CHAPTER TWELVE

Establishment and application of the National Parasitic Resource Center (NPRC) in China

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Contents

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Abstract

The National Parasitic Resource Center (NPRC) was created in 2004. It is a first-level platform under the Basic Condition Platform Center of the Ministry of Science and Technology of China. The resource centre involves 21 depository institutions in 15 regions of the country, including human parasite and vector depository, animal parasite depository, plant nematode characteristic specimen library, medical insect characteristic specimen library, trematode model specimen library, parasite-vector/snail model specimen library, etc. After nearly 15 years of operation, the resource centre has been built into a physical library with a database of 11 phyla, 23 classes, 1115 species and 117,814 pieces of parasitic germplasm resources, and three live collection bases of parasitic germplasm resources. A variety of new parasite-related immunological and molecular biological detection and identification technologies produced by the resource centre are widely used in the fields of public health responses, risk assessments on food safety, and animal or plant quarantine. The NPRC is the largest and top level resource centre on parasitology in China, and it is a leading technology platform for collecting and identifying parasitic resources.

1. Background

The National Parasite Resource Center (NPRC) was created in 2004 supported by the Ministry of Science and Technology (MOST) of China (Zhou et al., 2006). It was originally started with the research project on "*Standardization of Parasite Germplasm Resources Management, Integration and Sharing Pilot Project*" funded by the MOST of China, and became the "*National Parasite Germplasm Resource Sharing Service Platform*" in 2017, it renamed as "National Parasite Resource Center (NPRC)" in 2019 as one of 30 national resource centres in the country, located in the National Institute of Parasitic Diseases at China CDC (NIPD) based in Shanghai, China. After 15 years of construction and operation, this resource library has gained three major achievements, including (i) for the first time, a national level, most complete and comprehensive parasite germplasm resource bank has been established, covering eight types of physical libraries and databases, e.g. protozoa, trematodes, tapeworms, nematodes, arthropods, molluscs, crustaceans, and important other parasites, etc.; (ii) a total of 28 new technologies for immunological and molecular biological detection tests and identification tools for various parasites have been developed through this

germplasm resource centre, and these tests or tools have been widely used in the fields of public health response, risk assessments of food safety, and animal or plant quarantine, which improved the accuracy of parasite species detection and identification, thus the NPRC has become a leading technological platform in parasite detection and identification in the country; (iii) a platform for sharing the parasite and tropical disease germplasm resources has been created on website: http://www.tdrc.org.cn, this web-based platform can share the resource information for dissemination and provide services in domestic and international scientific researches, teaching and training activities, science popularization, and medical treatment, etc. The above three achievements have also become the main features of the resource centre (Shen et al., 2007; Zhou, 2008, 2009).

With the rapid development of world economic integration and the implementation of the "Belt and Road" initiative (Chen et al., 2019a; Qian et al., 2017), the global population movements and animal trading has caused more pathogens and vectors to spread widely, thus pathogens and their vectors have become important resources in prevention and control of infectious diseases which requires the joint efforts of countries around the world (Bahl et al., 2013; Dugan, 2012; Galsworthy et al., 2011; Saegerman et al., 2018; Si et al., 2009). For example, the outbreak of Ebola virus disease in West Africa in 2014 (Carias et al., 2018; Li et al., 2018a), a new species of schistosome newly discovered in France which has infected to humans in 2015 (Horak et al., 2015; Jouet et al., 2015), and the first report of imported Africa human trypanosomiasis cases reported in China in 2016 (Chen et al., 2019b; Liu et al., 2018; Wang et al., 2018), all those response activities to those emerging and re-emerging diseases need the cooperation of global experts to timely and accurately isolate and identify pathogens or vectors in control the spread of disease risk. At the same time, animal and plant trade will cause more diseases to spread among animals and plants around the world, causing huge economic losses (Bai et al., 2018; Jesus et al., 2018; Torgerson et al., 2018; Yang et al., 2015). Therefore, preventing the spread of parasitic pathogens has become one of the main contents for the global health security, thus the primary task of the NPRC is to identify the pathogen or vector host in a timely and accurate manner during the response activities in combating the disease outbreak (Brown et al., 2018; Campeau et al., 2018; Li et al., 2018a). Therefore, we aim to build a world-class parasitic germplasm resource centre which can not only ensure the stability and availability in supporting to the national researches on parasitology, but also serve in supporting to the "Belt and Road" initiative in terms of involving more activities on the global health

security (Stothard et al., 2018). For this purpose, this article summarizes the achievements of the NPRC in the past 15 years, and proposes future development directions based on the analysis on future needs and deficiencies in sharing our resources.

2. History for the NPRC development

The development of the NPRC is divided into following four stages, such as initial platform, operational platform, sharing services platform, and resource centre.

2.1 Phase I: Initial platform

From 2004 to 2008, the "*Standardization pilot project on management, integration and sharing of important parasite germplasm resources*" was funded by the MOST of China for the first time in 2004, followed by the second project of "*Standardization of consolidation, integration, and sharing of important parasite species resources*" was continued for a period of 3 years granted in 2005. The entire project has accomplished the tasks on construction of a physical library and database of 11 phyla, 23 classes, 1115 species with 117,814 pieces of parasitic germplasm resources, and establishment of three live collection bases of parasitic germplasm resources (Chen et al., 2013; Shen et al., 2007; Zhou et al., 2006). The resource platform on parasitic germplasm involves 21 depository institutions in 15 regions of the country, including human parasite and vector depository, animal parasite depository, plant nematode characteristic specimen library, medical insect characteristic specimen library, trematode model specimen library, parasite-vector/snail model specimen library, etc. The resource platform consisting of 16 institutions from the country was performed as a way of distributing resources in different institutions and centralized the information in the NPRC of the NIPD, and safely storing the resources in duplicate by matching different species for a medium- and long-term designing. During this stage, a total of 11 new species of brook crab and 1 new species of nematode were discovered, the National Parasite Species Resource Network was established which formed as the national parasite germplasm collection centre. All those activities in the resource platform on parasitic germplasm by use of modern technologies such as information sharing and internet technology have established a national parasite resource sharing system, thereby paved a path to success for the long-term development of the resource platform.

2.2 Phase II: Operational platform

From 2009 to 2013, the recourse platform on parasitic germplasm have being kept in the NIPD by the way of operation with self-raised funds. Three exhibition halls or museums under the resource platform have been open to the public (Zhou et al., 2015). Among them, the Museum of Parasites and Vectors at the NIPD has become one of science education bases in Huangpu District of Shanghai Municipality, and has received 37,000 visits from home and abroad. The resource centre provided 16,720 resources to various research institutions and research projects for sharing, becoming an important source to share living resources for major national research projects, and training a group of young scientists in the identification and detection of parasite germplasm resources.

2.3 Phase III: Sharing services platform

In 2014, after the resource platform on parasitic germplasm was evaluated by the MOST of China, the resource platform on parasitic germplasm was included as one of components in the National Scientific Data Sharing Platform for Population and Health (National Scientific Data, 2018), under the MOST of China. Thus the resource platform on parasitic germplasm started the sharing services to use parasitic germplasm in the fields of public health responses, risk assessments on food safety, and animal or plant quarantine, etc., with the funds from MOST through the National Population and Health Science Data Sharing Service Platform (Chen et al., 2020). This sharing services platform has been maintained until 2016.

2.4 Phase IV: Resource centre

In 2017, after the resource platform on parasitic germplasm taken the second evaluation by the MOST of China, the platform was formally upgraded into the first-level platform as one of resource centres under the administration by the Basic Facility Platform Center of the MOST, namely "National Parasite Germplasm Resource Bank" with sustainable funds supported by the MOST of China. The newly official name was awarded as the "National Parasitic Resource Center (NPRC)" by the MOST of China in 2019, as one of 30 National resource centres in the country. Up to date, the NPRC composes of 16 sub-platforms involving the operation to collect more parasitic resources, maintain the classification and identification of various parasites and vectors, and share the resources for different purposes requested by research institutes and universities (Fig. 1). As of the end of

2018, the NPRC (http://www.tdrc.org.cn) holds a physical library and database with resources consisting of 11 phyla, 23 classes, 1115 species and 117,814 pieces of parasitic specimens. The NPRC has become the largest and top level parasite species bank in China (Chen et al., 2020). The physical library is an important facility in providing resources for hundreds of scientific research projects and research institutions at home and abroad. Those services, including scientific researches, training and teaching, science popularization, government decision-making, major research projects, emergency response events, corporate innovation, serving people's livelihood and information dissemination, has become an essential task of the NPRC, as a leading technological platform for collecting and identifying parasitic resources.

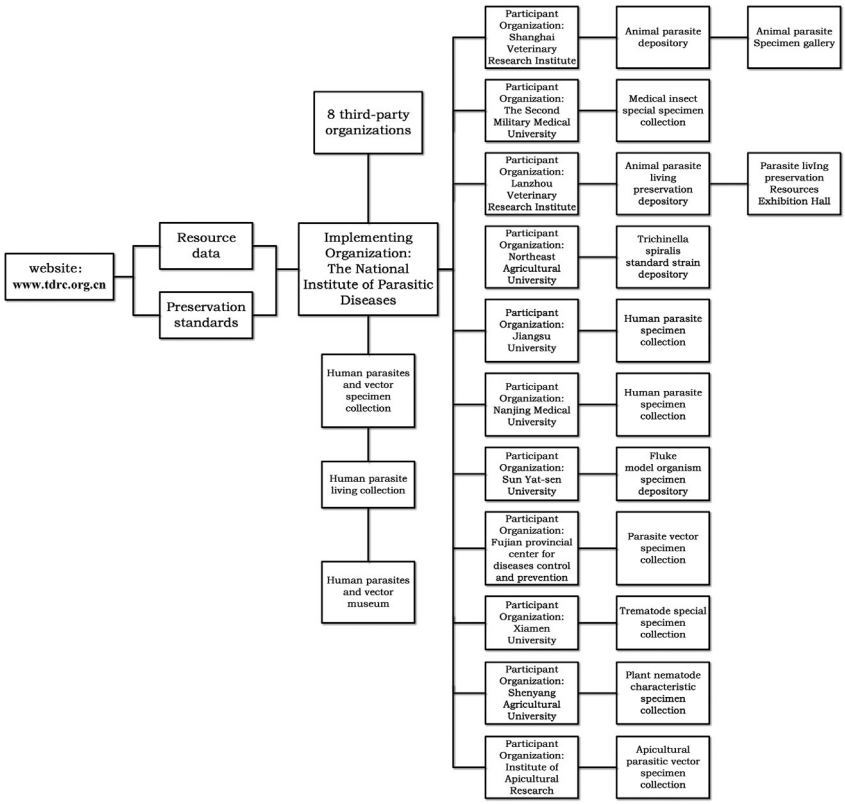

Fig. 1 The framework of the physical resource library in the National Parasitic Resource Center in China.

3. Main function of the NPRC

The main function of the NPRC is to formulate resource management system and standards, collect and preserve the parasitic resources, provide resource sharing and services, manage the resources facilities, and strengthen capacity building for the professionals in the field of parasitic resource identification and preservation (Dougherty et al., 2016).

3.1 Formulation of resource management system and standards

3.1.1 Establishment of a resource management system

The resource database has established in a complete set of operation management systems, which includes nine sub-systems, such as expert group review system, financial management system, work quality supervision system, joining system, information and data network reporting system, resource application registration system, platform user registration system, resource utilization filing and registration system, the rules and regulations of the parasites and vectors museum and the depository, in order to ensure the normal operation of the resource centre. At present, the resource centre implements the system of responsibility of the main person in charge, regularly communicates the progress of the work, timely discovers problems and proposes solutions. At the same time, an expert group is set up to be responsible for the review of various standards and the quality assessment of the implementation projects twice a year. During the implementation of the resource centre quality control is carried out according to the "Work Quality Scoring Standard", which is used as an indicator for allocating work funds for the next stage, and an assessment dynamic management mechanism is implemented. Each participating institutions under the resource network has a resource working group responsible for daily maintenance. The participating institutions cooperate and complement each other, and exchange information from time to time.

3.1.2 Formulate the description protocols, preservation procedures and inventory of parasite species resources

3.1.2.1 Principles in developing the protocol documents

Prioritized work for developing the platform documents is to develop the description protocols and standards for the existing database accompanied with the current needs, such as resource research and resources used for

teaching. At the same time, taking into account the needs of resource platform's development, priority is given to specimen collection based on current settings and international information extracted from the published descriptor table of foreign parasite germplasm resources (Kumar et al., 2017).

3.1.2.2 Description of the protocols or norms

Several documents to describe the specimen during collection and management have been formulated, such as the "General Description Table of Animal Germplasm Resources", "Description Table of Common Characteristics of Parasite Germplasm Resources", and the individual description table of various types of parasite germplasm resources one by one, in accordance with the descriptions and standards in the "Animal Germplasm Resource Common Description Specification", "Parasite Germplasm Resource Common Description Specification", and various description on specifications of the parasite germplasm.

3.1.2.3 Formulation of relevant standards

A total of 29 preservation specifications have been developed: including "Specifications for Parasite Germplasm Resource Description", "Technical Regulations for the Conservation of Chicken Coccidia", "Technical Regulations for the Conservation of Piroplasma", "Technical Regulations for Conservation of *Brugia malayi*", "Technical Regulations for Conservation of *Trichinella spiralis*", etc. The standards and specifications basically cover the main parasite species in China, including all kinds of parasite species resources, so as to achieve the goal of comprehensive and refined management in resource collection and preservation quality control, resource sharing and collation standardized management.

3.2 Resource collection and preservation

3.2.1 Resource screening

The purpose of resource screening is to ensure the scientifically, systematically and operationally establishing the information database, to standardize the procedures in collection, preservation and biosafety of resources, and to promote the efficient sharing and sustainable use of resources collected. The resource screening is mainly aimed at parasites and related vectors that infected in humans and animals, including those specimens of living parasites, slide specimens, liquid immersion specimens, genetic resources and biological materials, which can be included in the scope of parasite species resources in this resource centre. Highly pathogenic pathogens are not

included in the resource centre. The living parasites collected or operated by the resource collection institutions must have a biosafety level laboratory required by the state for the corresponding parasite operation. The representativeness of resource selection have to give full play to the advantages of each institution, and collect resources according to the collaborative division of labour to ensure the representativeness and integrity of the resource database.

3.2.2 Physical library construction

Systematic research on the species and distribution of global parasite resources has been carried out, and surveys of global parasite resources have been completed through literature searching and other means. At the same time, a survey of parasite resources in China has been completed, and a gap analysis was performed with reference to the existing types and quantities of the resource centre (Poulin, 2014).

We also established a directory that covers the world's important parasitic pathogens and vectors, and planned to undertake specimen collection based on gaps existed (Spencer and Zuk, 2016). On the basis of maintaining the existing sorting scope, we have expanded the scope and varieties of parasite specimen collection and sorting, and strengthened the cooperation and promoted exchanges between the resource bank and parasitoid-related research institutions around the world. Supplementary collection of new, rare, invasive parasites or vector species worldwide are encouraged through field collection, specimen exchange, etc. The long-term work is to make local resources covering more than 50% of the total species of parasites and vectors.

3.2.3 Information database construction

3.2.3.1 Digitization of numbers

Each depository institution establishes a "Parasite Classification List of Parasite Germplasm Resources" according to the "Specifications of Common Description of Natural Science and Technology Resources (Trial)" and the "Specifications of Data Reported by Resource Institutions (Trial)", and renumbers different parasite resources uniformly. Perfect records, captured image data are saved as. JPG files (pixels $>$ 300 dpi).

3.2.3.2 Digitization of resources

The digitization of resources includes following steps, such as inputting data, establishing and assessing the database, upload the database into system and

feedback, etc. These steps provide the bases for construction of the database, by the way of cross-regional integration of important parasite species resources covering medical parasites, veterinary parasites, medical arthropods and medical shellfish in China, in order to achieve complementary advantages and resource sharing.

3.2.3.3 Construction of the database

The integrated data has been used to establish eight databases in a unified format on the shared platform. The main databases include parasitic protozoa, parasitic flukes, parasitic nematodes, parasitic maggots, other important parasites, medical arthropods, medical molluscs, and medical crustaceans. The database was established according to the relationship of various parasites and the relationship between attributes in order to ensure the integrity, redundancy, security of the data, and to ensure all types of databases to be stored, retrieved and analysed in the form of both pictures and text (Nunn and Altizer, 2005).

The primary task of the resource platform is to provide services for scientific researches (Stephens et al., 2017). For parasites infected in humans, animals and plants as well as relevant vectors, priority of the specimen collection is to collect those endangered species or species that are extremely rare in the region (Campeau et al., 2018; Mordecai et al., 2016; Stringer and Linklater, 2014). We have not only vigorously strengthened the collection and preservation of rare, emerging or re-emerging parasites, but also established animal models, provided sample to be used in the research projects, such as projects on pathogenic mechanisms, diagnostics development and drug screening of rare parasites (Kumar et al., 2017; Li, 1989). It is ensured that the data in the resource library are shared in a unified manner through the resource sharing platform, and it is also ensured that the established resource depository, specimen exhibition hall, living deposit centre can be shared across institutions or universities through specific mechanism of sharing data and specimen.

3.3 Resource sharing and services

3.3.1 Establish a set of parasite species resource service sharing system

With the increasing needs to share the resources, a parasite species resource alliance system was established that covers 21 national depository institutions across the three major fields of animals, humans and plants. The distribution of depository institutions across the country is shown in Fig. 2.

Fig. 2 The distribution of deposits across the country (1. The Northeast Agriculture University; 2. Shenyang Agriculture University; 3. Institute of Apiculture Research, Chinese Academy of Agricultural Sciences (CAAS); 4. Lanzhou Veterinary Research Institute, CAAS; 5. Nanjing Medical University; 6. Jiangsu University; 7. The Second Military Medical University; 8. National Institute of Parasitic Diseases, China CDC; 9. Shanghai Veterinary Research Institute, CAAS; 10. Fujian Provincial Center for Disease Control and Prevention; 11: Xiamen University; 12. Sun Yat-sen University).

3.3.2 Resource services

In terms of resource services, we strive to add more applications to the old resources collected early, use new DNA identification technology, obtain bioinformatics data with clear background information, and provide new applications for resources. For newly collected resources, we obtain multiple

types of information from the same resource through data mining according to the needs of subject development and subsequent applications, so that the potential information of the resources becomes possible for multiple applications to improve resource utilization. We are carrying out a large number of biological determinations on important samples, that comprehensively covered parasitic protozoa, trematodes, nematodes, cestodes, arthropods, molluscs, crustaceans and other invasive parasitic species. At the same time, we are further providing intensive services to expand resource utility in the research projects on development of diagnostic and therapeutic related products, and providing a more comprehensive database of sequencing or mutation sites in identification and detection of the invasive species and in tracing the rare or important parasites.

3.3.3 Resource sharing

In terms of sharing, we have improved the working mechanism of the parasite resource bank, and carried out resource collection, integration specifications, germplasm resource sharing service system and formulation of corresponding national standards. In the future, the resource bank will continue to improve various technical standards and specifications, and strive to basically cover the main parasite species in China, covering the entire operation process of the species resources from quality control to standardization.

Our key services on resource sharing are as follows:

- *Special services for the public through the internet and new media:* We undertake the identification of human parasites and set up the network of diagnostic testing services in major clinical hospitals across the country, which help clinical hospitals in precision diagnosis of parasitic diseases. We use new media to provide public-oriented knowledge dissemination, and also provide test results query services.
- *Participation in the emergency response and disease epidemic control services*. We participate in the national public health emergency responses, disseminate various information, and provide identification and detection services through the internet to ensure public health safety (Stringer and Linklater, 2014).
- *Implementation of research cooperation services through sharing of data and physical resources*. We open a service port for major scientific research projects, and open a download information window related to standards to achieve a bridge connection between germplasm resources and research users, thereby further promoting physical resource services for major scientific research projects (Bell et al., 2018).

- *Providing professional training and education services through on-site training and new media methods*. We provide a teaching service for continuing education training courses, through providing parasite teaching resources. We continue to interact with various media to provide health education videos on parasitic diseases.

3.4 Management of resources facilities

We have established high-quality preservation venues for the resource centre. The resource depository is distributed in 15 provinces and cities across the country. There are 21 professional depository institutions participating in the resource network. All participating institutions have their own sites and maintain independent depository. Each depository institution constructs a physical repository of parasite resources in accordance with unified standards, the largest of which is the human parasite and vector depository of the NIPD. The exhibition hall and three supporting specimen libraries cover a total area of more than 1000 square meters, and its exhibition hall is regularly open to the public. In terms of databases, we built a germplasm resource service platform website, and based on this, we have produced a number of supporting software or systems such as resource standardization management software, project management software, parasitic disease and parasite species picture recognition software, parasitic disease outpatient information software, parasitic disease health education and outpatient result query public numbers. At present, our portal website and system management software have been transformed into BS mode, and due to the requirements of offsite backup, we have used the cloud servers of other participating institutions to undertake. In addition to the main management system, 21 participating institutions have their own specimen library management and query systems, using the platform's unified resource number as the unique identification code to exchange data between the systems. The system is managed and operated by the information centre or network centre of each unit, and the maintenance costs are shared by the parasite germplasm resource service platform and the host institution.

3.5 Capacity building

The NPRC is implemented by the director-responsibility system under the leadership of the board of the NPRC facilitated by the NIPD. The director of the NIPD serves as the general manager of the resource base platform, and the chief of the main deposit base institution is a member. There are

currently nine expert groups and a total of 171 staff members working in the NPRC. Among them, the head of the resource bank and the key senior participants are 30 people. This team involves multidisciplinary fields such as medical parasitology, veterinary parasitology, pathogen biology, medical malacology/vector biology, molecular biology, veterinary science, etc., and is responsible for reviewing and assessing the system specifications of the resource centre.

4. Achievements of the NPRC

4.1 Development of resource management systems and standards

Based on the biological characteristics and classification system of parasites and vectors, the "Description protocol of the parasite species from human, animal and plant" was issued firstly, followed by "Collection protocol of China's parasite species resources", e.g. *Taenia rapae* collection protocol, "Technical regulations for parasite preservation (Volume 1)" and "Directory of China's livestock and poultry parasite", etc. (Zhou, 2008, 2009) All of these documents laid the foundation for the taxonomic research of parasites. In the process of developing the inventory of parasitic resources, 11 new species of vectors, 1 nematode and 1 rare parasite have been discovered after we established the technical procedures for preservation, labelling and integration of parasitic resources. For example, the rare parasite of *Armillifer agkistrodontis* which causes visceral pentastomiasis has also been investigated, the life history of *Armillifer agkistrodontis* was revealed for the first time in the world with animal models established which can provide scientific evidence for the pathogenic mechanism and drug screening of this rare parasite (Chen et al., 2010).

4.2 Resource collection and preservation

A total of 21 parasite species resources institutions, 3 physical exhibition halls and 3 parasite live collection centres from 15 provinces and cities have been established nationwide. A total of 1200 species/125,000 pieces of parasite resources in 11 phyla were recorded (Table 1), including human parasites and vector depository, animal parasite depository, plant nematode characteristic specimen library, medical insects characteristic specimen library, trematode pattern specimen library, and parasite vector snail pattern specimen library. Resources were stored in a manner of network with all of

Table 1 Table of co-constructed institutions of the National Parasite Resource Bank.

No.	Area	Depository	Resource preservation repository type	No. of data exchanged	Reason for inclusion	Number of participants (person)
1	Shanghai	Institute of Parasitic Disease Control and Prevention, Chinese Center for Disease Control and Prevention (undertaking unit)	Human parasite and vector library	315/29，059 pieces	The only national parasite research institute	37
2		Shanghai Institute of Veterinary Medicine, Chinese Academy of Agricultural Sciences	Animal parasite depository	754 species/ 30751 pieces	Covers the largest variety of animal parasite banks, participating in the construction of parasite platforms for 15 years	18
3		Chinese People's Liberation Army Navy Medical University	Medical insect specimen collection	69 species/ 5290 pieces	The museum has a large collection of parasites and vectors that are characteristic of medical insects, and has participated in the construction of the platform for 15 years.	2
4		Fudan University	Human parasite gene bank	27 species/ 645 pieces	Specializing in genomics of parasites, revealing the whole genome of schistosomiasis for the first time in the world.	6
5		Shanghai Customs Animal and Plant and Food Inspection and Quarantine Technology Center	Invasion vectors and parasite-specific specimen libraries	80 species/ 2071 pieces	As the nation's largest port, a large number of invading vectors and parasite specimens have been collected to ensure national security.	5

Continued

Table 1 Table of co-constructed institutions of the National Parasite Resource Bank.—cont'd

No.	Area	Depository	Resource preservation repository type	No. of data exchanged	Reason for inclusion	Number of participants (person)
6	Gansu	Lanzhou Veterinary Research Institute, Chinese Academy of Agricultural Sciences	Animal parasite living depository	114 species/ 9805 pieces	The leading institution of national veterinary parasite research has the most complete collection of animal parasite living deposits and has participated in the construction of the platform for 15 years	22
7	Heilongjiang	Northeast Agricultural University	Trichinella spiralis standard collection bank	158 species/ 6399 pieces	The construction of the platform was last for 15 years, and has obtained many patents in the research of Trichinella spiralis living preservation technology and veterinary drugs	10
8	Jiangsu	Jiangsu University	Human parasite collection bank	71 species/ 4758 pieces	The construction of the platform was last for 15 years, and has a full set of human parasite teaching specimens	3
9		Nanjing Medical University	Human parasite collection bank	46 species/ 3645 pieces	The construction of the platform was last for 10 years, and has a full set of human parasite teaching specimens	3

10	Guangdong	Sun Yat-sen University	Trematode specimen collection bank	72 species/ 3771 pieces	Participated in the construction of the platform for 15 years, and is a large base for parasite research and preservation in southern China	13
11		Shenzhen Center for Disease Control and Prevention	Invasive parasite vector and pathogen depository	4 species/ 781 pieces	It has a variety of invasive parasite vectors and pathogens in China	5
12	Fujian	Fujian Provincial Center for Disease Control and Prevention	Trematode and vector specimen collection bank	80 species/ 4597 pieces	Participated in the construction of the platform for 15 years, and has a base of human parasitic flukes in the southern part of China	5
13		Xiamen University	Trematode special specimen collection	112 species/ 3906 pieces	Participated in the construction of the platform for 15 years, and is the animal parasite base and storage in southern China	6
14	Jilin	Shenyang Agricultural University	Plant nematode specimen collection	138 species/ 5037 pieces	Participated in the construction of the platform for 15 years and is the only depository institution that studies plant parasites	7
15	Beijing	Chinese Academy of Agricultural Sciences	Bee parasite vector collection bank	4 species/ 2699 pieces	Participated in the construction of the platform for 10 years, and is a preservation research institution featuring research on insect parasites	2

Continued

Table 1 Table of co-constructed institutions of the National Parasite Resource Bank.—cont'd

No.	Area	Depository	Resource preservation repository type	No. of data exchanged	Reason for inclusion	Number of participants (person)
16	Jiangxi	College of Medicine, Nanchang University	Parasite vector crustacean depository	67 species/ 1582 pieces	Participated in the construction of the platform for 15 years, and is a depository institution that specializes in studying the transmission of parasites	5
17	Sichuan	Sichuan Academy of Animal Science	Animal Parasite Specimen Bank of Southwest China	115 species/ 2449 pieces	Participated in the construction of the platform for 5 years and is an animal parasite preservation institution in southwest China	6
18	Henan	Henan Agricultural University	Zoonotic parasite bank	21 species/ 3890 pieces	It is a parasite preservation institution that is specialized in the research of parasite protozoa	3
19	Qinghai	Qinghai Institute of Animal Husbandry and Veterinary Medicine	Animal parasite depository	89 species/ 2520 pieces	Participated in the construction of the platform for 5 years and has a large number of animal parasite preservation institutions	6
20	Yunnan	Yunnan Provincial Institute of Parasitic Diseases	Invasive parasite vector and pathogen depository	1 specie/642 pieces	With a large number of invasive parasite vectors and pathogens, it is the base for research and preservation of human parasites in southwest China	3
21	Guangxi	Guangxi Provincial Center for Disease Control and Prevention	Invasive parasite vector and pathogen depository	6 species/ 703 pieces	It has a large number of invasive parasite vectors and pathogens	4

information centralized in the NIPD, and stored securely in duplicate locations. The amount of resources have accounted for 45% of the total in the country.

Meanwhile, eight major databases of the resource database, including parasite species resource database, a parasitic fluke species resource database, a parasitic nematode species resource database, a parasitic tapeworm species resource database, other important parasite resource databases, medical arthropod germplasm resource databases, medical molluscs and medical crustacean germplasm resource database, have been developed which become the largest and top database for parasite species collection in China.

4.3 Resource sharing

The shared services are the main function of the NPRC through sharing port platform (http://www.tdrc.org.cn), which mainly used in three major areas, such as public health responses, risk assessment of food safety, and animal breeding or quarantine. The research work on resource sharing and services have produced a number of patents and technical standards.

In the field of public health response, several technical methods developed through the NPRC have been used for the rapid clinical diagnosis as well as epidemiological response. For instance, the parasite egg recognition system based on multi-features of eggs' morphology can be applied to diagnostic services through remote network, which will provide diagnostic references for clinical hospitals and disease control centres. Established detection methods for *Clonorchis sinensis* and *Angiostrongylus cantonensis* have provided rapid and accurate diagnosis for epidemiological screening and control of *A. cantonensis* and *C. sinensis* infections (Chen et al., 2012, 2016a; Cheng et al., 2018; Chu et al., 2013; Li et al., 2018b; Qian et al., 2019). A protozoa staining method has been established to improve the long-term preservation of protozoa specimens. In addition, several devices have been developed for parasite identification, e.g. an improved Bellman's device, a digestive tract nematode culture device, a venom aspirator and stool sampling, and a parasite concentrator device, etc. A total of nine detection and identification patents, including detection methods for *C. sinensis* and *Toxoplasma gondii*, have been invented (Chen et al., 2016b; Cheng et al., 2018; Liu et al., 2016). All of those innovative activities have not only helped the collection of parasites and provided a convenient means for the accumulating more parasites in the resource bank, but also laid a foundation for the control of parasitic diseases (Ying-Dan et al., 2017).

In the field of risk assessment of food safety, six parasite species detection and identification technologies have been developed, of which patent authorizations have been awarded, such as "Universal real-time fluorescent PCR detection method for *Trichinella spiralis*", "High-density fermentation process of recombinant *Pichia yeast*", "Recombinant gene, vaccine for porcine cysticercosis and preparation method", "Indirect ELISA detection kit for porcine cysticercosis disease and preparation method", "A test methods for *Trichinella spiralis* and *Cysticercus cellulosae* in food", "Primers and probes and kits for detecting bradyzoite of *Toxoplasma gondii*" (Wei et al., 2011). Three industry standards have been formulated for the detection and identification of aquatic products, namely: "Identification methods for *Clonorchis sinensis* in fish" (SN/T 2975-2011), "Quarantine technology of metacercaria from trematode in crustacean aquatic products" (SN/T 3504-2013) and"Technical specifications for *Gnathostoma quarantine* in aquatic products" (SN/T 3497-2013). All aforementioned patented techniques and standard products have improved the risk assessment of food safety.

In the field of animal breeding and quarantine, about four tests and identification patents have invented, including "Kit and method for differential diagnosis of *Theileria annulata*", "Diagnostic kit and application recombinant antigen of *Babesia jerkii*", "Test method and kit for the detection of lyme disease pathogens in ticks", "A method for biosafety evaluation of genetically modified animals in a hard tick model", all above kits have provided fast methods for field diagnosis, prevention and control of animal diseases, in particular, to block the spread of zoonotic parasitic diseases (Gao et al., 2007).

4.4 Resource services

Since 2008, the NPRC has made important contributions to the scientific research, teaching, information dissemination and diagnostic services, through its networks.

4.4.1 Scientific research services

The physical library provided physical resources for 100 scientific research projects from 52 scientific research institutions in domestic and abroad. Up to date, there were 16,720 resources in 7 categories for physical sharing to support various research projects, including 2 for the major national infectious disease projects, 16 for the national supporting-plan research projects, 2 for the national 863 research projects, 2 for the national 973 research projects, 6 for the international projects, 24 for the research projects supported

by the National Natural Science Foundation of China, 48 for other R&D projects. The resource sharing ensured smooth performance of research projects. A total of 288 publications, including 178 and 110 articles were published in Chinese and English, respectively. Twelve monographs have been published at the same time.

4.4.2 Education and training services

The resource bank provided teaching services for 36 training courses on parasitic disease. The participants of those training course were from 20 countries, hosted by 5 institutions and universities. A total of 12,494 person-times participants were trained with a provision of 2298 parasitic specimen in teaching.

4.4.3 Information dissemination

The three exhibition halls under the NPRC were open to the public since their establishment. A total of five health education films have been published, including "*Beware of Prevention from Paragonimiasis*", "*Beware of Prevention from Liver Fluke Infections*", "*Beware of Prevention from Angiostrongyliasis cantonensis Infections*", "*Beware of Prevention from Pentastomiasis*" and "*Trichinelliasis on the Tip of the Tongue*". Great impacts of the series films on food-borne parasitic infections have gained in health education and information disseminations. For example, "*Beware of Prevention from Paragonimiasis*" won the 2013 Medical Science Award of the Chinese Medical Association. We also provided those health education materials to assist media, such as CCTV10, CCTV7, Hunan Satellite TV, Heilongjiang Satellite TV and China Rural Magazine, etc., to disseminate the health information by shooting videos for promotion of prevention measures to parasitic infections, and by conducting a series of lectures (Table 2).

4.4.4 Consultation and testing services

The NPRC has provided social-oriented services specialized in parasitic infections. For instance, it has provided consultation and testing services to clinical or medical institutions for 54,558 person-times, animal quarantine for 8791 animal tests, and plant protection for 642 times, respectively. The platform has created a parasite egg identification system applied to diagnosis through remote network, providing technical inspection, egg identification, and species identification thematic service entrances to help clinicians with differential diagnosis.

Table 2 Services on information dissemination from the NPRC, 2008–2018.

Year	The number of services on information dissemination	Number of people served for dissemination
2008	1	1000
2008	1	1200
2010	2	1600
2011	4	2200
2012	5	More than 200 million
2013	5	More than 200 million
2014	4	More than 200 million
2015	7	More than 60 million
2016	12	More than 200 million
2017	13	More than 200 million
2018	13	More than 200 million

4.4.5 Database services

The NPRC has provided services supported by the important parasitic and biological information database, human pathogen gene and biomarker database, Chinese *Anopheles* species graphic retrieval system, parasite monitoring data sharing and analysis platform, and parasite disease literature abstract database services. Among them, the important parasitic and biological information database, the first comprehensive parasitic biological information database in China, has help to analysis genome data covering 22 parasites, 24 transcriptome databases, 7 proteome databases, such as *Schistosoma japonicum*, *Schistosoma mansoni*, *Brugia malayi*, *Leishmania spp.*, *Cryptosporidium spp.*, *T. gondii*, *Trichinella*, *Giardia lamblia*, *Plasmodium,* and *Trypanosomes*. Meanwhile, the system integrated related analysis software and analysis modules, including membrane protein prediction, signal peptide protein prediction, secreted protein prediction, epitope prediction, multiple sequence alignment, homology alignment, domain analysis, and phylogenetic analysis (Hu et al., 2003). In addition, parasitology literature database provided articles, abstracts and other information related to tropical diseases, forming a unique parasitology literature summary database. The database also provided the Tropical Disease Academic Briefings with 128 hot-topics analysis issues.

4.5 Capacity building

Through the establishment of the network on parasite resource collection and shared platform in China, the NPRC has trained a huge number of professional teams engaged in parasitology research in multiple fields.

In last 15 years, the NPRC has developed a well-balanced talent team structure. There were a total of 171 staff members working in the network of the NPRC, of which 30 at the top level are taking the leading role in each field of parasitic resources, or the main backbone of the NPRC. The specialized staff of the NPRC network are working in eight positions, including parasite germplasm resource collection staff, collation and integration staff, separation and identification staff, data mining analysts, shared service staff and technical support staff, in which contained 40 people at senior level (24%), 74 at medium level (43%), and 57 with junior titles. In addition, a consultation group consisting of nine famous experts who familiar with the parasitic resources work provided various consultancy and academic evaluation for the NPRC. During the operation period, a total of 288 research papers and 12 monographs were published, and 1575 postgraduates and 630 doctoral students were trained and graduated. All these achievements have a great impact to the capacity building in the fields of tropical medicine, public health, inspection and quarantine, food safety, and animal husbandry and veterinary medicine.

5. Looking forward

In the future, the NPRC will further improve the means in collection and integration of parasitic resources, sharing services, and management mechanisms based on recommendation from the consultation group and a series of standard specifications (Chang, 2006; Ying-Dan et al., 2017). More works will focus on supplementary collection of new, rare, and invasive biological species resources (Chen et al., 2010; Liu and Zhou, 2015; Molina et al., 2019; Scare et al., 2018; Song et al., 2018). It is expected that the NPRC will be one of advanced resource centres in the world by following actions: (i) transitioning from national level to the global level in resources collection and preservation, scientific research services, and intelligence of resource sharing; (ii) building a national top platform or resource bank by integrating functions on research, dissemination, specimen exhibition, training, networking and information sharing to improve parasites;

(iii) promoting the R&D activities in modern biology and relevant fields (Cable et al., 2017).

The detail activities to be a world well-known NPRC will be arranged in the following seven actions, including (i) improving the working mechanism of the parasite germplasm resource bank; (ii) expanding the scope and variety of parasitic species collection by cooperation and exchanges; (iii) further standardization of the parasitic specimen library by formulation of more standards or norms; (iv) building a genetic material library for human, animal, and plant parasitic resources; (v) construction of gene tag information database for parasitic resources by sequencing more important parasites and vector organisms; (vi) building a parasitic resource data warehouse; (vii) improving the public impacts on using information resources and services of the NPRC.

In order to keep the same space with the international development on parasite collection and resource preservation, we need to learn the rich experience from the world well-known institutions on parasite resource preservation, such as the British Museum of Natural History of UK (True, 1885), the Smithsonian Institute of USA (Rubinoff and Leigh, 1990; Smithsonian Institute, 1920), and the U.S. National Parasite Collection Center (Hoberg and Phillips, 2014), etc. We also need to keep cooperation with other international emerging institutions in the field of parasite collection, such as Japan, South Korea, the Philippines, etc. Therefore, a gap analysis between the NPRC and other international parasitic resource centres is warranted to perform in order to better design the further directions for the NPRC development (Hai-Juan et al., 2019).

6. Conclusion

The parasitic resource bank is an important and basic facility on science and technology. The NPRC has been built as the most comprehensive and largest parasite resource bank in China led by the NIPD based in Shanghai, supported by the Ministry of Science and Technology of China since 2004. In spite of the NPRC has well developed last 15 year to break through the zero-blank situation in China's systematic parasite resource bank, but compared with the internationally advanced parasite resource bank, huge gaps are still existed in terms of scale and number of collections, the level of resource services, and research capacity in resource utilization. Therefore, there is still a long way to go for further collection and

utilization of the parasitic resources. It believes that in the near future, the NPRC will definitely become the leading parasitic resource centre in the country and the well-known one in the world.

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Competing interests

The authors declare that they do not have competing interests.

Authors' contributions

S.-H.C., H.-M.S., Y.L., L.A. and X.-N.Z. conceived the study; S.-H.C., H.-M.S. and X.-N.Z. wrote and revised the manuscript; S.-H.C., H.-M.S., Y.L., L.A., J.-X.C., X.-N.X., P.S., Y.-C.C. and X.-N.Z. revised the manuscript and gave approval of the version to be published. All the authors read and approved the final version of the manuscript.

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