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A digital repository of samples from arthropod vectors

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ABSTRACT
Sustained by urbanization, globalization and climate change, infectious diseases transmitted by arthropod vectors, such as mosquitoes, ticks and sandflies, are emerging or resurging in Europe, including Italy. There are limited therapeutic treatments and vaccines for most arthropod-borne pathogens, thus monitoring and control of vectors remains the most-effective prevention strategy. Supported by a country-wide initiative that aims at providing strategic guidance for preventing vector-borne diseases in Italy, including suirveillance and control initiatives that results in the acquistion of a large number of field samples, we conceived a digital repository of samples from arthropod vectors and their metadata to promote their sharing among the scientific community. We built a relational database called RAV-IT, accessible at https://mosqit.unipv.it/. Currently, RAV-IT aggregates seventeen Italian institutions and hosts nearly two thousand vector samples and their metadata, which can be viewed and requested for research purposes. RAV-IT is interactive and can accept further samples from any users. RAV-IT is a non-profit repository that is expected to enhance resource sharing for research on arthropod vectors.

KEYWORDS
Artrhopod vectors; repository; material exchange; infectious diseases; data digitalization

Background

Roughly 55 years ago, on November 17th 1970, the World Health Organization (WHO) declared Italy "malaria-free" as the result of an intensive and long-term integrated control plan, which is considered one of the greatest public health successes of the country and has been taken as a paradigm for a public health intervention worldwide ever since [1]. Despite this success, malaria and other vector-borne diseases such as dengue, chikungunya, West Nile, leishmaniosis and Lyme disease have seen a (RE)-emergence in the past twenty years in Italy either as import cases or outbreaks sustained by autochthonous transmission through autochthonous vectors. This scenario is exacerbated by the introduction and establishment of new vectors [2], such as the arboviral vectors *Aedes albopictus, Aedes koreicus* and *Ae. japonicus*, the re-appearance of native vectors as the malaria vector *Anopheles sacharovi* [3] and the geographic expansion of native vectors, including the tick *Ixodes ricinus* [4] and sand flies of the genus *Phlebotomus* [5], sustained by current climate and environmental changes. Recognising the risk of vector-borne disease, in 2022, the Italian Ministry of University and Research financed an Extended Partnership initiative on Emerging Infectious Diseases through the National Recovery and Resilience Plan (NRRP) with funds from the European Union – Next Generation EU initiative. This partnership resulted in the INF-ACT foundation (http://www.inf-act.it/board.php?l=IT), which aims at providing strategic guidance for preventing vector-borne disease and responding to outbreaks by strengthening

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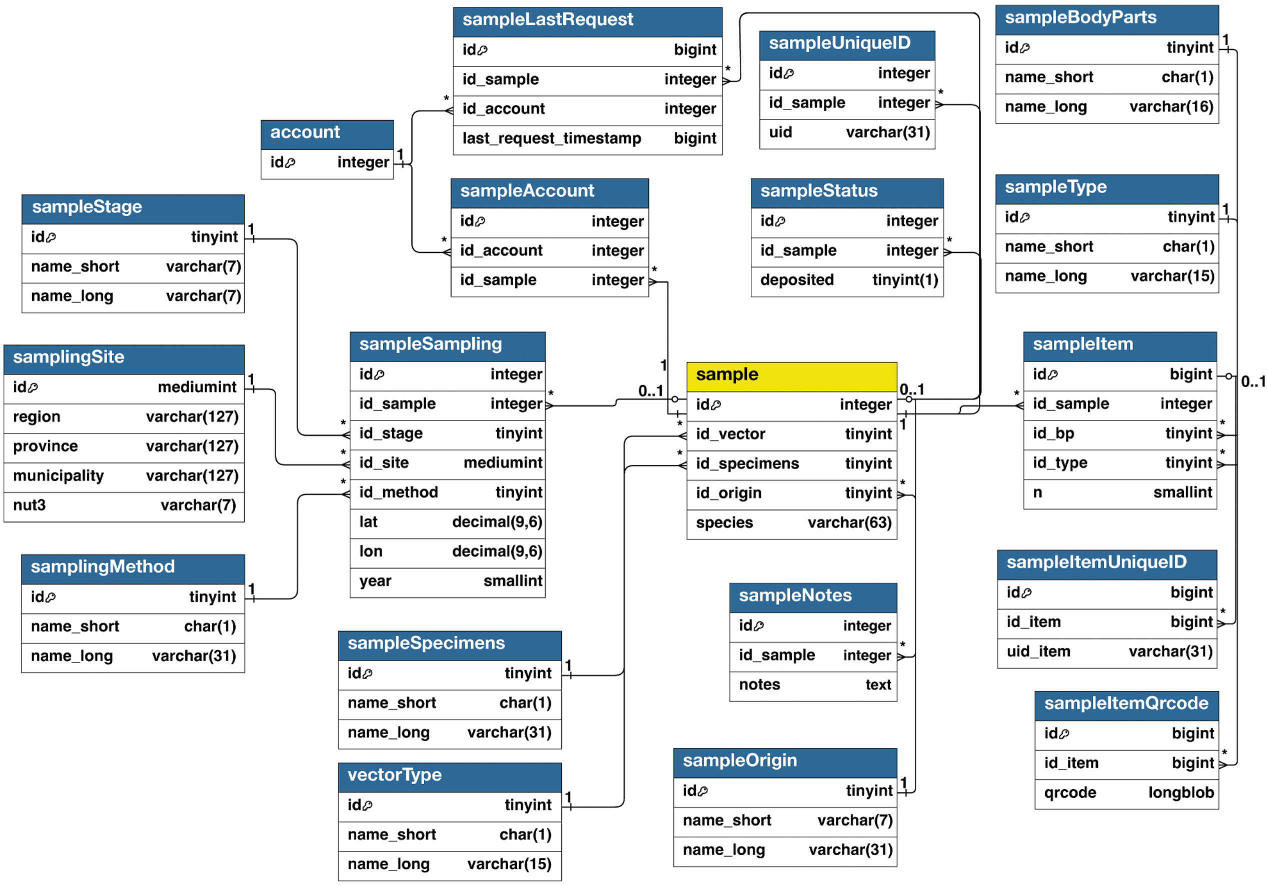

Figure 1. Entity-relationship (ER) diagram of sample-related tables. The 'sample' table uniquely identifies each sample. A set of seven static tables named 'sampleStage,' 'samplingMethod,' 'vectorType,' 'sampleOrigin,' 'sampleSpecimens,' 'sampleBodyparts,' and 'sampleType' are associated with the 'sample' table and store controlled-vocabulary options that define the sample. The 'samplingSite' table reports geographic information relative to the sampling site, including Italian municipalities or foreign sites. The 'sampleNotes' table holds optional annotations linked to each sample. All items derived from a sample are stored in the 'sampleItem' table. Each sample item receives a unique string code stored in the 'sampleItemUniqueID' table. A corresponding QR code is generated and saved in the 'sampleItemQRcode' table. The 'sampleUniqueid' table similarly stores a unique code assigned to each sample. The 'sampleStatus' table indicates whether a sample is available for request, while the 'sampleAccount' table associates each sample with its depositor's account. Finally, the 'sampleLastRequest' table logs whether a particular account has requested a given sample and provides the associated timestamp.

vector monitoring and surveillance, promoting vector control initiatives and infrastructure and increasing basic knowledge on vectors. INF-ACT initiatives result in the acquisition of extensive samples and their metadata. To support management and promote public access of these samples and associated data, we built a digital repository, which we named Repository of Arthropod Vectors of Italy, RAV-IT. Here, we describe the structure of RAV-IT and provide instructions on how to access and request samples along with strategies to further contribute and expand sample library.

Methods

RAV-IT digital repository: the model

RAV-IT is a scalable digital repository for storing samples from arthropod vectors and associated metadata. RAV-IT is implemented as a relational database in MySQL 8.0.21 on a LAMP stack (Linux, Apache, MySQL, PHP) hosted by the University of Pavia. This database persistently stores information including samples, deposit records, user accounts, institute affiliations, and authentication credentials. In total, the scheme comprises 35 tables designed to minimize data redundancy, enforce data integrity, and facilitate efficient operations (e.g. SELECT, UPDATE, INSERT).

Core entities include samples (Figure 1), deposits and accounts (Figure 2), each defined by discrete tables. To ensure data consistency and simplify form-driven input, we introduced small static lookup tables containing values that standardize permissible fields and streamline user interactions with dropdown menus.

All tables are structured according to database normalization principles to minimize redundancy and improve consistency. Primary and foreign key constraints ensure referential integrity, and indexes accelerate query performance.

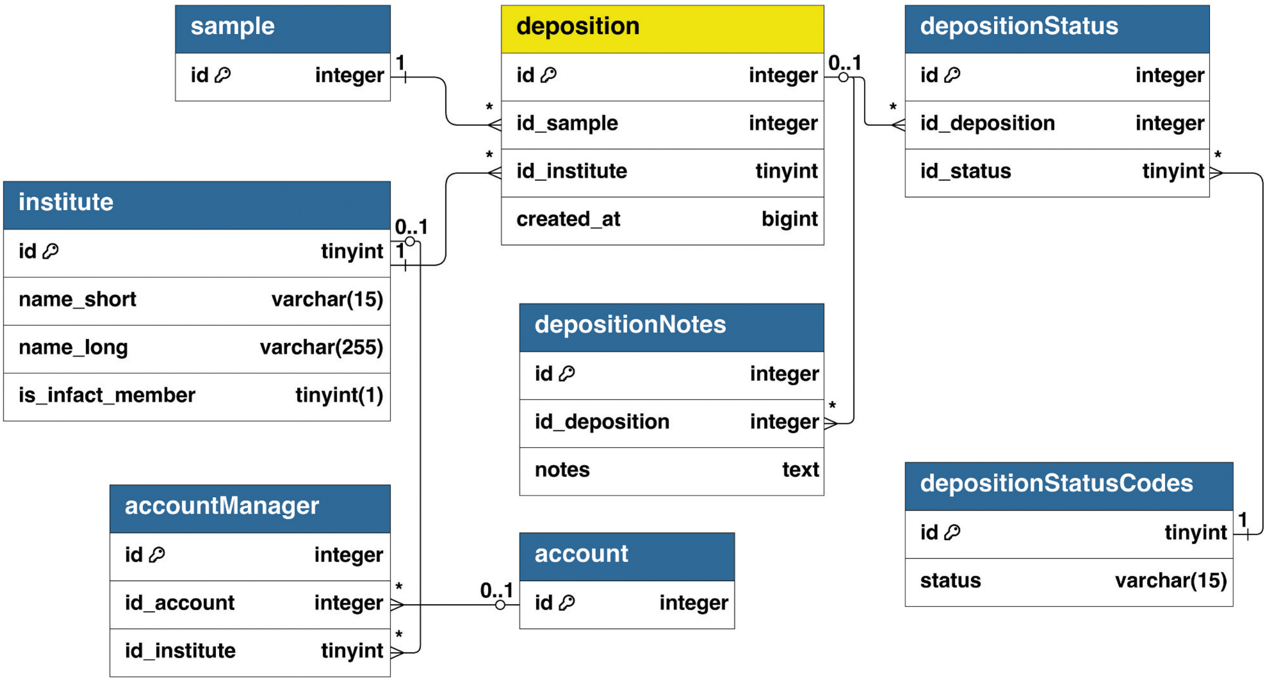

Figure 2. Entity-relationship (ER) diagram of deposit-related tables. The 'deposition' table records a deposit request and stores the submission timestamp. The state of each request is stored in the 'depositionStatus' table, with valid states defined in the 'depositionStatusCodes' table. The 'depositionNotes' table stores supplementary annotations of individual deposits. The 'institute' table contains metadata of institutes, while the 'accountManager' table records manager – institution assignments used for authorization checks.

Data abstractions

RAV-IT is structured around two primary data abstractions: samples and deposits. A sample represents a collection of one or more units of stored biological material, which we call 'items,' while a deposit formalizes the association of a sample with a hosting institute.

Each sample in RAV-IT is described by the following attributes:

(1) Vector type. It specifies the arthropod vector category. Options are: mosquito, tick, sandfly and other.
(2) Vector species. It indicates the species name. It is optional.
(3) Sample specimens. It describes the sample composition. Options are: single (when the sample contains only one specimen) or pool (when the sample is composed of multiple specimens or items). We designed options of pools of 1–10, 11–50, 51–100 or > 100 items.
(4) Sample origin. It specifies the origin of the sample from the laboratory, a field collection or citizen science initiatives.
(5) Sample notes. This field allows users to add any additional information.
(6) Sample unique identifier . For each sample, a unique string is automatically-generated to ensure traceability. The sample unique identifier is stored under 'sampleUniqueID' and is generated by concatenating an uppercase letter corresponding to the vector type (M for mosquitoes, T for ticks, S for sandflies, O for others) with the last two digits of the sampling year (e.g. '23' for 2023) and the last 8 characters of a random base 64-encoded string.
(7) Sample items. It is a collection of attributes describing if and how each sample is partitioned (see below).

Items represent discrete units of biological material contained within a sample (Figure 1, 'sampleItem' table). Each item is described by the following attributes:

(1) Number of specimens. It is a positive integer indicating the count of specimens per item.
(2) Sample type. It specifies if specimens are carcass, tissue, DNA, RNA, chromosome slides, protein extracts or other biological entities.
(3) Body part. It identifies the body part from which the specimen was derived from. Options include: carcasses, abdomen, thorax, midgut, salivary glands, ovaries, legs, head, anthennae, other.
(4) Item unique identifier. An expansion of the sample unique identifier to ensure a unique identifier for each item within each sample.
(5) Item QR code. It refers to a 75 × 75pixels PNG image generated via the Endroid QR code PHP

library (version 4.6, https://github.com/endroid/qr-code) and stored in the database as a long blob object.

Sampling details are captured to contextualize the environmental and collection parameters of each sample (Figure 1, 'sampleSampling' table). For each sample, the following sampling details are collected:

(1) Sampling site. Italian municipality or foreign place where the sample was collected.
(2) Sampling latitude. If available, the geographical latitude of the collection site.
(3) Sampling longitude. If available, the geographic longitude of the collection site.
(4) Sampling method. It reports the technique used to collect samples. Options include CO_2 traps, ovitraps, BG traps, raft sampling, other.
(5) Sampling stage. It defines the developmental stage of the vector when it was collected. Options include: egg, larvae, nymph, adult.
(6) Sampling year. It specifies the year of sample collection.

Sample deposit procedure

A deposit associates a given sample to a specific institute, allowing the repository to track custody, movement, and verification of the origin of each sample. As illustrated in Figure 2, each deposit is recorded and managed through the 'deposition' table and related entities. Each deposit has the following attributes:

(1) Deposition institute. It is the unique identifier of the INF-ACT associated institution which physically hosts the sample.
(2) Sample. Numeric identifier of the sample linked to the deposit.
(3) Deposition status. A value, such as pending, accepted, rejected, completed and stale, indicating the state of the deposit.
(4) Creation timestamp. It refers to a UNIX timestamp, which marks when the deposit was initiated.
(5) Deposition notes. It allows the addition of notes.

The deposit procedure begins with the submission of a deposit request by the depositor and it ends with the sample being deposited (Deposition). Thus, the lifecycle of a deposit comprises subsequent phases such as:

(1) Pending, when a deposit request is submitted and is under review by a manager.
(2) Accepted, when a manager accepts the deposit request.
(3) Rejected, when a manager rejects the deposit request.
(4) Completed, when the deposit request is accepted and the sample described in the deposit request is stored at an INF-ACT associated institution.

RAV-IT web application: the repository envelope

We developed the RAV-IT web application using the Yii2 framework (version 2.0.51) to make the digital repository accessible from any modern web browser (e.g. Chrome, Safari). The application follows the client-server model with a user-friendly web interface rendered clientside and core application logic executed server-side. The frontend web interface is structured with HTML5. We used CSS (version 4.15) to create customized style and ensure responsiveness across various screen sizes. A custom Bash script consolidates and minifies the CSS into a single file allowing browsers to cache it and reducing page load times. Incoming client requests are managed by the Apache2 web server (version 2.4.37, CentOS). We configured a '.htaccess' file to securely redirect requests to the application's entry script and to deny direct access to source code. Upon initialization, the application loads configuration files into the PHP environment and creates a new PHP session. The application verifies the presence and validity of the authentication cookie in every client request. This cookie, which is generated upon successful login and cryptographically signed with a secret key, has a maximum validity of seven days and enables authenticated users to access protected resources. Upon log out, the cookie is invalidated and removed. Access to RAV-IT services requires a verified user account. New users may register at https://mosqit.unipv.it/web/site/signup by providing a valid e-mail, a password and affiliation. Passwords must be at least 8 characters long, include lowercase, uppercase, numeric, and special characters (@$!%*?&), and not exceed 30 characters. They are valid for six months and stored as bcrypt hashes. All input data undergo validation and sanitization before processing or storage.

After registration, an automated e-mail is sent with a link directing the user to a verification page. The user must confirm identity by reentering the password. Verification links are valid for 24 hours after which a new link needs to be requested at https://mosqit.unipv.it/web/request-new-account-verification. Users can reset their password at https://mosqit.unipv.it/web/request-password-reset-link. Both the account verification and password reset workflows are based on cryptographically secure, single-use tokens with time-limited validity. Repeated account verification or

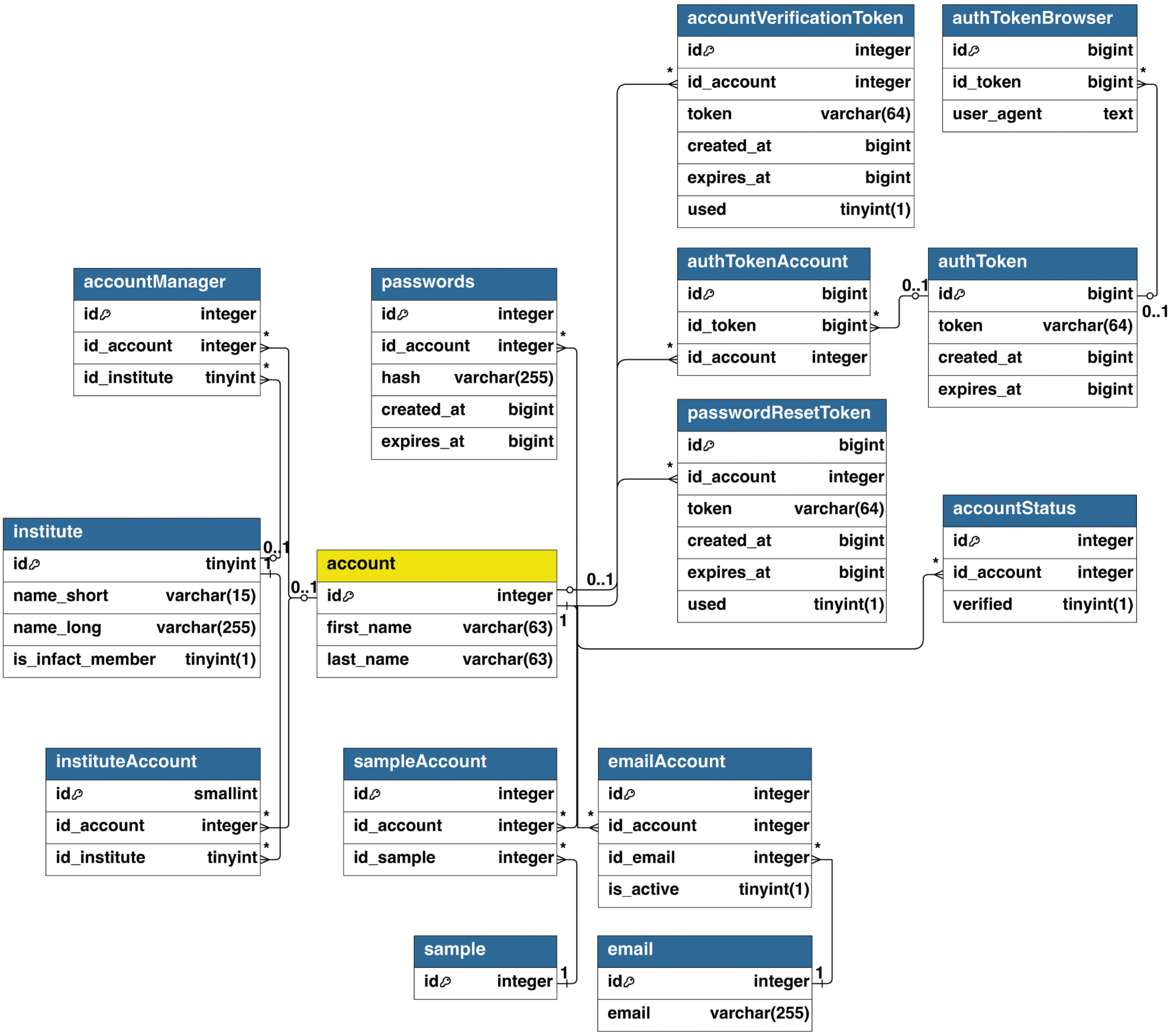

Figure 3. Entity-relationship (ER) diagram of account-related tables. RAV-IT defines two user roles: manager and general user. Managers manage sample acquisitions and records. General users can browse the library of samples, request samples and submit deposit requests. For efficient authorization checks, manager accounts are indexed in a dedicated 'accountManager' table and linked to their institution. The 'accountStatus' table indicates whether an account is verified. The verification process is supported by cryptographically secure tokens stored in the 'accountVerificationToken' table. User passwords are managed via the 'passwords' table, which stores hashed passwords, and the 'passwordResetToken' table, which maintains cryptographically secure tokens for resetting account passwords. E-mail addresses are stored in the 'email' table; the 'emailAccount' table maps addresses to accounts and indicates whether each address is active. Authentication tokens are stored in the 'authToken' table, while the 'authTokenAccount' table associates a given token to the corresponding user account. Finally, the 'authTokenBrowser' table links a given authentication token to the user agent string for session context.

password reset requests are rate-limited to one request every 60 seconds.

Type of users

The platform recognizes two types of users, which have different roles (Figure 3). 'Manager' users approve or reject requests of sample deposition within RAV-IT and manage sample records. General users can browse the sample library, request samples and submit deposit requests.

Currently RAV-IT has seventeen managers, one for each INF-ACT institution. Samples are provided by users defined as 'depositor.' Depositor initiates a deposit request by first identitifying the host institution, which will be physically hosting the sample. Through this operation, an automated e-mail is sent to the corresponding manager notifying of the incoming samples. Managers contact the

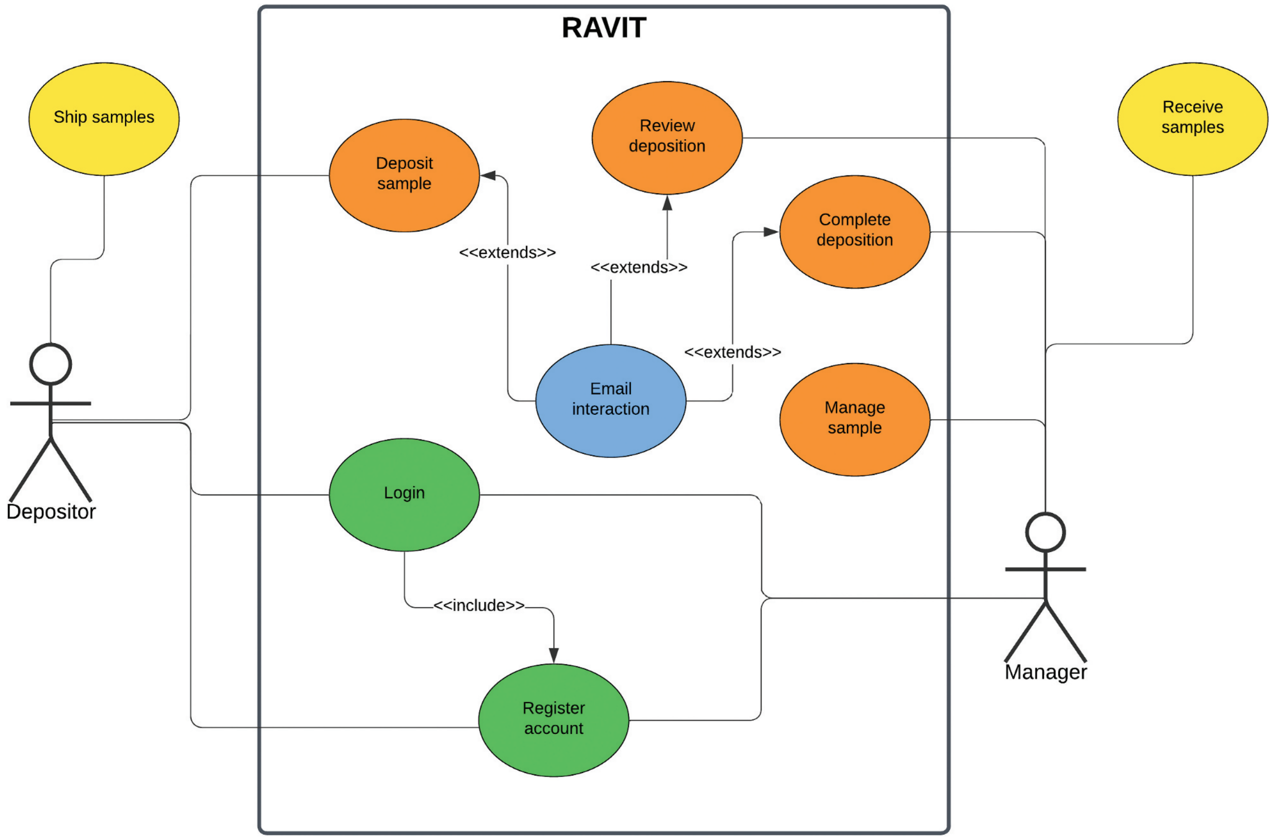

Figure 4. Use case diagram of the RAV-IT digital repository system. The 'depositor' and the 'manager' are the two type of users that interact with the RAV-IT system via the web application. Functionalities are accessible after registration and secure login. Depositors can submit biological samples of arthropod vectors and engage in e-mail-based interactions related to their deposits. Managers will review, finalize and manage submitted samples, ensuring proper curation and data integrity of the repository.

Depositor, who completes a 'Deposition Agreement' that legally confirms the depositor's consent to transfer custody of the sample to the host institute. Managers are authorized to adjust the composition of a given sample by adding or removing items according to the sample's availability and follow up requests for the transfer of items within each samples. A Use-Case diagram (Figure 4) illustrates the interactions among depositors, managers, and users, as well as their respective roles within the platform's operational framework.

Automatic emailing

The RAV-IT web application dispatches e-mails exclusively when user action is required based on assigned roles. This approach ensures that local managers are assisted in handling incoming deposit requests, while depositors are notified only when sample relocation is needed. To enhance security, an automatic confirmation e-mail is sent following each successful login. E-mail functionality is implemented using the PHPMailer library (version 6.9.1), and messages are transmitted through the University of Pavia's mail servers from the official e-mail account noreply@unipv.it. Users are strongly advised to disregard any purported RAV-IT communication originating from alternative e-mail addresses.

Results

We launched RAV-IT in September 2024. RAV-IT is the first Italian digital platform that connects seventeen institutions (Table 1), which host biological samples of arthropod vectors. These samples can be shared with the

Table 1. Institutions contributing to RAV-IT. RAV-IT sample deposit interface shows the list of institutions that currently host samples and can receive futher samples.

IRCCS Sacro Cuore Don Calabria Hospital
Istituto Superiore di Sanita'
Istituto Zooprofilattico Sperimentale del Lazio e della Toscana
Istituto Zooprofilattico Sperimentale del Mezzogiorno
Istituto Zooprofilattico Sperimentale del Piemonte, Liguria, e Valle d'Aosta
Istituto Zooprofilattico Sperimentale dell'Abruzzo e del Molise
Istituto Zooprofilattico Sperimentale della Lombardia e dell'Emilia
Istituto Zooprofilattico Sperimentale della Puglia e della Basilicata
Istituto Zooprofilattico Sperimentale delle Venezie
University of Bologna
University of Camerino – Camerino (MC)
University of Federico II – Napoli
University of Milano Statale
University of Padova
University of Pavia
University of Roma La Sapienza
University of Siena

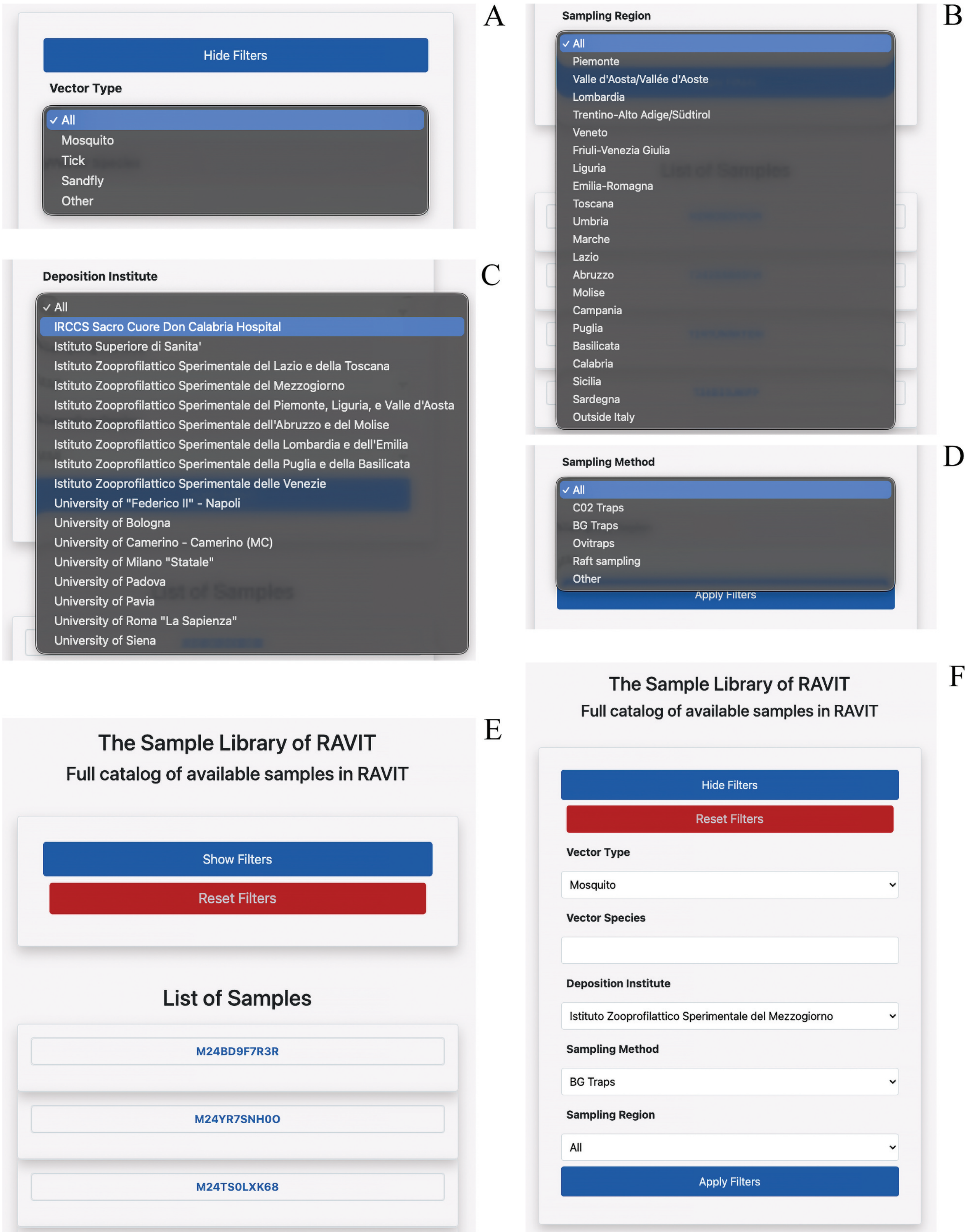

Figure 5. RAV-IT library interface. It allows users to search samples by vector species, vectory type (A), sampling region (B), deposit institute (C), and sampling method (D). Samples are displayed in a compact format showing only the sample unique identifier (E). Users can change a single filter value or reset all filters using the 'reset filters' button (F).

scientific community (Figure 5). Currently RAV-IT hosts 1936 samples of mosquitoes, ticks and sandflies in various biological forms, including whole carcasses and nucleic acids ammounting to over 14,000 items. Each sample is described through detailed information, which include the vector type, the species (if provided), the number of items or specimens it is composed of, the sampling site with latitude and longitude, the sampling year, stage and

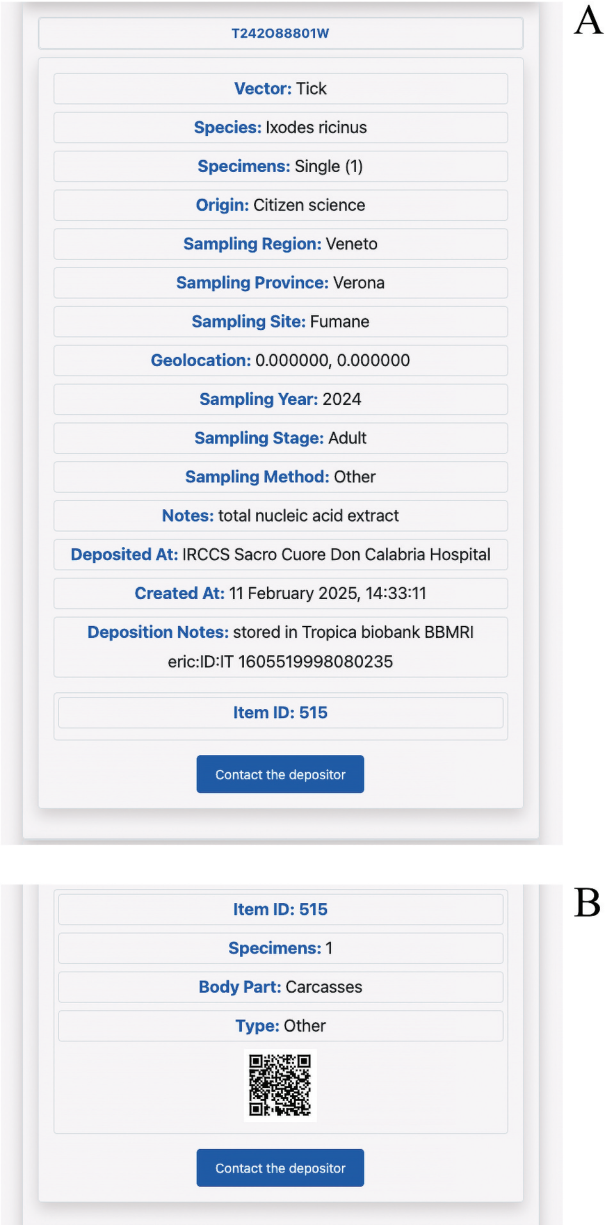

Figure 6. Details of a sample, and its items, available in the RAV-IT library. The top panel shows details of a sample, which include the vector type, species, number of items it is composed of, origin, sampling region, sampling province, sampling municipality, latitude and longitude, sampling year, sampling stage, deposit institute, sample digital record creation date, and deposition notes (A). The bottom panel shows details of each item, including the body part, type and the associated qr code (B). Details of a sample and of an item can be shown by clicking on their unique identifiers, here T242088801W and 515, respectively.

method of collection; each samples and items are assigned a unique identifier (Figure 6). Current samples were acquired from various sources, including citizen-science initiatives, laboratory studies and field collections. RAV-IT is set to further accept samples, including from external contributors. To contribute to RAV-IT, users need to register and submit their sample record through a dedicated web form (mosqit.unipv.it/web/deposition/new). Bulk submission of multiple samples is supported via *ad hoc* CSV upload (mosqit.unipv.it/web/deposition/bulk-upload). Once accepted in RAV-IT, samples become visible to authenticated users and can be shared. RAV-IT accepts requests for samples or items.

Discussion

Here, we describe the first Italian repository of vector samples. RAV-IT was first conceived as a mosquito-only repository named MOSQ-IT, which was later expanded within INF-ACT to include all vectors. Currently, RAV-IT includes samples acquired through INF-ACT initiatives. These samples are being exchanged and used among INF-ACT members to monitor insecticide resistance in *Aedes albopictus*, analyze vector microbiota and describe species distribution and abundance. These initiatives are allowing to build maps of vector distribution, identify adequate vector control strategies and work toward the development of innovative and eco-friendly control methods, which are essential to face the emerging risks of vector-borne diseases in Italy. We are making RAV-IT public to favor acquisition and exchange of samples beyond INF-ACT associated members. We can accept samples from citizen science initiatives, amateur entomologists and scientists. The advantage of RAV-IT is that it offers a centralized administration and classification system, without the need for a centralized sample collection facility, thus favoring the acquisition of local and remote samples, along with material exchange. We expect RAV-IT to become a valuable resource for acquiring samples and fostering collaborations.

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Author contribution

Davide Colombo: Conceptualization, Methodology, Investigation, Formal analysis, Data Curation, Writing – Original Draft; **Alejandro Nabor Lozada-Chàvez**: Conceptualization, Methodology, Investigation, Review & Editing; **Andrea Matucci**: Data contribution and Curation; **Marco Di Luca**: Data contribution and Curation; **Adele Magliano**: Data contribution and Curation; **Claudio De Martinis**: Data contribution and Curation; **Silvio Gerardo D'Alessio**: Data contribution and Curation; **Maria Beatrice Boniotti**:Data contribution and Curation; **Loredana Capozzi**: Data contribution and Curation; **Federica Gobbo**: Data contribution and Curation; **Maria Paola Maurelli**: Data contribution and Curation; **Alessandra Mistral De Pascali**: Data contribution and Curation; **Claudia Damiani**:Data contribution and Curation;**Paolo Gabrieli**: Data contribution and Curation;

Cristiano Salata: Data contribution and Curation; **Davide Badano**: Data contribution and Curation; **Federico Forneris**: funding acquisition and Review & Editing; **Verena Pichler**: Conceptualization, Methodology, Data contribution and Curation; **Beniamino Caputo**: Conceptualization, Methodology, Data contribution and Curation, Review & Editing; **Alessandra Della Torre**: Conceptualization, Methodology, Data contribution and Curation, Review & Editing; **Mariangela Bonizzoni**: Conceptualization, Project Management, Formal analysis, Data Curation, Writing – Original Draft.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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