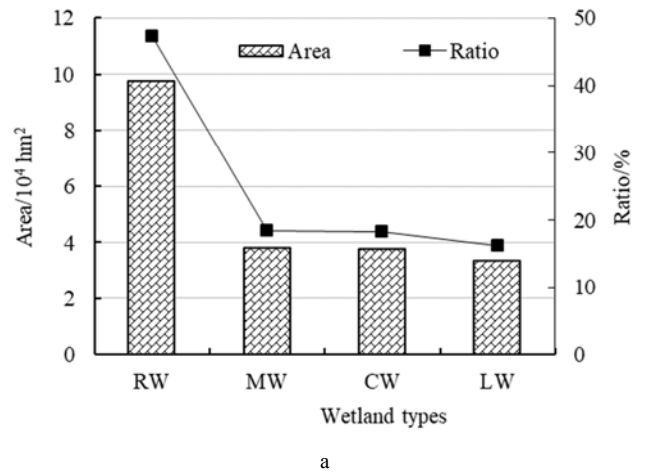


Figure 1. Area of different wetland types (a) and in regions (b) of Ningxia.

3.2. Estimated Wetland Area

The quantity of sampling grids typically decreased in an

inverted J curve across the sizes, from 1 km×1 km to 6 km×6 km, while the area of sampling grid rose in a linear fashion (Figure 2a). Obviously, when the sampling grid size increased to 4 km × 4 km, the CV tend to stable, the same goes for the proportion of wetland area occupation in a sampling grid (Figure 2b).

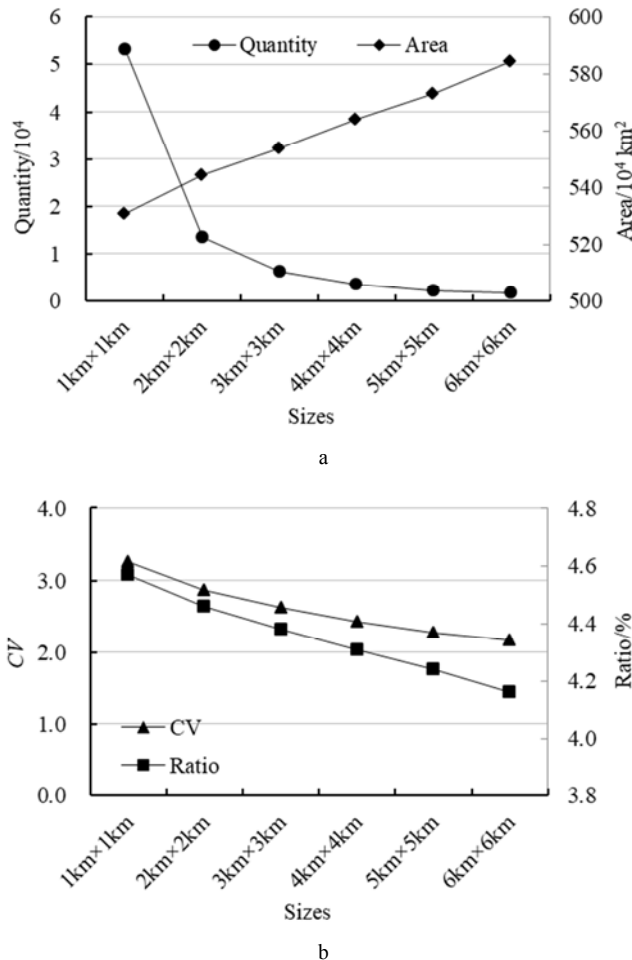


Figure 2. Quantity & area (a), coefficient of variation & proportion (b) of wetland sample grid at different sizes.

As showed in Figure 3a, there was no significant difference between real area of wetland (Area_0) and estimated area of wetland (Area_1). Such as the estimated value of $21.85 \times 10^4 \text{ hm}^2$ compared with all wetland area of Ningxia as $20.72 \times 10^4 \text{ hm}^2$. Estimated accuracy for total wetland area of Ningxia reached 94.53%, and sampling accuracy reached up to 99.78%. Marsh had the highest estimated accuracy of 90.42%, closely followed by river 85.28%, CW and lake had similar but lower estimated accuracy as 73.07% and 71.37%. The amount of wetland area in all sampling grids was 14131.88 hm^2 , accounted for just 6.82% of all (Figure 3b). Better still, land coverage ratio of wetland area had been sampled (Ratio_sampling) was 4.2%, with those of 4 types were all relatively close to actual values (Ratio_real).

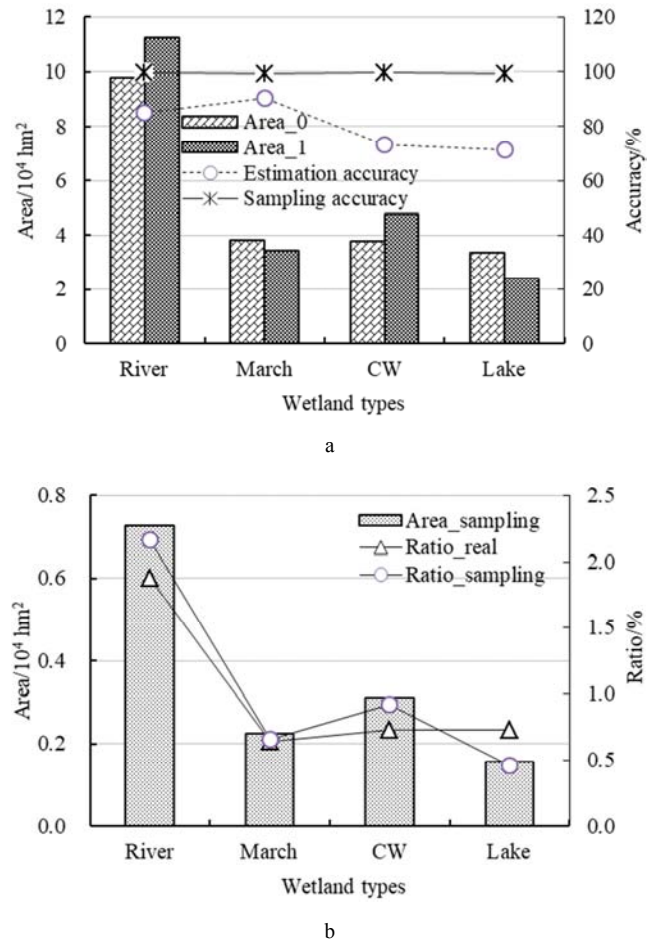


Figure 3. Areas obtained by measured, sampling, estimated of different wetland types in Ningxia.

3.3. Dynamic Change of Wetland Area

Based on the above results and analysis, we take Wuzhong as an instance to describe the dynamic change of wetland area. Firstly, wetland area values had been selected directly from SNWR in 2013 (phase_0) were defined as Area_0. And then, wetland area values had been interpreted and extracted from GF-1 RS images in 2015 or 2016 (phase_1) were defined as Area_1, which referred to 61 $4 \text{ km} \times 4 \text{ km}$ sampling grids. According with sampling estimation method, area of 4 wetland types would be calculated. Thus, wetland area of Wuzhong in phase_1 was estimated as 52320.67 hm^2 , with a high accuracy of 98.58% (Figure 4a). In the aspect of monitoring, wetland area of Wuzhong increased 731.78 hm^2 , specifically from 51588.89 hm^2 of phase_0 to 52320.67 hm^2 of phase_1 (Figure 4b). Among different wetland types, estimation accuracy of river and marsh were both under 85%, and that of CW was only 64.37% (Figure 4a). This phenomenon mainly was due to sampling grids, which were designed for Ningxia but not for Wuzhong directly. In addition, the incremental wetland area was consisted by marsh and CW, lake area was nearly unchanged, but river area reduced apparently.

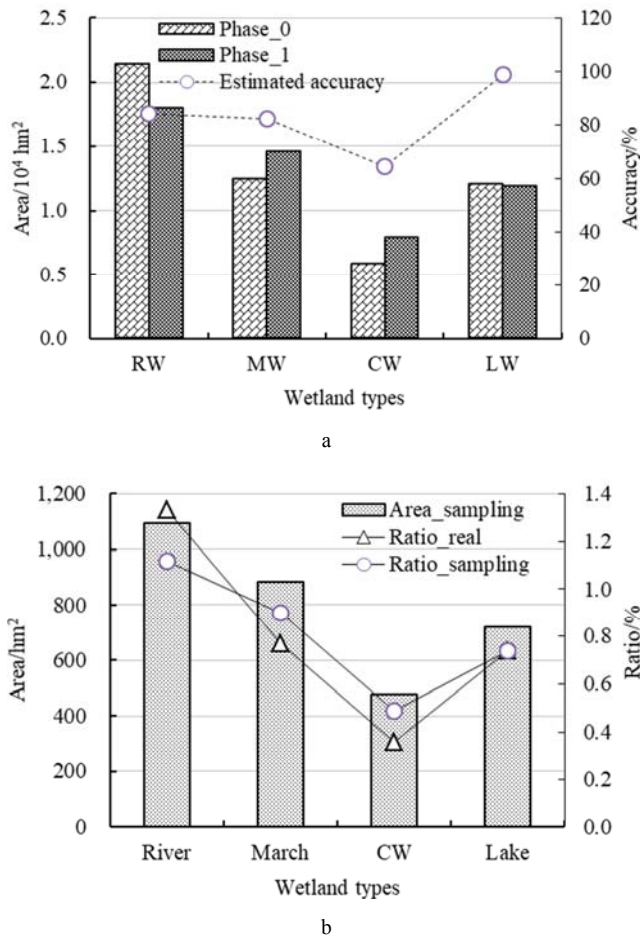


Figure 4. Estimated areas and changes of different wetland types in Wuzhong at two stages.

4. Discussion

RS technology contributed to large-scale survey, real-time monitoring, multi-source mass data, rapid information extraction, high comparability for investigation and monitoring of natural resource [20, 24]. Combine with multiple advantages just described, the spacial sampling method for wetland area proposed in this research had higher efficiency. In particular, the method would cut purchase and using cost of data, reduce division workload of wetland patches and improve estimation accuracy.

However, how to separate natural or constructed wetlands and reduce interpretation error were still need further study [25]. Estimation accuracy of some wetland types would be low caused by resolution and scenes of RS data, and also could not reflect real changes of wetland patches in short-term [26-27]. Moreover, sampling grids had not connected with wetland survey and monitoring, and its boundary were hard to distinct in field. Those result in inconformity of estimated wetland area and SNWR, but could be used as reference in appropriate region. Those showed, either on patch, landscape, district or macro scales [18, 28], wetland investigation and monitoring system with RS data source, was needed to be resolved immediately. In addition, establishment of integrative multi-resources monitoring system would be

beneficial to information sharing, lessen repetitive observation and cost reduction [13, 22].

For the foreseeable future, the spacial sampling method for wetland resource inventory and dynamic monitoring would improve, with the technology improvement of RS processing and interpretation. Thus, coordinating with field survey, wetland distribution and dynamic changes would be estimated accurately and instantaneity, and achieve goals of protection, management, restoration and sustainable development for wetland resource [3, 27, 29-30].

5. Conclusion

Our research supports a spacial sampling method for the estimation of wetland area, which is available and worth of spreading within certain realms. We had figured out 3525 sampling grids as 4 km×4 km were need suitably for Ningxia, with its variation coefficient was 2.42%. Furthermore, 210 sampling grids with the interval of 15 km were extracted to estimate wetland area of Ningxia, which also met the accuracy requirement of 90.0%.

Based with sampling grids, we estimated wetland area of Ningxia was 218 497.43 hm², with estimation accuracy of 94.53% and sampling accuracy of 99.78%. Compared to real values from the Second National Wetland Resources Survey, estimated area of marsh was closest, river and constructed wetland were slightly higher, but lake was lower obviously. Sampling accuracy would decline with the proportion decrease of sampled wetland area, river had the highest accuracy, following with constructed wetland, marsh and lake.

On account of 61 in 218 sampling grids for Ningxia were applied directly, but without encrypted sampling, estimation accuracy of Wuzhong wetland area in 2015~2016 was dissatisfactory. Estimation accuracy of wetland area in Wuzhong was 98.58%, and that of lake was the highest as 98.86%, but constructed wetland was the lowest as 64.37%, besides river and marsh were similar as 84.26% and 82.53% respectively.

According to the estimated results, wetland area of Wuzhong had risen by 731.78 hm² from 2013 to 2016. During this period, marsh and constructed wetland were increased significantly due to the protection and restoration of marsh, and the expansion of swag, water conservancy facilities and landscape construction. On the other hand, for the reason of water withdrawals growth, area of river reduced significantly, and lake reduced slightly.

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